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Reduction of energy usage during storage and transport of bananas by management of exogenous ethylene levels

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ABSTRACT

Unripe Australian-grown Cavendish and Lady Finger bananas were stored at 15, 20 and 25 °C in an atmosphere containing 0.001, 0.01, 0.1 and 1.0 μL/L ethylene in air and the green life was determined as the time to reach the respiratory climacteric. As expected, green life increased as the temperature and ethylene concentration decreased. The equation describing the relationship between temperature, ethylene concentration and green life of Cavendish bananas was applied to a five-day 3000 km road transport route from the major tropical production area to the major urban markets. It predicted that bananas transported in the prevailing mean summer temperature of 25 °C would not require refrigeration if the ethylene level did not exceed 0.58 μL/L while transport at the mean winter temperature of 14 °C fruit could withstand a level of about 0.90 μL/L without ripening en route. The equation was also applied to a shipment protocol of 19 days for bananas exported from Central America to southern Europe. This predicted that fruit could be transported without refrigeration if ethylene levels were maintained at 0.04 μL/L during the winter temperature of 17 °C and at 0.002 μL/L at the summer transport temperature of 24 °C. Since a range of technologies are available to maintain such low ethylene levels or reduce the action of ethylene, these findings suggest that the current refrigerated transport of bananas could be minimised or eliminated. The use of higher temperatures in the supply chain would reduce energy consumption with resultant environmental and economic benefits.

1. Introduction

The postharvest handling of horticultural commodities under refrigeration dramatically increases marketing options and reduces wastage for a wide range of commodities. However, the widespread adoption of cool chain technology was introduced in an era where energy was cheap and there was no concern about greenhouse gas emissions. In recent years, the horticultural industry, in common with many other industries, has become interested in reducing its carbon footprint. The twin drivers of change are economic, arising from government actions that markedly increase the cost of energy, and community pressure for industry to be seen as a good corporate citizen. East (2010) reviewed postharvest energy usage of horticultural commodities and cites that in California, cooling and storage of fresh horticultural produce uses close to 1 billion kWh of energy which was 5.5% of the electricity used by agriculture in the state (Thompson and Singh, 2013). In addition, refrigeration in US supermarkets is the main use of energy accounting for 36% of all energy costs (E-source, 2013). Given the large volume of fresh horticultural produce traded and sold around the world, there would seem to be scope and incentive for considerable reductions in energy usage.

Reduction in energy consumption in postharvest handling can be achieved if produce are stored and transported at higher temperatures than the optimal low temperature currently mandated by the respective commodity sectors. This will require the use of some other intervention that can inhibit ripening and senescence. An obvious technology is to control the concentration or activity of ethylene in the atmosphere around produce or receptivity of produce to ethylene action. The active threshold level of ethylene for physiological action was often cited to be 0.1 μL/L (Burg and Burg, 1962) but studies on a range of produce have found a more realistic threshold level to be <0.005 μL/L (Knee et al., 1985; Wills et al., 1999a, 2001; Pranamornkith et al., 2012). In practical terms this means that any reduction in the ethylene concentration in the atmosphere around produce will be beneficial in extending postharvest life. It is immaterial whether the source of ethylene in the atmosphere is from the produce itself or from exogenous sources.

Bananas are the most traded horticultural commodity with substantial imports into temperate countries in Europe, USA and Japan from a range of tropical countries (FAO, 2011). This has resulted in

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the long distance transport of bananas by sea under refrigeration at 13–15 °C in order to prevent ripening during the voyage which may be up to three weeks but above the threshold temperature for development of chilling injury, which is in the range 12–15 °C depending on cultivar, fruit maturity and time of harvest (John and Marchal, 1995). Recent lifecycle analysis reports that the refrigerated shipping of bananas around the world is the largest source of greenhouse gas emissions in banana production (Lescot, 2012). In addition, in a large country such as Australia, banana production occurs in tropical regions that are a considerable distance from major urban centres and refrigerated road transport at 14–16 °C has become the standard mode of local transport (Australian Bananas, 2013).

Wills et al. (1999b) reported that the green life of bananas at 20 °C was doubled when the concentration of exogenous ethylene was reduced from 0.1 to 0.01 μL/L. This suggests that controlling the ethylene in the atmosphere around green banana fruit may offer a partial or possibly even a total offset to the use of refrigeration during the storage and transport of bananas. While it is well known that endogenous ethylene production and produce sensitivity to ethylene decrease as the temperature is reduced (Liu, 1978), the interaction of temperature and ethylene concentration on the postharvest life of commodities is not well described or understood. In this study, we quantified the relationship between ethylene concentration, temperature and green life (i.e. the time to ripen) of Australian grown Cavendish bananas and with a smaller study of Lady Finger bananas. We also speculate on how the relationship may be applied to commercial shipments both within Australia and internationally to reduce the need for refrigeration.

