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EFFECT OF WATER LOSS ON THE RIPENING OF CLIMACTERIC FRUITS

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SUMMARY

Moisture loss from preclimacteric avocado, banana and pear fruit was found to hasten ripening. Weight losses of up to 1·2% per day were recorded, and times to ripen were reduced by up to 43%. The finding has important experimental implications, and may be of significance commercially.

I. INTRODUCTION

The effects of water loss on the physiological processes of plants are of great importance and have been extensively investigated (Vaadia, Raney and Hagan 1961; Kozlowski 1964, 1968). In spite of this, the literature relating moisture loss to fruit ripening, a process of considerable commercial importance, is scant and contradictory.

The only direct evidence that water loss affects ripening is reported by Gac (1956), who showed that Passe Crassane pear fruit stored in dry air pass through a respiratory climacteric maximum before those stored in humid air. Gac failed to find a similar result with apples or strawberries, and reported an opposite effect with grapes.

Shamel (1917) reported a similar effect when Bartlett pears were stored at approximately 90°F and 90% relative humidity. He found that they were hard and green when removed after 30 days and ripened normally at the ambient conditions. Similar fruit held continuously at ambient conditions ripened after about 7 days. Shamel assumed that the effect was due to relative humidity, apparently not considering that temperature could have this effect. Shamel's conclusions were investigated by Overholser and Taylor (1920), who indicated that pear ripening was retarded by high temperature and that relative humidity had no influence.

Wardlaw and Leonard (1940) dealt with the respiratory behaviour of bananas at different humidities, but drew no conclusions about the effect of humidity, or moisture loss, on time to ripen. However, Tsalpatouros (1956) reported that high humidities hasten ripening in harvested banana fruit.

Recent observations made during fruit storage experiments in this laboratory have suggested that water loss hastens the ripening of harvested preclimacteric fruit (B. C. Peacock and J. R. Blake, personal communication 1971).

Indirect evidence that water loss may affect ripening is to be found in its effects on various characteristics of ageing. Dehydration produced effects similar to ageing in the water-holding capacity of protoplasm and its ability to swell (Ratner 1944, cited by Henckel 1964), in the pattern of dry-weight accumulation in tomato plants (Gates 1955*a*, 1955*b*, 1957), in the hastening of senescent yellowing of sugar-beet leaves (Morton and Watson 1948), in response of tomato leaf RNase to applied phytokinin (McHale and Dove 1969), and in shifts in acid metabolism (Zholkevich and Koretskaya 1959).

Scott and Roberts (1967) showed that moisture loss influences incidence of breakdown in stored apples and suggested that absence of humidity control has possibly resulted in temperature, rather than water loss, being adjudged the cause of measured effects (Trout, Tindale and Huelin 1940; Smith 1958). If ripening is also hastened, then further doubt may be cast on the interpretations made in these and other experiments.

The aim of this work was to establish whether post-harvest moisture loss does in fact influence the green-life of climacteric type fruit. (Green-life of climacteric type fruit is defined (Peacock and Blake 1970) as the time that elapses until the onset of the respiratory climacteric. In this paper the term green-life has been used in a more general way to include other indices of ripening, e.g. time to half colour. Variations from the definition are nominated in the text).

II. MATERIALS AND METHODS

Fruit.—Since an objective assessment of time to commence ripening was required, fruits which were known to exhibit a well-defined climacteric were chosen for the experiments. Fruits used were banana (*Musa acuminata* Colla cv. Giant Cavendish), avocado (*Persea americana* Mill. cv. Hass) and pear (*Pyrus communis* L. cv. William's Bon Chretien). All fruit were selected sufficiently immature to allow time for differences in ripening to become apparent, but sufficiently mature to ensure normal ripening.

A number of experiments were undertaken with bananas, and in any one experiment all fruit were from the one bunch, and usually from the one hand. The proximal hand (or most proximal hands) were normally selected. On two occasions the position of the hand on the bunch was introduced as an additional variable in the experiments. In the one trial with avocadoes, all fruit were selected from the one tree. In the experiment reported with pears, fruit were selected from a sample obtained from a number of trees.

Bananas were obtained from The Gap, near Brisbane, pears from the Granite Belt near the Queensland/New South Wales border, and avocadoes from the Tamborine Mountain district south of Brisbane. All fruit after harvest were immediately transported to the laboratory, weighed individually, dipped in an aqueous solution of the fungicide "Thibenzole" at a concentration of 600 p.p.m. of the active constituent 2-(4-thiazolyl) benzimidazole, and placed in individual respiration jars ventilated with air.

