Predictors of Shelf Life in Long English Cucumber

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ABSTRACT. Variation in shelf life of greenhouse-grown 'Mustang' cucumber (*Cucumis sativus* L.) fruit was enhanced by preharvest experimental treatments of fruit thinning and fruit shading. Treatments also affected the dynamics of fruit elongation, fruit color at harvest, and chlorophyll fluorescence of the pericarp. Fruit color (grey level) at harvest, as measured by image analysis, had the highest simple (positive) correlation with shelf life. Rapid elongation and high photochemical quenching of fluorescence also characterized fruit having longer shelf life. The ability to predict cucumber yellowing is improved using a multiple regression approach, but prediction achieved by the best subset model is still too low to segregate commercially fruit having a short shelf life.

Incipient yellowing of the pericarp limits the shelf life of marketable long English cucumbers after harvest (Lin, 1989). Fruit shelf life can be up to 3 weeks long, but some fruit can start yellowing after only a few days of storage. Shelf life can vary widely among individual fruit stored under similar conditions, and this complicates the postharvest handling and marketing of long English cucumbers.

Preharvest factors appear to be responsible for much of the variation in cucumber shelf life. High nutrient concentrations during plant growth prolong shelf life but reduce marketable fruit production per plant (Lin and Ehret, 1991). Preharvest lighting conditions seem to be particularly important. Shelf life is longer if fruit are well exposed to sunlight during growth, as demonstrated in experiments using different shoot training and pruning regimes (Klieber et al., 1993). Shelf life progressively decreases with increasing shade and can be increased using supplemental lighting above or in the shoot canopy (Lin and Jolliffe, 1995, 1996). The physiological roles of light in extending shelf life are not yet clear. The responses to fruit thinning, light intensity, and spectral quality indicate that photosynthesis by the fruit or nearby leaves may be involved. At low light intensities, however, phytochrome may also be involved (Lin and Jolliffe, 1995, 1996).

The ability to predict postharvest longevity of cucumbers would facilitate the commercial segregation of fruit with different storage potentials. Cucumber shelf life has been found to decline with increasing fruit age at harvest (Kanellis et al., 1986; Lin and Ehret, 1991), and it was hypothesized that factors that allow rapid fruit growth will result in longer shelf life (Lin and Ehret, 1991). Fruit elongation of field-grown cucumbers was analyzed photographically (Wehner and Saltveit, 1983), and all sections of the fruit contributed proportionately to growth during a 30-d period. Measures of the dynamics of fruit growth may be useful as predictors of shelf life. Also, cucumbers are harvested when immature, and several studies have found that shelf life is longer in fruit having high color (chlorophyll) at harvest (Klieber et al., 1993; Lin and Ehret, 1991; Lin and Jolliffe, 1995, 1996). Color

assessment has been proposed as a possible approach for predicting the duration of fruit marketability (Lin and Ehret, 1991), and color can be evaluated nondestructively by video imaging (Lin et al., 1993). Another approach would be to test the functionality of chlorophyll in the pericarp using chlorophyll fluorescence (Kraus and Weis, 1984). Chlorophyll fluorescence was found to be a useful indicator of freshness and quality of harvested broccoli (Toivonen, 1992), although the functionality of chlorophyll in cucumbers has not been reported. The aim of the present studies was to compare the ability of different measures of fruit growth, color, and fruit pigment function to predict shelf life.

Materials and Methods

Shelf life and other characteristics of 'Mustang' long English cucumbers were manipulated by fruit thinning, by selecting fruit from different canopy positions (Expt. 1), and by growing fruit under different shading and spectral regimes (Expt. 2). In Expt. 1, the course of fruit elongation was monitored, providing a means to assess the relationship between growth dynamics and shelf life. Experiment 2 explored the relationship between shelf life and measures of fruit size, color, and chlorophyll fluorescence.

DYNAMICS OF FRUIT ELONGATION (EXPT. 1). Seeds were individually sown in rockwool cubes on 21 Jan. and transplanted on 20 Feb. 1992 at the four- to six-leaf stage, into 20-L bags of sawdust, one plant per bag, at a density of 1.6 plant/m². Plants were grown in a greenhouse at the Pacific Agri-Food Research Centre, Agassiz, B.C., with air temperatures at 22/19 ± 2 °C (day/night). The nutrient solution was based on the *Nursery, Greenhouse Vegetables and Ornamental Production Guide for Commercial Growers* (British Columbia Ministry of Agriculture and Fisheries, 1988). All plants were irrigated with 200 mL/plant provided every 1 to 2 h depending on the prevailing light level. The electrical conductivity of the fertilizer solution was 1.8 to 2.5 mS·cm⁻¹ and its pH was 5.3 to 6.2. Plants were trained according to an umbrella system as previously reported (Lin and Ehret, 1991).

