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A study of respiratory and physico-chemical changes of four kiwi fruit cultivars during cool-storage

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Fruits of *Actinidia deliciosa* cv. Allison, Bruno, Hayward and Monty harvested at the proper stage of maturity with a mean soluble solids content of 6.7% were stored at 0°C in an ethylene-free atmosphere for a 17-week period. Respiration rates, production of ethylene, shelf-life, composition and changes in quality attributes were measured at regular intervals throughout the storage season. Cv. Hayward showed the lowest respiration rate and produced less ethylene than Allison or Bruno. During storage, the most remarkable changes in quality characteristics were observed in flesh firmness and soluble solids. The softening process was remarkable in Allison even after the 9th week of storage, followed by Bruno and Monty. The ascorbic acid content was statistically higher in Bruno and lower in Monty. Best results and storage performance were obtained with cv. Hayward followed by Monty. Comparing those results it can be seen that the physiological behaviour of kiwi fruit varieties is related to storage time at 0°C.

INTRODUCTION

Cultivation of kiwi fruit was first introduced into Greece in 1973, in Pieria prefecture, in the north part of the country. Since then cultivation has expanded to many other areas with a mean production of 42 000 tonnes over recent years. Kiwi fruit is considered an important commercial fruit with confirmed export potential which corresponds to the 30–60% of the total production.

After a study performed in New Zealand in 1958 (Fletcher, 1958) the varieties with the best attributes and possibilities for commercial-scale production, were Abbot, Allison, Bruno, Monty and Hayward. Among them, Abbot is an early variety, rich and delicate in flavour but less storable compared with Monty, Bruno, Allison and Hayward (Bourbos, 1977; Broussovanas, 1982). Hayward is a late season cultivar, widely spread, large, rich in sugars, with good storage performance (Gorini, 1978). Wright and Heatherbell (1967) were the first to study the respiration rate at 25°C in the cultivars Abbot, Bruno and Hayward, and the response to applied ethylene, together with the effect of various temperatures and some chemical changes only for the fruits of Hayward variety. Later Pratt and Reid (1974) made a more comprehensive study throughout the life of the Bruno variety and gave patterns of growth, respiration, ethylene production and response to applied ethylene at 20°C.

The objective of this work was to study changes in terms of the respiratory rate, emission of ethylene and chemical composition during air storage at 0°C for a period of 4 months, and the shelf-life after storage at different time intervals of four cultivars grown in Greece, i.e. Allison, Bruno, Hayward and Monty, in an attempt to evaluate their quality and storage performance.

MATERIALS AND METHODS

Kiwi fruit of all the varieties were harvested during mid-October from the same commercial plantation located in Ganohora, in Pieria prefecture.

Fruits of Hayward and Monty were harvested at 6.3 and 6.2% soluble solids (SS), which is considered to be the minimum maturity index, while fruits of the Allison and Bruno varieties with an acceptable slightly higher SS content of 7.4 and 7.0%. Fruits of all cultivars were transported within 24 h and stored at the same cool

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room at 0°C and 90% relative humidity (R.H.) in an ethylene-free atmosphere. A sample of 10 fruits was used to measure respiration and ethylene emission. Gas exchange measurements (CO_2 and ethylene) were made on individual fruits in small glass jars (0.5 litres). These jars were placed in the same cool room with the rest of kiwi fruit at 0°C or at 20°C for the determination of shelf-life. One millilitre of the gas sample was removed using a special syringe, after the jars had been closed for 1 h, and injected into a gas-chromatograph Perkin–Elmer 8700 with a TC and FID detector. All results are expressed as ml CO_2/h/kg and μl C_2H_4/h/kg. A preliminary measurement to test the possibility of CO_2 accumulation in these jars did not alter the respiration rate. Measurements were made at 0°C after 0, 6, 9, 14 and 17 weeks of storage and during shelf-life at 20°C for a period of 15 days.

Determinations of firmness, soluble solids, reducing sugars and ascorbic acid were carried out in samples of 10 separate fruits from each cultivar at the same time intervals, using standard methods as follows. Flesh firmness was measured using an Alpha-Brass penetrometer with a 5/16 in. plunger and expressed in lb. Soluble solids expressed as Brix were measured by an Abbe refractometer calibrated against sucrose. Reducing sugars were determined by the Lane–Eynon method. Ascorbic acid measurements were made following the indophenol dye titration method. Results are presented for the second season only because no variation in the measured values during the 2 years of the study was observed. Data were subjected to the analysis of variance using the least significant differences (LSD) procedure to determine differences between variables ($P < 0.005$).