Air.—Air was scrubbed of carbon dioxide and ethylene, and was provided at a number of constant humidities for passage over individual fruit. Air flowrate was metered at 100 ml/min. Taking into account cross sectional areas of container and fruit, this figure gave a calculated air-speed over banana fruit surfaces of approximately 2 cm/min.

Conditions.—A temperature of 20°C was selected to provide conditions under which normal ripening of all fruits would be expected to occur.

Carbon dioxide was removed by scrubbing air through a 15% solution of caustic soda. The level of CO_2 in scrubbed air was usually less than 0·005%.

A column of ethylene absorbent was included in the airstream. This consisted of a 6 ft length of polyvinyl tubing of $\frac{1}{2}$ in. internal diameter, filled with "Purafil", a commercial product of alumina-based pellets containing potassium permanganate. Gas chromatographic monitoring during the experiments failed to reveal an ethylene peak, so the ethylene level was less than 0·005 p.p.m., the limit of detection of the instrument used. To avoid the possibility of effects due to the permeability of the tubing to ethylene, all airlines from the purafil to the respiration chambers were made of equal length and kept as short as possible.

The humidity range was obtained by passing the airstream through a condenser at —29°C, splitting it into two and bubbling through either distilled water or concentrated sodium or potassium hydroxide solution. The wet and dry airstreams were then metered through flow meters and mixed in the required proportions. The humidities of the extreme airstreams were monitored gravimetrically, and mean values for relative humidity (RH), with estimates of standard deviation, were $13 \cdot 1 \pm 4 \cdot 0\%$ for dry air and $95 \cdot 0 \pm 1 \cdot 8\%$ for moist air.

Data.—An accurate means of determining the commencement of ripening is to estimate the onset of the climacteric, and this was the method used in most of the trials reported in this paper. Evolved carbon dioxide was used as the measure of respiration, and this was determined in the effluent airstream from the respiration jars by an infrared gas analyser (Model SB2, Grubb-Parsons & Co. Ltd., England). Respiration rates were graphed as mg CO_2/kg/hr against time, and time of onset of each climacteric rise was estimated from the graphs.

Colour was also used as an indication of fruit ripening in one of the banana experiments. Daily assessments were made, colour being rated from dead green (1) to fully coloured (7). Graphs of colour rating against time were constructed and an assessment was made of the time to half colour, this stage being the most accurately determined subjectively.

Firmness readings were made in the same experiment, using the "mechanical thumb" described by Schomer, Olsen and Yeatman (1963). Results were again graphed and an assessment made of time of firmness change. Relationships between the time of firmness changes, colour change and onset of climacteric in banana fruit were described by Peacock (1966). Moisture loss was measured directly as weight loss, and is expressed as percentage weight loss per day (PWLD).

III. RESULTS

The results of one avocado trial (experiment 1), four banana trials (experiments 2–5) and one pear trial (experiment 6) are reported. In experiment 5, green-life was assessed as days to half colour and days to change in firmness. In all other experiments, time to onset of the climacteric was estimated. Experiment 3 was replicated in time, and experiments 4 and 5 were replicated by hands down the bunch.

The result of experiment 1 with avocadoes is shown in Figure 1, where green-life is plotted against percentage daily weight loss. The result of a similar trial with banana fruit (experiment 2) is shown in Figure 2. Each point was provided by a single fruit and the results were obtained from fruit which had been placed under three storage humidities. Regression data for these experiments are shown on the graphs.