In Expt. 1, the course of elongation was followed on fruit growing on 48 plants that were subjected to six treatments, with two blocks and four plants per treatment per block. Three of the treatments involved fruit thinning to maintain different leaf to fruit ratios. The fruit on the main stem were thinned, starting with the ninth node (up to where no fruit occurred) in such a manner to have one, two, or four leaves per fruit, and having nine, five, or three fruit per stem, respectively). In commercial practice one leaf per

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fruit is common; higher leaf to fruit ratios were experimentally created to promote fruit growth by increasing potential assimilate supply per fruit. In the remaining three treatments a constant leaf to fruit ratio was maintained on the main stem, but fruit were sampled from different regions in the canopy. Three regions were selected: fruit from lower nodes (nodes 9 to 13); upper nodes (nodes 14 to 18), and fruit from both lower and upper nodes involving fruit sampled from alternate nodes along the main stem, starting at the ninth node.

A total of 254 fruit was used in this experiment, 134 of which were from the thinned plants. Individual fruit were tagged at anthesis for identification, and, after fruit length had reached ≈ 5 cm, fruit were measured three times per week until harvest. Harvest occurred when fruit exceeded 34 cm in length. Fruit length, fresh mass, and diameter were measured at harvest. After harvest, each fruit was stored in an unsealed polyethylene bag at 13 °C and 90% to 95% relative humidity. Stored fruit were examined three times a week to detect incipient pericarp yellowing (20% of the fruit surface becoming pale yellow-green in color). Shelf life was defined as days between harvest and the occurrence of incipient yellowing.

Scatterplots indicated that fruit length (L) followed a sigmoid time (t) course. Logistic and Gompertz functions were fitted to data from a random selection of 24 fruit, representing all treatments, using a nonlinear regression procedure. The Gompertz function was used for further analysis because it produced slightly lower residuals and was fitted to the data for each of the remaining fruit. The Gompertz function was as follows: $L = L_0 \exp\{[C(1 - e^{-Dt})]/D\}$, where $D = C/\ln(L_t/L_0)$. Parameters of the function indicate asymptotic fruit length (L_t), fruit length when $t = 0$ (L_0), a growth rate coefficient (C), and exponent (D). Gompertz parameters were used to evaluate several aspects of elongation, including the time of inflection of the sigmoid curve ($t_i = [\ln(C/D)]/D$), fruit length at the inflection point ($L_i = L_t/e$), and fruit elongation rate ($GR = CL e^{-Dt}$). Due to the sigmoid pattern of growth, maximum elongation rate (GR_{max}) occurred at t_i , and GR was also calculated for the time at which the fruit reached 34 cm (GR_{34} , t_{34}). Possible relationships between shelf life and these measures of fruit growth were assessed by Pearson correlations.

ELONGATION, COLOR AND CHLOROPHYLL FLUORESCENCE (EXPT. 2). This experiment involved shading and filter treatments and was conducted in the spring and summer, when natural daylight was high enough to allow studies of the effects of reduced light intensity and altered spectral quality. Except as noted below, plants were grown as in Expt. 1. Seeds were planted in rockwool on 27

Apr. and transplanted on 21 May 1992. This experiment also involved six treatments and 48 subject plants grown in two blocks and four plants per treatment per block. When plants were sufficiently tall, the main stems were topped at 1.8 m above the ground and two laterals were allowed to continue. Each plant had one fruit on each of nodes 9, 11, 13, and 15 on the main stem and one fruit on each of nodes 9, 11, and 13 of both laterals. Treatments were imposed on fruit borne on the main stem and on one of the laterals, resulting in seven treated fruit per plant.

The six shade and color filter treatments were applied to individual fruit during growth. In addition to an unshaded group of fruit, neutral density filters were suspended around individual fruit to maintain 66% or 31% of the photosynthetic photon flux density (PPF) of natural daylight, as determined using a quantum sensor (LI-190SB; LI-COR, Lincoln, Nebr.). The shading treatments did not alter R/FR ratios, as determined using a spectroradiometer (LI-1800). In addition, color filters were suspended around other fruit to modify spectral balance as well as PPF levels. Color treatments used Rasco filters (William F. White Ltd., North Vancouver, B.C. Canada) and consisted of 1) control using Rasco 119 clear filter, 2) red filter using Rasco 24 red plus Lee 270 neutral, and 3) far-red filter using Rasco 24 red plus Rasco 93 green. The PPF reaching the fruit surface was 88%, 10%, and 10% of daylight, respectively. The R to FR ratios for the three filter treatments, calculated by dividing the radiation transmitted in the 650- to 700-nm waveband by that in the 700- to 750-nm range, were 1.0, 1.4, and 0.15, respectively.