RESULTS AND DISCUSSION

Respiratory changes during storage at 0°C

The respiration rate and ethylene emission of the varieties Allison, Bruno, Hayward and Monty are shown in Fig. 1. Fruits of Allison and Bruno behaved similarly and presented an intense respiration rate which was statistically significant when compared with fruits of the Hayward and Monty varieties. Hayward presented the lowest respiration rate, which is closely related to the fact that this variety has been proved to be the most storable. In this experiment fruits of Allison, Bruno and Monty presented a typical curve of a climacteric fruit (Kader, 1985; Pratt and Reid, 1974) with the exception of fruits of Hayward which did not behave similarly, probably because the duration of storage time was not sufficienty long for this variety.

Measurements made in fruits of Allison and Bruno indicate that ethylene production was higher in these varieties and results differ statistically compared with those of Hayward and Monty. Ethylene production in the varieties of Allison, Bruno and Monty increased steadily until the 40th day followed by a slight fall and then a rise. The curve tends to resemble that of most climacteric fruits where the two rises (respiratory and ethylene) appear to coincide (Pratt and Reid, 1974).

These results provide new information on the behaviour of kiwi fruit varieties, because the only data concerning respiration changes available in the literature were from fruits of the Hayward variety stored at 0°C and for short periods.

Respiration and ethylene production during shelf-life

Patterns of respiration and ethylene production during shelf-life are presented in Figs 2–6. Fruits of all the varieties presented a respiration curve typical of a climacteric fruit during shelf-life immediately after harvest (Fig. 2). No statistical differences were observed between the varieties, but the statistical analysis gave same large confidence limits, probably because the data represented mean values of measurements in individual fruits which assumes a strong effect of the fruit's individuality. According to Pratt and Reid (1974) kiwi fruit present an unusually wide variation in timing of the initiation of the ripening process and this degree of variability has not been reported for any other fruit.

Concerning the emission of ethylene, it was observed that fruits of the Allison variety produced large quantities of the gas, this was not always statistically significant compared with the other varieties in which no statistical differences were observed.

Respiration rates and ethylene emmission for the four cultivars during shelf-life and after storage at 0°C for 6 and 9 weeks are presented in Figs 3 and 4. In general, measurements of respiration rate showed a decrease during the first 8 days and then an increase. Fruits of the Allison variety presented a low respiration rate during the shelf-life, probably due to the fact that they were in a more mature stage, something that is in accordance with the measurements of firmness (Table 1), a parameter which is considered as one of the indicators for the degree of maturity and especially as an index of the end of storage life (Gorini, 1983).

After 14 weeks of storage at 0°C and during shelf-life (Fig. 5), fruits of the Allison variety presented the lowest respiration rate, this was statistically different. All the other varieties presented curves typical of climacteric fruits with a rise in the rate of CO_2 at different time intervals. Differences in ethylene production was not statistically between the varieties.

After 17 weeks of storage, fruits of cultivars Allison and Bruno were overipe so measurements were made only in fruits of Hayward and Monty. Monty had an intense respiration rate during the first 5–6 days as shown in Fig. 6. This difference was not observed later probably due to the different stage of maturity of these two varieties, as shown in Table 1. Concerning ethylene production (Fig. 6) the two remaining varieties presented almost similar behaviour.