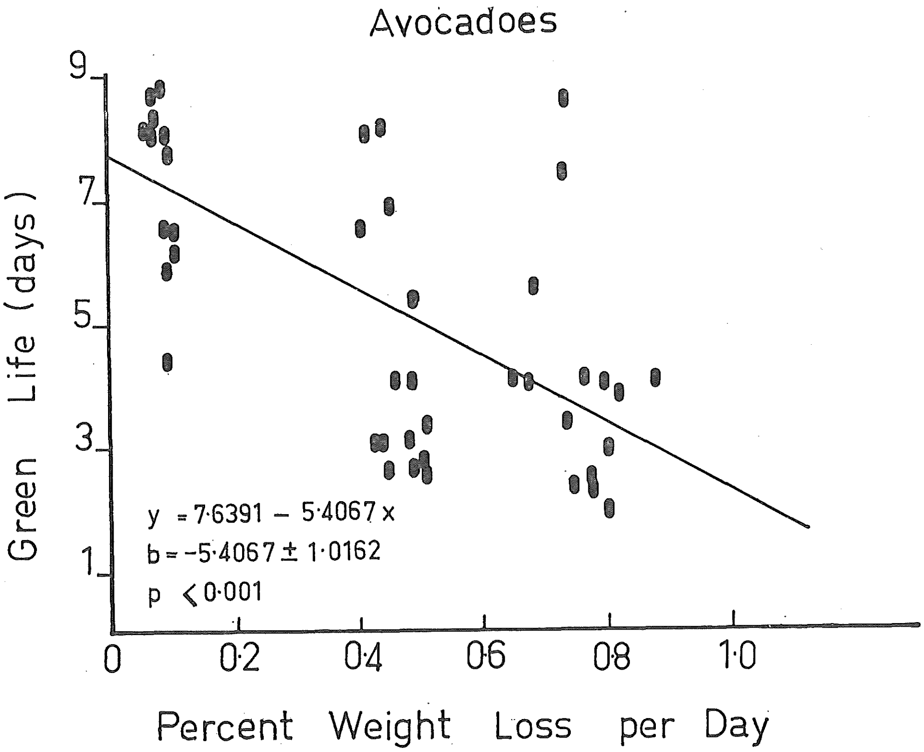

Fig. 1.—Relation between green-life and percentage daily weight loss in avocadoes (Expt. 1).

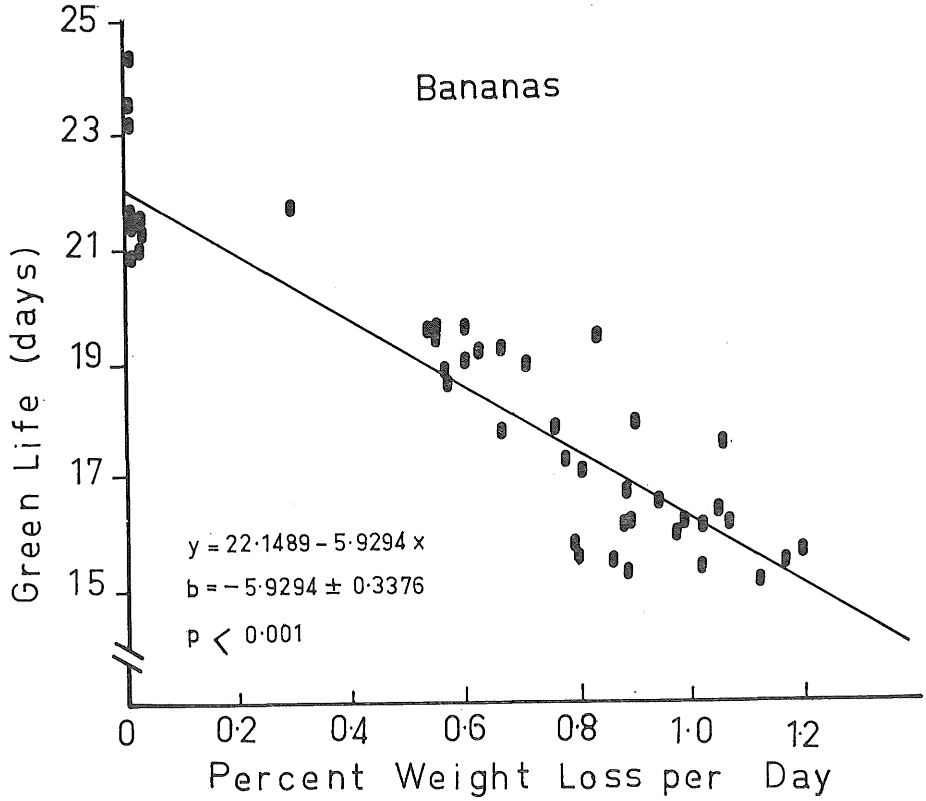

Fig. 2.—Relation between green-life and percentage daily weight loss in bananas (Expt. 2).

Results of experiments 3 and 4 (bananas) and experiment 6 (pears) are given in Table 1. Statistical analyses were done as *t* tests between the means of green-life obtained from fruit held at the two extremes of humidity.

In Table 2 are presented regression data of percentage daily weight loss against time to half colour and time to firmness change of experiment 5 with bananas. Fruit from five consecutive (proximal) hands of a bunch were taken, and fruit from each hand stored at five humidity levels.