In all, 297 fruit were harvested from Expt. 2 within 3 weeks after their date of anthesis. The experimental structure offered a potential of 336 fruit, but some were lost due to abortion or were rejected from the study due to malformation. Fresh mass, length, and diameter per fruit were measured at harvest, and the time between anthesis and harvest was recorded. Whole-fruit color at harvest was estimated by video imaging (Lin et al., 1993), and the average grey level of each fruit surface was recorded. A low grey level is obtained for dark-green fruit having high chlorophyll content. Parameters of photosynthetic fluorescence induction were measured at harvest using a chlorophyll fluorescence measuring system (CF-1000; P.K. Morgan Instruments Inc., Andover, Mass.). Five fluorescence parameters were recorded automatically (Rock et al., 1992): base level fluorescence (F_0), maximum fluorescence (F_m), variable fluorescence (F_v), F_v/F_m ratio, and the half-time for the rise in fluorescence from F_0 to F_m ($t_{1/2}$). Fruit were held in darkness for 1 h before fluorescence was measured (Toivonen, 1992). Fluorescence was measured at 12 sites per fruit: at 90°

Table 1. Shelf life and some measures of fruit growth (Expt. 1).

Treatment or sampling method ²	Fruit observed (no.)	Shelf life (days)	Max growth rate ^y (cm·d ⁻¹)	Time when L = 34 cm (d after anthesis)	Growth rate when L = 34 cm (cm·d ⁻¹)	Asymptotic fruit length (cm)	Fruit length at growth inflection (cm)	Gompertz coefficient C (d ⁻¹)
Two leaves/fruit	24	6.1 ± 0.5 ^x	2.65 ± 1.26	14.5 ± 1.1	1.91 ± 0.35	58.2 ± 11.2	21.4 ± 4.1	0.26 ± 0.05
Upper nodes	40	5.5 ± 0.5	2.19 ± 0.22	15.6 ± 2.0	1.52 ± 0.39	52.1 ± 9.7	19.2 ± 3.8	0.26 ± 0.04
Lower nodes	71	5.4 ± 0.5	2.07 ± 0.14	16.8 ± 1.6	1.33 ± 0.33	48.8 ± 7.0	18.0 ± 2.6	0.27 ± 0.05
Four leaves/fruit	40	4.7 ± 0.7	2.68 ± 0.16	12.5 ± 1.0	2.45 ± 0.24	64.7 ± 6.1	23.8 ± 2.2	0.24 ± 0.04
Upper and lower	39	4.0 ± 0.4	2.26 ± 0.18	14.9 ± 1.5	1.79 ± 0.33	56.0 ± 9.2	20.6 ± 3.4	0.24 ± 0.05
One leaf/fruit	40	3.7 ± 0.3	1.89 ± 0.24	21.0 ± 4.5	0.89 ± 0.51	45.1 ± 11.4	16.6 ± 4.2	0.26 ± 0.07

²In Expt. 1, six independent pruning and sampling regimes were used to produce variation in fruit shelf life. Three pruning regimes were used to maintain ratios of one, two, or four leaves per fruit. Three sampling regimes involved fruit collected from lower nodes (nodes 9 to 13), upper nodes (nodes 14 to 18), or both upper and lower nodes (alternate nodes starting at node 9).

^yEstimates of maximum growth rate and other measures of elongation in columns to the right of shelf life were obtained from the Gompertz regressions; L = fruit length.

^xMeans and standard errors.

intervals around the circumference of each fruit near both ends and in the middle. Subsequently, each fruit was placed in a perforated polyethylene tube (48 × 13 cm) with one end unsealed. Fruit were stored in darkness at 13 °C and 90% to 95% relative humidity for 2 weeks and visually inspected every 2 d for incipient yellowing.

Statistical analysis of the experimental results was performed using SigmaStat 2.0 (Jandel Scientific, San Rafael, Calif.) to explore relationships between shelf life and other fruit measures. Pearson correlations were calculated between shelf life and measures of fruit growth (Expt. 1) or measures of fruit color and fluorescence (Expt. 2). In addition, a best subset multiple regression was performed to identify the group of fruit measures that best predicts shelf life.

