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MODELLING THE WATER BALANCE OF CUT ANTHURIUMS IN STORAGE

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ABSTRACT

Experimental trials were conducted to investigate the basic components of water balance (water uptake, transpiration, water accumulation) and their relationship to senescence and vase life in cut anthuriums stored under ambient and refrigerated conditions. Anthuriums were held in distilled water and stored under ambient conditions (28 °C; rh 60–80%) and in refrigerated storage chambers set at 18, 13 and 8 °C (rh 80–90%) for a maximum of 30 days. Water uptake, transpiration, water accumulation, flower fresh weight, moisture content and keeping quality (determined through spathe blueing, spathe gloss, spadix necrosis and abscission) were monitored at 5-day intervals. Storage of anthuriums in water at 18 and 13 °C extended shelf-life. The changes in water uptake, transpiration, transpiration:uptake ratio, fresh weight and moisture content were accurately described by logarithmic, exponential and inverse quadratic models. Post-harvest life was directly related to flower turgidity and the rate of water accumulation, which was dependent on the balance between the rates of uptake and transpiration.

INTRODUCTION

Water balance, a term used to describe the relationship between water uptake and transpiration, is a major factor affecting the longevity of cut flowers as the most common reason for the termination of vase life is wilting and not natural senescence (Halevy, 1976). Many authors have studied the different aspects of the water relations of the cut flower. The bsic parameters commonly investigated are water uptake, transpiration and flower fresh weight. Generally both water uptake and transpiration are initially high and then decline with storage time (Durkin and Kuc, 1966; Marousky, 1969; Burdett, 1970; Carpenter and Rasmussen, 1973; Mayak et al., 1974; Halevy, 1976; Paull and Goo, 1985). The initial rapid uptake of water follows the release of the normal tension in the xylem vessels when the stems are recut in air (Van Meeteren, 1992) and the subsequent reduction has been attributed to many factors including air embolisms, microbial plugging and physiological plugging (Halevy and Mayak, 1981). Transpiration is influenced by the water uptake capacity of the flower, the surface area:volume ratio and the surface coating of the flower, as well as by environmental factors such as air temperature, humidity and air velocity. When the rate of transpiration exceeds that of water uptake, a water shortage occurs and the cut flower will wilt. Typically, flower fresh weight initially increases and subsequently decreases, and or most flowers, vase life is terminated when the flower weight decreases to 10% below the original fresh weight (Rogers, 1963; Coorts et al., 1965; Mayak et al., 1974).

The objectives of this present work were to investigate the basic components of water balance (water uptake, transpiration, water accumulation) and their relationship to senescence and vase life in cut anthuriums stored under ambient and refrigerated conditions and to describe the changes in the various parameters using mathematical models. The anthurium (cv. Trinidad Pink) was chosen as a flower 'model' as it is commonly grown and easily available, long lasting, and of increasing demand on both the local and foreign market.

MATERIALS AND METHODS

Anthurium flowers (cv. Trinidad Pink), were obtained from a commercial cut anthurium producer in Lalaja, Trinidad. Undamaged flowers that were at least three-fourths mature – based on the percentage of open flowers on the spadix (Paull, 1982) – were cut to a length of 30 cm and placed singly in plastic bottles containing distilled water. The mouth of each bottle was sealed with waterproof parafilm to ensure that water loss occurred only via the flower. Bottles were placed in refrigerated storage chambers set at 8, 13 and 18 °C (rh 80–90%), as well as under ambient conditions (28 °C, rh 60–80%) for a maximum of 30 days.

At the start of the experiment and at 5-day intervals the following were measured:

(a) weight of bottle + water + flower (g)
(b) weight of bottle + water without flower (g)
(c) weight of the flower only (g)

From the change in weight between two consecutive measurements, divided by the number of hours during that interval, the rate of water uptake, transpiration and water accumulation were calculated (Halevy et al., 1974). The difference between consecutive weighings of (a) was used to calculate transpiration (T). The difference between consecutive weighings of (b) was used to calculate water uptake (U). Changes in flower fresh weight (c) were expressed as a percentage change over the initial weight. Changes in flower fresh weight were attributed to the accumulation or loss of water, thus, the difference between consecutive weighings was used to calculate water accumulation (A). All rates were expressed in g water/cm^2 spathe per hour. From a strictly physical concept of water balance, it is possible to relate the rates as follows:-

$$\text{Uptake rate} = \text{Transpiration rate} + \text{Accumulation rate} \qquad (1)$$