2. Materials and methods

2.1. Produce

Cavendish bananas (*Musa acuminata* Colla., AAA group, Giant Cavendish subgroup, cv 'Williams') were obtained from three growing districts on the east coast of Australia spanning 2000 km of far north Queensland, Tweed Valley (northern New South Wales) and Coffs Harbour (mid-north coast of New South Wales). One carton of commercially mature, preclimacteric, non-ethylene treated Cavendish bananas from each growing region was obtained from the Sydney wholesale markets at three times at 6-monthly intervals. Lady Finger bananas (*Musa acuminata* × *Musa balbisiana*, AAB group, Pome subgroup) were obtained from the Tweed Valley on one occasion. Individual fingers from each box were selected at random, disregarding atypical, blemished and wing fruit, to allow three fingers to be assigned to each of the required number of treatment units. Each finger was placed in a 1.8 L glass jar.

2.2. Treatment and assessment of bananas

The fruit in a treatment unit were stored at 15, 20 or 25 °C in air containing 1.0, 0.1, 0.01 or 0.001 μL/L ethylene. Ethylene levels were maintained using the method described by Wills et al. (1999b). The actual concentration of the nominated 0.001 μL/L ethylene treatment was <0.002 μL/L which was the limit of detection. Ethylene and carbon dioxide emissions were monitored at the inlet port of glass jars by gas chromatography and infrared gas analysis, respectively, and respiration rates were calculated from carbon dioxide emissions, according to the methods of Wills et al. (1999b). The green life of each banana was taken as the number of days to reach a maximum in respiration (respiratory climacteric). The mean value for green life was calculated for the three fruit in each treatment.

2.3. Statistical analysis

A linear mixed model was used to describe days of green life for Cavendish bananas in response to storage temperature, ethylene concentration, growing district and purchase time. Fixed terms in the model were ethylene concentration, temperature, their interaction as well as the square of ethylene concentration. The specification of growing district and purchase time as random effects allowed the green life response equation to be generalised to other banana growing districts and times of purchase. The addition of random coefficients allowed the slope and intercept of the green life response to the fixed effect of ethylene concentration to vary with growing district and time of purchase. The general form of the equation was: $y = a + b * x + c * x^2 + d * z + e * x * z + \textit{district} * \textit{time} + \textit{district} * \textit{time} * x$ where y = green life (days), $x = \log_{10}$ ethylene concentration (μL/L) and z = storage temperature (°C). Random terms are italicised.

The modelling was conducted using the AsReml package (Butler et al., 2009) in the R programming environment (R Core Development Team, 2012). Ethylene rate was $\log_{10}$ transformed to help linearise the response of green life and since green life was observed to be more uniform at the high (1.00 μL/L) ethylene concentration, the linear mixed model specification included an extra variance component for the other 3 concentrations. This model was shown to be an improvement over the homogeneous variance model according to its reduced Akaike Information Criterion. Ethylene concentrations were calculated from the fixed model parameters for given values of green life and storage temperature. Standard errors, calculated with the delta method on the $\log_{10}$ scale, were then used to interpolate 95% confidence limits on the back transformed scale (μL/L) using the R package *car* (Fox and Weisberg, 2011).

For Lady Finger bananas, the effects on $\log_{10}$ green life of $\log_{10}$ ethylene concentration, storage temperature and their interaction as well as the square of $\log_{10}$ ethylene concentration were tested using multiple linear regression analysis.

3. Results and discussion

3.1. Relationship of green life with temperature and ethylene concentration

3.1.1. Cavendish bananas

The data in Table 1 show that the green life of Cavendish bananas sourced from three growing districts decreased with an increase in storage temperature and an increase in ethylene concentration. Significant effects of $\log_{10}$ ethylene concentration ($P < 0.001$), storage temperature ($P < 0.001$), their interaction ($P < 0.001$) and the square of $\log_{10}$ ethylene concentration ($P = 0.019$) were observed. The general equation for the fixed variables was calculated as: $y = 5.714\ (\pm 0.456) - 21.081\ (\pm 1.861) * x - 0.824\ (\pm 0.349) * x^2 - 0.097\ (\pm 0.022) * z + 0.547\ (\pm 0.066) * x * z$ where y = green life (days), $x = \log_{10}$ ethylene concentration (μL/L) and

Table 1
Green life of Australian-grown Cavendish bananas (mean ± standard error) stored at different temperatures and in air with different ethylene (C_2H_4) concentrations.

C_2H_4 (μL/L)	Green life (days)			
	0.001	0.01	0.1	1.0
Temp				
15 °C	34.6 ± 3.6[a]	31.7 ± 3.1	15.1 ± 1.3	4.5 ± 0.1
20 °C	27.2 ± 2.0[b]	20.0 ± 1.5	11.4 ± 0.8	3.4 ± 0.8
25 °C	15.2 ± 1.6[a]	14.5 ± 1.2	8.50 ± 0.7	3.6 ± 0.1

[a] Means in this row are from 18 fruit (3 districts × 2 purchase times × 3 fruit).
[b] Means in this row are from 27 fruit (3 districts × 3 purchase times × 3 fruit).