Results

Among different treatments, mean shelf life of harvested fruit ranged from 3.7 to 6.1 d in Expt. 1 (Table 1) and from 0 to 9.2 d in Expt. 2 (Table 2). As indicated by the differences between means and their standard errors, these variations are significant ($P < 0.05$). Similarly, significant treatment differences occurred among other fruit measures, except for the Gompertz growth rate coefficient (Table 1) and the time between anthesis and harvest (Table 2). In Tables 1 and 2, treatments are ranked in descending order of mean shelf life, but this ranking is not followed by the other fruit measures. The effects of shade and color filters (Expt. 2) have been reported previously (Lin and Jolliffe, 1995, 1996). The focus of the present study, however, is not to analyze treatment influences, but to form relationships between shelf life and other fruit characteristics.

The Gompertz function was an effective model for describing the time course of fruit elongation. Significant Gompertz regressions were obtained for all 254 fruit in Expt. 1. Coefficients of determination for all regressions exceeded 0.96. Indices derived from the Gompertz function detailed different aspects of the dynamics of fruit growth, and shelf life was significantly correlated with several of these measures (Table 3). The strongest correlation was a positive correlation ($r = 0.33$) with maximum elongation rate, and other positive correlations existed with elongation rate at the time of harvest, asymptotic fruit length, fruit length at the inflection point, and the Gompertz growth rate coefficient. Time required to reach marketable length was negatively correlated with shelf life.

Results from Expt. 2 also produced significant correlations between shelf life and fruit growth, color, and fluorescence (Table

4). Time between anthesis and harvest, a measure similar to t_{34} in Expt. 1, was negatively correlated to shelf life. Fruit color at harvest, as measured by image analysis, had the strongest correlation to shelf life of any individual characteristic. The measure provided by image analysis, grey level at harvest, is inversely related to fruit pigmentation and was negatively correlated with shelf life, i.e., darker green fruit had better postharvest performance. The ability of photosynthesis to quench fluorescence (F_v/F_m) and the half-time required to reach maximum fluorescence were positively correlated with shelf life.

Significant correlations also exist among many of the various measures of growth, color and fluorescence (Tables 3 and 4). Because most of these correlations are <1.0 , it is possible that a multiple relationship may predict shelf life better than a simple correlation. A best subset multiple regression was performed on the data from Expt. 2 to reduce the number of variables and determine if the use of a group of measures would collectively improve the prediction of shelf life. Results from Expt. 2 were used for this purpose because those data had a broader range of shelf life and included the measures that had the highest simple correlations with shelf life (Tables 3 and 4). All of the measures taken in Expt. 2 were included as potential independent variables. The best subset model (Table 5), accounting for 52% of the variation in fruit shelf life, was selected on the basis of minimum Mallows' C_p statistic. The relative contributions of different independent variables can be judged according to the absolute magnitudes of the standard partial regression coefficients. The best subset model further supports the importance of fruit color: grey level at harvest is the dominant variable. Significant contributions, however, are also made by time from anthesis to harvest, fluorescence quenching, and fluorescence half-time. Fruit diameter at harvest is included in the best subset model, although it was not a significant simple correlate of shelf life (Table 4) and was not significant according to the regression t test (Table 5).

Discussion

Most measures of fruit growth, color, and pigment function were affected by experimental treatments and were correlated with shelf life. Not all of the relationships with shelf life, however, can be explained through the effects of treatments. The Gompertz coefficient C (Expt. 1), and the time between anthesis and harvest (Expt. 2) were not significantly affected by treatments, but both had significant correlations with shelf life (Tables 3 and 4, respectively). Shelf life was not correlated to initial fruit length (L_0), the

Table 2. Shelf life and some measures of fruit growth, color and fluorescence (Expt. 2).