Since the relationship between transpiration and water uptake is an important consideration in cut flower life, it follows by extension from Equation (1):

$$\frac{\text{Transpiration rate}}{\text{Uptake rate}} = 1 - \frac{\text{Accumulation rate}}{\text{Uptake rate}} \qquad (2)$$

Spathe areas were determined using an automatic areameter (Tokyo Hayashi Denko Ltd., Type AAM5). Moisture content, expressed as percentage of dry weight, was determined after a 48-h oven drying of the tissue at 65 °C (Paull and Goo, 1985). Vase life and keeping quality were evaluated by monitoring spathe blueing, spathe gloss and spadix senescence following the procedure developed by Paull (1982). Marketability and percent abscission were also assessed. The data were evaluated using statistical programs (Comparison of Linear Regressions COLR and MINITAB Data Analysis Software) to determine the effect of time and temperature on the various post-harvest changes in the stored anthuriums.

RESULTS AND DISCUSSION

Keeping quality

Based on the visual assessment of flower quality, storage temperature was found to have a dramatic effect on the keeping quality of cut anthuriums ($P \leq 0.001$) as the use of low temperatures such as 18 and 13 °C delayed the development of common symptoms of senescence such as spathe blueing, loss of spathe gloss and spadix dehydration. The shelf-life of flowers stored under ambient conditions averaged 15 days while flowers stored at 18 °C were marketable after 25 days. Flowers stored at 13 °C seemed slightly deteriorated after 30 days but were still marketable. Flowers stored at 8 °C rapidly deteriorated at this chilling temperature, developing a dull, brown unattractive colour beyond 10 days of storage.

Rates of water uptake and transpiration

As shown in Figure 1 and Figure 2 water uptake and transpiration rates were initially high then declined rapidly during the first 5 days, after which the rate of decline was reduced. The decline in water uptake and transpiration rates were found to be accurately described by a logarithmic model of the general form:

$$y = a + b \log(t) \qquad (3)$$

where y represents rate of water uptake or transpiration, t represents storage time, a represents the intercept on the y axis or initial rate, and b is the slope which represents the rate of change in water uptake or transpiration. This means that plots of rates versus the log of storage time gave straight lines. Water uptake rates were significantly ($P \leq 0.001$) affected by storage time at 28, 18, 13 and at 8 °C. Transpiration rates were significantly affected by storage time at 28 °C ($P \leq 0.01$), at 18 °C ($P \leq 0.001$), at 13 °C ($P \leq 0.001$) and at 8 °C ($P \leq 0.05$).

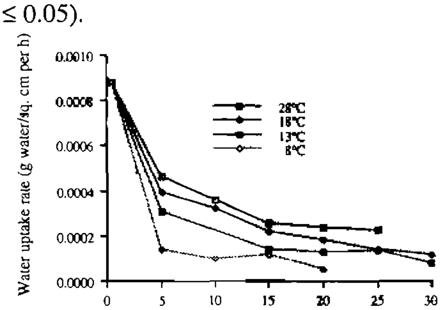

Figure 1 Water uptake rates of stored anthuriums

Logarithmic regressions :

28 °C: $dU/dt = 7.5370e^{-4} - 4.0008e^{-3} * \log(t)$ $r^2 = 0.995$

18 °C: $dU/dt = 7.3484e^{-4} - 4.3050e^{-3} * \log(t)$ $r^2 = 0.993$

13 °C: $dU/dt = 7.0477e^{-4} - 4.4601e^{-3} * \log(t)$ $r^2 = 0.969$

8 °C: $dU/dt = 6.6206e^{-4} - 5.2150e^{-3} * \log(t)$ $r^2 = 0.919$

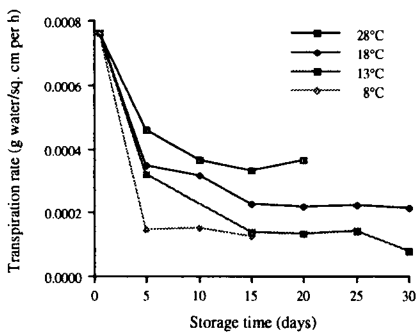

Figure 2 Transpiration rates of stored anthuriums

Logarithmic regressions :

28 °C: $dT/dt = 6.6627e^{-4} - 2.6976e^{-4} * \log(t)$ $r^2 = 0.965$

18 °C: $dT/dt = 6.3196e^{-4} - 3.1433e^{-4} * \log(t)$ $r^2 = 0.959$

13 °C: $dT/dt = 6.2473e^{-4} - 3.7971e^{-4} * \log(t)$ $r^2 = 0.983$

8 °C: $dT/dt = 5.8648e^{-4} - 4.5249e^{-4} * \log(t)$ $r^2 = 0.919$

Water uptake and transpiration rates were also significantly affected by storage temperature ($P \leq 0.001$). As the storage temperature was lowered, the rates were reduced. Lowering the temperature of the environment reduces its evaporative demand thereby reducing transpiration, and also reduces the temperature of the water thereby resulting in the more rapid removal of entrapped air and facilitating undisturbed water uptake (Van Meeteren, 1992). Decreasing the storage temperature from 28 to 8 °C did not alter the general pattern of decline in water uptake or transpiration, but did reduce the actual rates, and this is reflected in a reduction of intercept values.