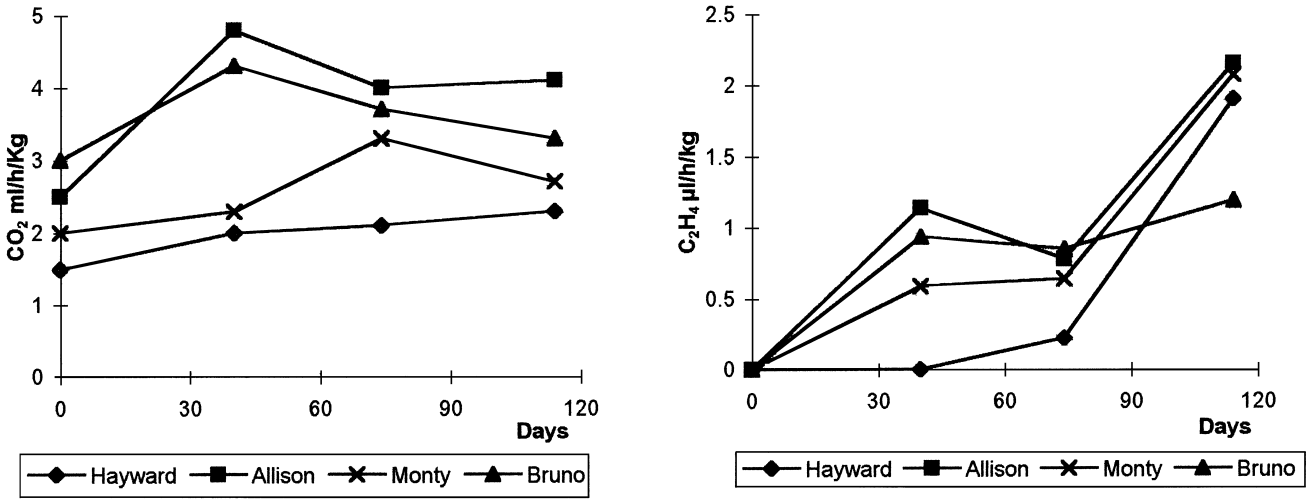

Fig. 1. Evolution of respiration and emission of ethylene of kiwi fruit varieties during air storage at 0°C.

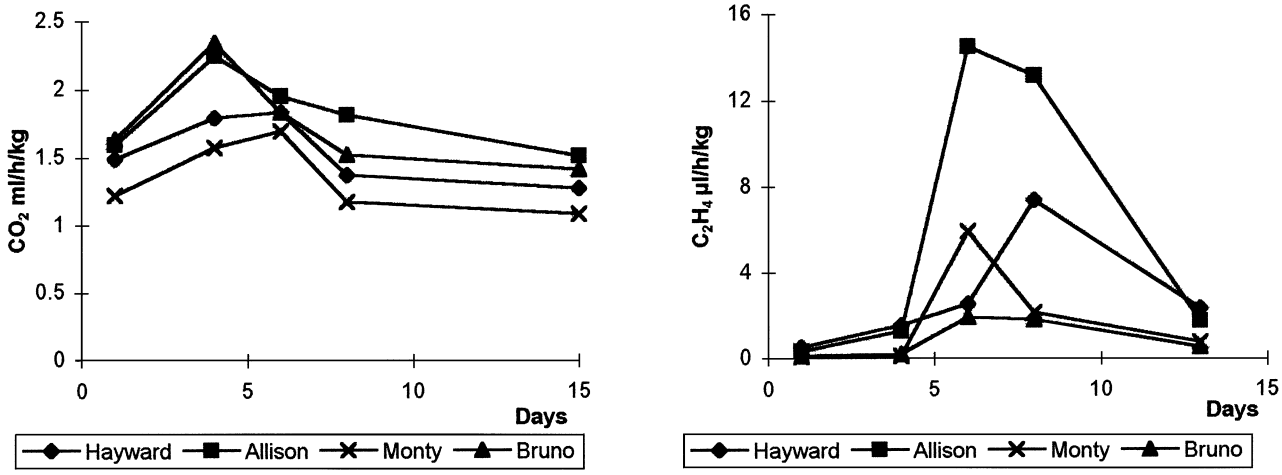

Fig. 2. Evolution of respiration and emmission of ethylene of kiwi fruit varieties during shelf-life immediately after harvest (0 weeks of storage).