Treatment ^a	Fruit observed (no.)	Shelf life (d)	Time from anthesis to harvest (d)	Grey level	Fruit diam at harvest (cm)	Fluorescence ^b half time (ms)	Fluorescence ^b quenching
No shade	51	9.2 ± 0.7 ^x	10.4 ± 0.2	92.2 ± 0.5	5.4 ± 0.1	22.5 ± 0.3	0.767 ± 0.001
Clear filter	55	8.4 ± 0.6	9.9 ± 0.2	92.8 ± 0.5	5.1 ± 0.1	21.7 ± 0.3	0.764 ± 0.002
Light shade	46	4.7 ± 0.7	9.9 ± 0.2	94.7 ± 0.5	5.0 ± 0.1	21.5 ± 0.3	0.769 ± 0.002
Heavy shade	45	0.8 ± 0.3	10.1 ± 0.2	102.3 ± 0.8	4.8 ± 0.1	19.2 ± 0.3	0.754 ± 0.002
Red filter	51	0.0 ± 0.0	10.1 ± 0.2	112.8 ± 1.1	5.2 ± 0.1	19.9 ± 0.3	0.764 ± 0.003
Far-red filter	49	0.0 ± 0.0	10.2 ± 0.2	134.6 ± 1.4	5.1 ± 0.1	22.6 ± 0.4	0.808 ± 0.002

^aIn Expt. 2, six independent fruit shading and light filtering regimes were used to produce variation in fruit shelf life. No shade, light shade, and heavy shade allowed 100%, 66%, or 31% of ambient light to reach the fruit surface, respectively. The shade treatments were wavelength neutral. Note, the red and far-red filters transmitted those wavebands, respectively, and blocked other wavebands.

^bFluorescence half time is the time required for half the rise in fluorescence from base level to maximum. Fluorescence quenching is the ratio of variable to maximum fluorescence.

^xMeans and standard errors.

Table 3. Correlations^z among shelf life and measures of fruit elongation obtained from Expt. 1.

Measure	Correlated measure ^y					Gompertz growth rate coefficient
	GR _{max}	t ₃₄	GR ₃₄	L _f	L _i	
Shelf life	0.33 [*] (177)	-0.31 [*] (174)	0.30 [*] (174)	0.20 [*] (184)	0.20 [*] (178)	0.18 [*] (234)
Maximum elongation rate (GR _{max})		-0.65 [*] (174)	0.54 [*] (174)	0.11 ^{NS} (177)	0.11 ^{NS} (177)	0.45 [*] (177)
Time when L [*] = 34 cm (t ₃₄)			-0.81 [*] (174)	-0.52 [*] (174)	-0.52 [*] (174)	0.16 [*] (174)
Growth rate when L = 34 cm (GR ₃₄)				0.88 [*] (174)	0.88 [*] (174)	-0.35 [*] (174)
Asymptotic fruit length (L _f)					1.00 [*] (178)	-0.53 [*] (179)
Inflection point length (L _i)						-0.52 [*] (177)

^zCorrelations were confined to measures derived from significant regression parameters, i.e., all 254 Gompertz regressions were significant, but individual parameter estimates were not always significant, according to a *t* test.

^yPearson correlation coefficient (number of observations given in brackets below).

^xL = fruit length.

^{NS},^{*}Nonsignificant or significant at *P* = 0.05, respectively.

Table 4. Correlations among shelf life and measures of fruit growth, color and fluorescence obtained from Expt. 2.

Measure	Correlated measure ^z								Fruit diam at harvest
	GL	F _v	F _m	F _v /F _m	t _{AH}	W	F _o	t _{1/2}	
Shelf life	-0.60 [*]	-0.38 [*]	0.35 [*]	0.22 [*]	-0.19 [*]	0.18 [*]	-0.18 [*]	0.14 ^{NS}	0.10 ^{NS}
Grey level (GL)		0.68 [*]	0.56 [*]	0.64 [*]	-0.02 ^{NS}	-0.23 [*]	0.11 ^{NS}	0.09 ^{NS}	-0.14 [*]
Variable fluorescence (F _v)			0.98 [*]	0.23 [*]	-0.43 [*]	-0.27 [*]	0.69 [*]	-0.32 [*]	-0.12 [*]
Maximum fluorescence (F _m)				0.03 ^{NS}	-0.50 [*]	-0.28 [*]	0.82 [*]	-0.44 [*]	-0.13 [*]
Fluorescence quenching (F _v /F _m)					0.27 [*]	-0.02 ^{NS}	-0.54 [*]	0.57 [*]	0.00 ^{NS}
Time from anthesis to harvest (t _{AH})						0.30 [*]	-0.56 [*]	0.37 [*]	0.35 [*]
Fruit fresh mass at harvest (W)							-0.23 [*]	-0.03 ^{NS}	0.89 [*]
Base level fluorescence (F _o)								-0.70 [*]	-0.11 ^{NS}
Fluorescence half time (t _{1/2})									-0.05 ^{NS}

^zPearson correlation coefficient (number of observations was 297 in all cases).