Flower fresh weight

Figure 3 shows the changes in fresh weight of anthuriums with time and temperature calculated as a percentage change over the initial weight. In general, anthuriums showed an initial increase in flower fresh weight, and with the exception of flowers stored at 13 °C, this increase was followed by a decline as the storage period increased. In order to mathematically describe the change in flower fresh weight, various relationships were tested and an inverse quadratic model (Mead and Curnow, 1983) was found to be most accurate:

$$t/FW = a + bt + ct^2 \qquad (4)$$

This model produces a non-symmetrical curve where $c \neq 0$, and permits only positive values of fresh weight if a, b, and c are positive. The ratio of a to b describes the form of the rising portion of the curve, and the ratio of b to c the form of the falling portion. Also, the maximum fresh weight value occurs at time $\sqrt{(a/c)}$. Flower fresh weight was found to be significantly affected by storage time ($P \leq 0.001$) and storage temperature ($P \leq 0.01$).

Water accumulation rate

Figure 4 shows the changes in the rate of water accumulation (calculated from the change in flower fresh weight) of anthuriums stored at 28, 18, 13 and 8 °C. Flowers rapidly accumulated water at an initial average rate of 1.244×10^{-4} g H_2O/cm^2 spathe per h. After 5 days and at all temperatures, the rate of accumulation declined. With the exception of flowers stored at 13 °C, water accumulation rates declined further with increased storage.

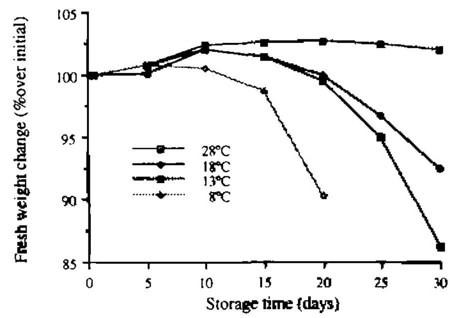

Figure 3 Fresh weight changes in stored anthuriums

Inverse quadratic regressions:

28 °C: $(t/FW) = 1.9164e^{-3} - 8.0327e^{-3}t + 1.3360e^{-4}t^2$ $r^2 = 0.999$

18 °C: $(t/FW) = 1.1885e^{-3} - 8.7654e^{-3}t + 8.0446e^{-5}t^2$ $r^2 = 1.000$

13 °C: $(t/FW) = 1.8933e^{-3} - 9.6458e^{-3}t + 5.7508e^{-6}t^2$ $r^2 = 1.000$

8 °C: $(t/FW) = 5.6432e^{-3} - 8.7773e^{-3}t + 1.5143e^{-4}t^2$ $r^2 = 1.000$

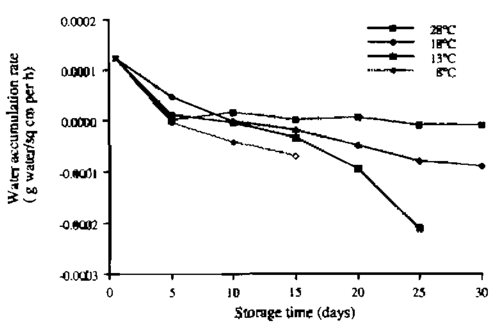

Figure 4 Water accumulation rates of stored anthuriums

Moisture content

Moisture content followed a similar pattern as that of fresh weight; increasing to a maximum early in post harvest life then declining (Figure 5). An inverse quadratic polynomial was therefore also used to model the change in moisture content with storage time. The moisture content of anthuriums was significantly ($P \leq 0.001$) affected by storage time at 28, 18, 13 and at 8 °C.

Water balance and transpiration:uptake ratio

Water accumulation rates calculated from the model proposed in Equation (1) were significantly similar ($P \leq 0.001$) to those obtained using the experimental data. This validates the model and means that for all storage temperatures, water accumulation directly depends on the difference between water uptake and transpiration and can therefore quantitatively represent the water balance of the flowers.