TABLE 1

EFFECT OF RELATIVE HUMIDITY (RH) OF STORAGE ON GREEN–LIFE OF BANANAS (EXPTS. 3 AND 4) AND PEARS (EXPT. 6)

Experiment	RH = 95%			RH = 13%			—	
	No. of Fruit	Mean Green-life	S.E. of Mean	No. of Fruit	Mean Green-life	S.E. of Mean	Differences	S.E. of Mean Differences
Bananas—								
Experiment 3a	13	26·52	± 0·93	11	15·02	± 0·52	11·50	± 1·07***
3b	9	21·46	± 0·89	9	15·86	± 0·42	5·60	± 0·99***
3c	7	16·80	± 0·24	7	13·33	± 0·39	3·47	± 0·45***
Experiment 4—								
Top Hand	7	21·66	± 0·32	5	16·14	± 0·39	5·52	± 0·51***
2nd Hand	6	21·93	± 0·50	6	16·33	± 0·38	5·60	± 0·63***
3rd Hand	5	21·94	± 0·39	7	15·73	± 0·18	6 21	± 0·39***
Pears—								
Experiment 6	10	12·10	± 1·43	9	8·44	± 0·82	3·66	± 1·65*

* $P < 0{\cdot}05$; *** $P < 0{\cdot}001$

TABLE 2

REGRESSION ANALYSES OF PERCENTAGE DAILY WEIGHT LOSS AGAINST TIME TO RIPEN EXPRESSED AS (1) DAYS TO HALF COLOUR AND (2) DAYS TO FIRMNESS CHANGE FOR BANANA FRUIT FROM FIVE HANDS OF THE ONE BUNCH (EXPT. 5)

Time to ripen = a + b × Percentage daily weight loss

—	—	Top Hand	2nd Hand	3rd Hand	4th Hand	5th Hand
(1) Half colour	a	30·3194	27·5329	29·2813	22·9158	21·9858
	b	− 9·2464***	− 8·5898***	− 9·7177***	− 6·2917***	− 6·3493***
	S.E. of b	± 1·1876	± 1·4013	± 1·1343	±10·7280	± 1·0800
	df	18	14	18	18	18
(2) Firmness change	a	21·6269	21·0521	21·5896	19·1245	17·8079
	b	− 2·4773**	− 2·1776	− 3·1070**	− 3·7039***	− 4·5340***
	S.E. of b	± 0·6338	± 1·0630	± 0·9414	± 0·6112	± 0·8509
	df	18	14	18	18	18

** $P < 0{\cdot}01$; *** $P < 0{\cdot}001$

The green-life which is lost by fruit subjected to moisture stress has been calculated by comparing means of green-life of fruit held under high and low humidity levels, using green-life at the high humidity as the basis of comparison. Mean percentage loss of green-life of fruit held at the low humidity calculated on mean green-life at the high humidity is given for a number of experiments involving the three fruit species in Table 3.

TABLE 3

EFFECT OF RELATIVE HUMIDITY (RH) OF STORAGE ON PERCENTAGE LOSS OF GREEN-LIFE OF FRUIT

Experiment	Mean Green-life (Days)		Percentage Loss of Green-life
	RH = 95%	RH = 13%	
Avocadoes			
Experiment 1	7·2	4·1	43·6
Bananas			
Experiment 2	21·9	16·0	26·8
Experiment 3a	26·5	15·0	43·4
3b	21·5	15·9	26·1
3c	16·8	13·3	20·7
Experiment 4			
Top hand	21·7	16·1	25·5
2nd hand	21·9	16·3	25·5
3rd hand	21·9	15·7	28·3
Experiment 5			
Colour			
Top hand	23·0	17·2	25·0
2nd hand	22·6	17·2	23·8
3rd hand	30·1	20·6	31·5
4th hand	27·8	19·1	31·3
5th hand	31·4	21·2	32·3
Firmness			
Top hand	18·1	14·2	21·4
2nd hand	18·7	15·7	16·3
3rd hand	21·1	18·4	13·0
4th hand	20·6	19·2	7·0
5th hand	21·5	18·7	13·0
Pears			
Experiment 6	12·1	8·4	30·2

IV. DISCUSSION

The findings clearly establish that moisture loss hastens ripening in the fruits investigated. Time to onset of the climacteric is the most meaningful physiological characteristic of the fruit measured, and statistical analyses have indicated a significant relationship between this character and moisture loss, for the three fruit species investigated. Regression coefficients for avocadoes (experiment 1) and bananas (experiment 2) were significant at a level of 0·1%. Differences between means of green-life at the extremes of humidity were significant at the 0·1% level for experiments 3 and 4 with bananas, and at the 5% level for experiment 6 with pears (Table 1).