^{NS},^{*}Nonsignificant or significant at *P* = 0.05, respectively.

inflection time of fruit growth (t_i), the Gompertz exponent (D), and fruit diameter at harvest. The latter, however, was included as a nonsignificant term in the best subset multiple regression. For similar measures, the two experiments produced similar relationships with shelf life.

Fruit color at harvest was the most important predictor of shelf life and was the most important component included in the best subset multiple regression. This supports the possibility of using video imaging techniques to sort fruit having different storage potentials, suggested previously (Lin et al., 1993). The grey level measurements assessed the color of one side of the entire fruit. This may have made grey level a more effective measure of pericarp pigmentation than fluorescence, which was measured at localized sites on the fruit surface.

Chlorophyll fluorescence is a useful indicator of the functional state of the photosynthetic apparatus, and has been used to monitor postharvest quality in broccoli (Toivonen, 1992). The degradation of photosynthetic light harvesting systems during fruit senescence should be marked by an increase in the balance between fluorescence and the use of light energy by photochemical processes (Kraus and Weis, 1984). In *Phaseolus* leaves (Jenkins et al., 1981) for example, F_o, F_v, and t_{1/2} declined in parallel with chlorophyll

content during senescence, although the F_v/F_m ratio remained unchanged. The lower F_v/F_m ratio was associated with photosynthetic dysfunction caused by photoinhibitory damage to leaves by chilling temperatures (Tyystjärvi et al., 1989) or water stress (Ben et al., 1987). Here, measures of fluorescence, F_o, F_m, and F_v were negatively correlated with shelf life. The quenching of fluorescence by photochemical processes, F_v/F_m, which more directly measures photosynthetic competence, was positively correlated with shelf life. Hence, longer shelf life is associated with fruit in which photosynthetic systems are more functional at harvest. Effects of shade and color filter treatments during growth may be connected to the development and maintenance of photosynthesis in the pericarp. It is not established, however, whether cucumber fruit photosynthesis has an important functional connection to fruit senescence or whether other physiological responses may be involved. The correlations between measures of fluorescence and shelf life was lower than that provided by video imaging. This, together with the number of measurements required and the long dark acclimation time (Toivonen, 1992; Tyystjärvi et al., 1989), seem to exclude fluorescence as an approach for prestorage commercial sorting of cucumber fruit.

The Gompertz function successfully modeled the dynamics of

Table 5. Parameters and statistics of the best subset multiple regression (Expt. 2).

Independent variable	Coefficient	Standard error	Standard partial regression coefficient
Constant	-18.3 ^{NS}	10.2	---
GL	-0.242*	0.019	-0.84
t _{HA}	-1.34*	0.16	-0.37
F _v /F _m	56.8*	17.2	0.24
t _{1/2}	0.466*	0.118	0.23
DI	1.46 ^{NS}	0.47	0.13

^{NS}, *Nonsignificant or significant according to a *t* test at *P* = 0.05. Regression statistics: *R*² = 0.52 and *C*_p = 7.3

cucumber elongation. Gompertz parameters indicated that shade, light filters, reduced leaf to fruit ratio, and low fruit position all reduce fruit growth. Increased shelf life was linked to elongation through its correlations with higher elongation rates (GR_{max}, GR₃₄, C), shorter time to reach marketable length (t₃₄, t_{HA}), and greater potential elongation (L_t). These relationships indicate the importance of preharvest conditions in support the hypothesis that more rapid fruit growth should benefit shelf life (Lin and Ehret, 1991). As shown previously (Ramirez et al., 1988), low leaf to fruit ratio reduced fruit growth, possibly indicating an influence of limited assimilate supply to the fruit. A similar cause may underlie the decline in shelf life at low leaf to fruit ratio. The fruit surface contributes <10% of the assimilates required for fruit growth (Schapendonk and Brouwer, 1984). Hence, light levels in the shoot canopy may not only affect fruit directly, but may also act on fruit growth and shelf life by influencing assimilate supply to developing fruit from the leaves.

Many significant correlations were obtained between shelf life and other fruit measures, but maximum Pearson correlation coefficients were 0.6 or less. The best subset multiple regression improved the prediction of shelf life through the use of a set of independent variables. In a commercial setting, some variables in the model would either be unavailable or time consuming and expensive to obtain. The multiple coefficient of determination of the best subset model was 0.52. The model is therefore inadequate for the commercial segregation of fruit having different storage potentials. This research has developed links among fruit growth and shelf life. This suggests that further studies on the preharvest physiology of cucumber fruit could lead to the identification of better predictors of shelf life.

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