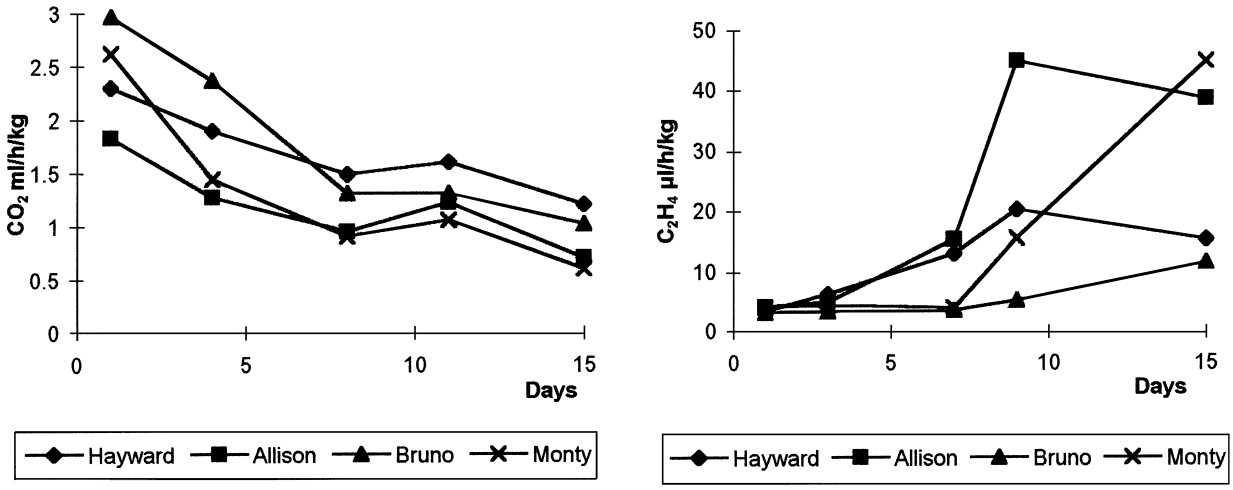

Fig. 3. Evolution of respiration and emission of ethylene of kiwi fruit varieties during shelf-life after 6 weeks of storage at 0°C.

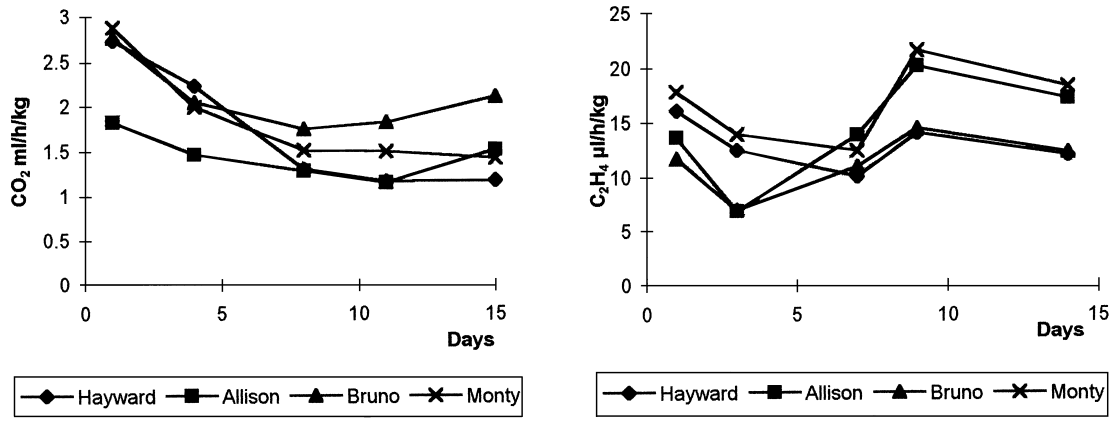

Fig. 4. Evolution of respiration and emission of ethylene of kiwi fruit varieties during shelf-life after 9 weeks of storage at 0°C.