The ratio of transpiration rate to water uptake rate (Equation 2) was found to increase with storage time in ambient flowers and in those stored at 18 °C and 8 °C (Figure 6). The transpiration:uptake ratio (y) is therefore a good quantitative index of the relationship between water uptake rate, transpiration rate and water accumulation rate. The transpiration:uptake data, with the exception of those for 13 °C, were most accurately described using an exponential model:

$$y = y_0 e^{bt} \qquad (5)$$

where y_0 is the initial value of y. Thus the relationship between log y versus t was found to be linear. Transpiration:uptake ratio was significantly affected by storage time ($P \leq 0.001$) and by storage temperature ($P \leq 0.001$).

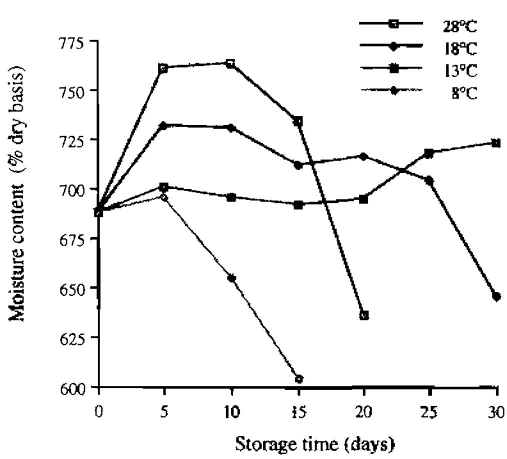

Figure 5 Moisture content of stored anthuriums

Inverse quadratic regressions:

28 °C: (t/MC) = $3.4449e^{-4} - 9.8034e^{-4}t + 2.7704e^{-5}t^2$ $r^2 = 0.998$

18 °C: (t/MC) = $4.1900e^{-4} - 1.1737e^{-3}t + 1.1115e^{-5}t^2$ $r^2 = 0.998$

13 °C: (t/MC) = $-1.5162e^{-4} - 1.5132e^{-3}t + 4.2101e\text{-}6t^2$ $r^2 = 1.000$

8 °C: (t/MC) = $3.0168e\text{-}^5 - 1.2939e^{-3}t + 2.3793e^{-5}t^2$ $r^2 = 1.000$

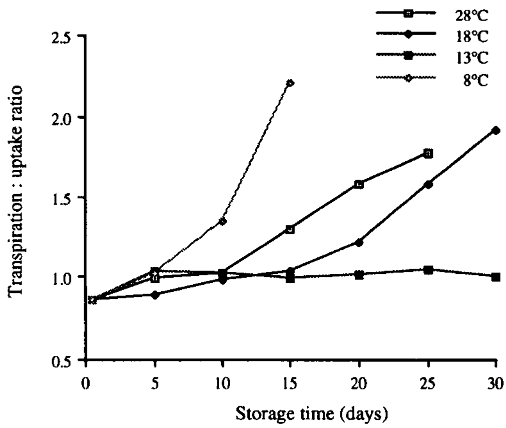

Figure 6 The transpiration:uptake ratio of stored anthuriums

Exponential regressions:

28 °C:	log dT/dU = $-0.0823 + 1.3215e^{-2}t$	$r^2 = 0.975$
18 °C:	log dT/dU = $-0.1127 + 1.1822e^{-2}t$	$r^2 = 0.929$
13 °C:	log dT/dU = $0.0238 + 0.1500e^{-2}t$	$r^2 = 0.260$
8 °C:	log dT/dU = $-0.1071 + 2.7891e^{-2}t$	$r^2 = 0.959$

CONCLUSIONS

The vase life of cut anthuriums is limited by the development of a water deficit which occurs when the rate of transpiration exceeds the rate of water uptake, possibly due to stem plugging of an undetermined nature (Paull et al., 1985). This decreased uptake, coupled with continuous transpiration, results in a decline in water accumulation and therefore a decrease in flower turgidity and wilting. The changes in these water balance parameters can be successfully modelled using mathematical relationships.

Storage at 18 °C and to a greater extent, 13 °C, which lies within the optimum storage temperature range (Kamemoto, 1962; Paull, 1987; Adamczak, 1990), can extend shelf-life to 25 and 30 days respectively. Low temperature reduces respiratory and other metabolic activities (Kamemoto, 1962) and, as shown by the above results, improves water balance, hence reducing water stress and delaying senescence. Storage at too low a temperature, in this case 8 °C, adversely affected quality as a result of chilling injury (Kamemoto, 1962).

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