Time to half colour and time to firmness change are features which are less amenable to accurate determination because of the imprecise nature of the changes which occur. Time to firmness change was particularly difficult to estimate because the firmness change associated with ripening was partly masked by the wilting which accompanied moisture loss. However, in experiment 5, where the top five hands of the bunch were kept separate, the regression of percentage daily weight loss on time to half colour was significant at the 0·1% level for all five hands (Table 2). The regression of percentage daily weight loss on time to firmness change was not significant for one of the hands, but was significant at the 0·1 or 1% level for the other four.

The loss of green-life occurring at low humidity (Table 3) was observed to be 30·2% in pears, and losses of over 40% were recorded for avocadoes and for bananas in one experiment. In bananas, green-life was reduced from 26 days to 15 days. Losses of more than 20% were general. Also in Table 3, loss of green-life based on colour is shown to be comparable with losses based on time to onset, but when the basis of assessment is time to firmness change, lower losses appear to occur. Damage to fruit tissue by the mechanical thumb may be the reason for this effect.

The loss of weight suffered by a fruit up to the time of ripening in some instances approached 20%; e.g. one fruit in experiment 2 (Figure 2) lost 1·2% per day for 15·7 days. Also, because of gradually increasing stress in fruit maintained under dry conditions, the percentage reduction in green-life is a function of the green-life itself. This effect may be seen most clearly in Table 3, experiment 3, where fruit with green-lives of 26·5, 21·5 and 16·8 days lost green-lives of 43·4, 26·1 and 20·7% respectively. A similar trend may be seen in experiment 5 with colour. The absence of the trend in firmness in experiment 5 is thought to result from the inaccuracies in measurement mentioned above.

The only other published data found to be in agreement with these findings are some of the results of Gac (1956). He found that green-life (time to climacteric peak) of pears was 78 days at 100% RH and 72 days at 65% RH when fruit were held at 5°C. At 17°C, pears at 86% RH had a green-life of 21 days, compared with 19 days for fruit stored at 71 or 57% RH. No statistical estimate of the significance of these differences is given. Calculations made on Gac's data indicate that his fruit lost 8% green-life at 5°C and 10% green-life at 17°C. However, Gac's respiratory data are generally variable and indicate a number of respiratory peaks in some experiments, an unlikely pattern in single fruit. Because he used samples of a number of fruit for each treatment, his respiratory results must be cautiously interpreted. No explanation is offered for the conflicting results of Tsalpatouros (1956).

The mechanism by which water loss reduces green-life is open to conjecture. A number of authors (Wardlaw, Leonard and Barnell 1939; Wilkinson 1965) have reported increased resistance of fruit to gas exchange with increasing moisture loss. A more rapid accumulation of endogenous ethylene to stimulatory levels resulting in more rapid ripening would therefore seem possible. However, gas storage effects are induced by wax coatings on fruit and ripening is normally retarded with this treatment.

An alternative interpretation may be made, based on observations of the effect of stresses of widely differing types on the stimulation of the production of ethylene. A review by Pratt and Goeschl (1969) lists radiation, disease, wounds, chilling, high oxygen, chemicals, growing against obstructions, and changing orientation toward gravity as stimulating ethylene production. The role of the stimulated ethylene is unknown, but Maxie *et al.* (1968) found that mechanical injury to preclimacteric banana fruit caused an earlier increase in ethylene production, with consequent earlier ripening. If water stress also stimulates ethylene production, a likely mechanism for the effect in these experiments would be established.

The commercial significance of the findings reported in this paper requires determination, e.g. Hicks and Holmes (1935) considered that cooling of bananas by natural ventilation in railway louvered waggons may be effected mainly by evaporation of moisture from the fruit. J. R. Blake (personal communication) has reported weight losses of 0·8 and 0·2% per day from bananas in cases and cartons respectively, when transported under these conditions. On the basis of the present findings (see Figures 1 and 2) loss of green-life under commercial conditions could be significant. The relative importance in evaporative cooling situations of the opposing effects of cooling and drying on green-life remains to be determined.

Humidity is not always controlled in storage experiments and Scott and Roberts (1967) reported that, as a consequence of this, doubtful interpretations of apple breakdown data have been made by some authors. The results reported in this paper extend the experimental implications of lack of humidity control. Valid comparisons of ripening behaviour (and possibly other characteristics of ageing) of stored fruits require at least evaluation of the influence of water loss.

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