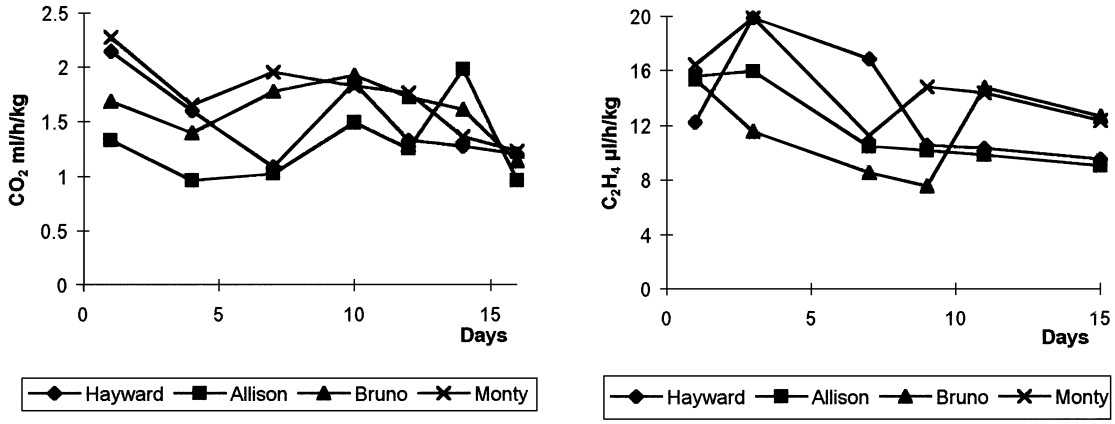

Fig. 5. Evolution of respiration and emission of ethylene of kiwi fruit varieties during shelf-life after 14 weeks of storage at 0°C.

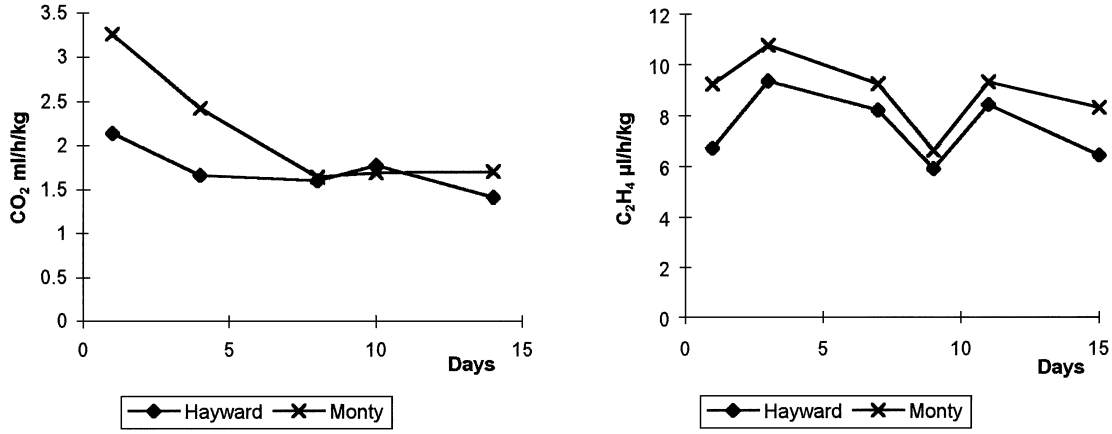

Fig. 6. Evolution of respiration and emission of ethylene of kiwi fruit varieties during shelf-life after 17 weeks of storage at 0°C.

Curves of ethylene production during shelf-life (Figs 2–6) show that after 6 weeks storage at 0°C kiwi fruits produced large quantities of ethylene. This period coincides with the climacteric maximum observed during storage at 0°C (40th day, Fig. 1). Similar findings and patterns for respiration and ethylene emission during shelf-life after storage at 0°C at different time intervals have not been reported before in kiwi fruit varieties.

Compositional changes

Typical changes in the main physico-chemical constituents of the kiwi fruits are given in Table 1. Fruits of Hayward and Monty were harvested at 6.3 and 6.2% SS which is considered to be the minimum maturity index, while fruits of Allison and Bruno were harvested at an acceptable slighty higher content of SS 7.4 and 7.0%,

Table 1. Compositional changes of kiwi fruit varieties during storage at 0°C

Varieties	Brix (weeks)					Ascorbic acid mg/100 g (weeks)					Reducing sugars (%) (weeks)					Firmness (lb) (weeks)				
	0	6	9	14	17	0	6	9	14	17	0	6	9	14	17	0	6	9	14	17
Hayward	6.3	11.3	13.0	13.8	14.2	105	122	102	107	115	1.3	6.8	7.8	8.1	8.9	19.0	11.6	7.8	5.8	5.7
Allison	7.4	11.7	12.2	13.6	12.8	132	139	129	122	113	1.8	6.8	7.0	7.1	7.3	15.0	9.5	1.9	—	—
Monty	6.2	11.0	12.6	13.2	13.6	76	77	73	72	54	—	6.2	7.6	7.4	7.9	20.4	11.4	6.7	3.8	1.1
Bruno	7.0	11.3	12.4	13.2	12.3	159	174	170	153	152	1.4	5.7	6.8	7.1	6.8	18.9	10.4	4.7	3.7	—
LSD	0.81	0.62	0.53	0.7	0.43	2.54	1.29	2.20	2.09	1.13	1.23	0.46	1.05	1.36	1.36	1.76	1.62	1.20	0.81	—

respectively. According to Harman (1981) fruits harvested at/or above the minimum maturity index 6.2% SS will store satisfactorily at 0°C for up to 6 months and subsequently ripen with acceptable flavour.

In all the varieties a steady increase in SS content was observed during storage at 0°C whereas no statistical differences were measured after the sixth week of storage. Only at the end of storage time (17th week) did fruits of Hayward have the highest content in SS followed by Monty, while fruits of Allison and Bruno had the lowest (Papadopoulou and Manolopoulou, 1989). The early mature stage of the varieties Hayward and Monty did not produce any problems in their normal maturation. Fruits of these varieties had a content of 14.2 and 13.6% SS at eating ripeness respectively. This parameter is considered as an important factor for the expression of quality at eating stage (Lallu *et al.*, 1989). After harvest and during storage and ripening of the fruits the content in reducing sugars was increased in parallel with the SS content. This finding confirm patterns already reported for starch, glucose, fructose and SS (Matsumoto *et al.*, 1983; Nicolas *et al.*, 1986). Sugar content in Hayward fruits after 17 weeks of storage at 0°C was measured to be the highest, with a statistically significant difference, compared with fruit from the other varieties. Differences between the other varieties do not differ statistically. Ascorbic acid content of kiwi fruit at harvest was 105 mg/100 g for Hayward, 132 mg/100 g for Allison, 76 mg/100 g for Monty and 159 mg/100 g for Bruno. Values for ascorbic acid content were reported to be 99 mg/100 g for Hayward, 76 mg/100 g for Monty and 110 mg/100 g for Bruno (Papadopoulou and Manolopoulou, 1989). Beutel *et al.* (1976) reported a value of 105 mg/100 g for Hayward, and Wright and Heatherbell (1967) a value of 120 mg/100 g. Okuse and Ryugo (1981) measured a value of 80 mg/100 g and Selman (1983) reported a mean value of 42 mg/100 g for the edible flesh which is low and according to Selman is possibly due to losses during transportation from New Zealand to UK. Matsumoto *et al.* (1983) measured a content of 215 mg ascorbic acid / 100 g in the unripe fruit. It appears that the ascorbic acid content of the kiwi fruit varies with growing conditions and the degree of ripeness. The data for ascorbic acid content of the fruits decreased slightly during storage in all varieties. At the end of the storage life (17th week) fruits of Bruno had the highest ascorbic acid content and those of Monty the lowest, both being statistically different.

Fruits of all the varieties were harvested at a firmness higher than 11 lb (5 kg) which is common practice. Sometimes firmness was tested to be around 31 lb (14 kg). Crisosto *et al.* (1984) found that a combination of initial SS content at harvest and flesh firmness seemed to be a maturity index for kiwi fruit. According to them, flesh firmness is the parameter of greater concern in kiwi fruit storage and marketing, because flesh softening is associated with senescence and fruit injuries. Although firmness does not apply as an index of harvest time, it is considered as an excellent criterion for assessing the optimum time to interrupt the conservation of the fruit. In this respect, according to Gorini (1983) fruits must be removed from storage when they have reached a firmness of 4–5 kg, in order to resist a longer period of marketing. However, in New Zealand, it is considered that kiwi fruit are suitable for export when firmness is measured to be of the order of 0.9–1 kg, a value close to that of eating ripeness, i.e 0.7 kg (MacRae *et al.*, 1989; Lallu *et al.*, 1989). Based on the data of Gorini (1983) which are in accordance to our results the storage life of Allison is 8–9 weeks, that of Bruno and Monty 14–15 weeks, while Hayward could be stored for up to 17 weeks.

CONCLUSION

The results of respiration rate, ethylene production and the changes in the physico-chemical attributes indicate some differences between the varieties studied. Cultivar Hayward showed a low respiration rate and ethylene emission during cool storage at 0°C, while Allison and Bruno presented higher values in respiration rate and ethylene production. After 17 weeks of storage, Hayward fruits had a higher SS content and level of reducing sugars, and their firmness was also determined to be the highest. Of all the varieties, fruits of Hayward had the longest storage life while fruits of Allison the shortest.

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