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Indices of physiological maturity and eating quality in Smooth Cayenne pineapples. 1. Indices of physiological maturity

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Abstract

In two experiments using summer crop pineapples (*Ananas comosus* [L.] Merrill), an assessment was made as to which of eight parameters of pineapple ontogeny was the most suitable to grade pineapples into classes of physiological maturity. The parameters used were ones known to change substantially during the final 20 to 30 days of fruit growth. On the intact fruit they were: skin colour (shell colour), and fruit specific gravity (SG); on the flesh: % total soluble solids (TSS), titratable acidity, pH, ethylene concentration, colour, and translucency. Measured values of the eight parameters were inter-correlated, and the resultant coefficients of determination (R^2) were averaged in each experiment and the means compared. Specific gravity was found to have the highest average coefficient of determination, and was concluded to be the best index of physiological maturity in pineapples. Flesh translucency and flesh colour were the next highest. A discussion on why SG can be a index of physiological maturity in pineapples is given, along with practical suggestions for measuring SG in the laboratory and in the field.

INTRODUCTION

In experimental trials involving the fruit of the pineapple (*Ananas comosus* [L.] Merrill), the effects of many preharvest or postharvest treatments depend to a large degree on the stage of the development, the physiological maturity of the fruit, usually described in published papers as the maturity of the fruit or sometimes the ripeness. Watada *et al.* (1984), and Wills *et al.* (1981) use the term physiological maturity to distinguish those aspects of fruit development related to the physiological life of the fruit to those closely associated with a particular commercial end use such as consumption, long distance transport, and storage.

Pineapples are commonly graded for maturity in experiments involving storage, postharvest dips, biochemical analyses, wax coatings, storage under modified atmospheres and also in various field trials involving fruit maturation or clone comparisons. Almost exclusively the degree of yellowness of the skin (also known as shell colour) is used for these purposes, yet this parameter is recognised as being a poor index (Anon. 1971; Teisson 1979; Bowden 1967; Smith 1984). Freshly harvested fruit of any particular degree of yellow skin colour commonly have widely different states of internal ripeness, as judged by the appearance of the flesh. Using skin colour can result in the collected data being variable and experimental findings being inconclusive.

A method of grading whole fruit for ripeness using specific gravity (SG) was developed (Smith 1984), based on findings of Singleton (1945). The internal translucency of fruits graded using SG were found to be very uniform but it was not clear whether the internal translucency itself is a good index of physiological maturity; that is, how well does the physiological maturity of the fruit correlate to the flesh translucency or to other parameters which change during the ontogeny of the pineapple.

For climacteric fruits, the time to the onset of the respiratory climacteric is an index of physiological maturity but for the pineapple fruit no climacteric exists. Gortner *et al.* (1967) examined the physiological maturity of the pineapple and examined changes in eight physicochemical parameters (shell chlorophyll, flesh pH, respiration rate, volatile ester concentrations, non protein nitrogen, reducing sugars, shell brix (% TSS), flesh and shell carotenoids), but grading fruit for maturity was not mentioned.

Sideris and Krauss (1938) monitored SG in growing pineapples and showed a continuous increase of SG during the growth of the fruit. Teaotia and Suraj Bhan (1966) reported that SG was a good maturity index, but no supporting data or discussion were presented. Pantasticao (1975), was dubious about SG being useful as a harvest maturity parameter, but again no supporting data were presented. None of these workers actually compared parameters of physiological maturity to determine which was most suitable for grading fruit.

A procedure for comparing indices of physiological maturity has not been previously addressed. The present paper proposes that the best parameter of physiological maturity is the one that shows the highest degree of correlation to the greatest number of major physicochemical parameters known to change during the period of ontogeny under study. The validity of this mathematical procedure depends to a degree on selecting a range of parameters which are representative of the major changes known to occur during the period of physiological maturity under study.

MATERIALS AND METHODS

Two similar experiments were conducted 12 months apart, each using 150 pineapples cv. Smooth Cayenne harvested in summer and grown 50 km north of Brisbane (27°S). Fruit in Experiment 1 were grown under a good commercial regime, were well supplied with fertiliser, and had an average fruit weight of 1.5 to 2.5 kg. Experiment 2 fruit were grown nearby but under conditions of poor plant nutrition, were neglected, overgrown with weeds, and were much smaller, 0.9 to 1.3 kg.

In each experiment the fruit were selected to encompass a very wide range of fruit physiological maturity, as judged by skin colour and also the flatness and gloss of fruitlets. The fruit were brought to the laboratory the same day, weighed, the skin colour of each recorded, (0 = green, 8 = fully yellow). The SG of each fruit, including top, was determined by apparent weight loss during water immersion and ten subsamples, each of five fruit, were selected such that each subsample contained fruit of a wide and approximately similar range of skin colours and SG values. The selected fruit were immediately placed under refrigeration at 10°C.

Twice a day for the next five days, one subsample of five fruit was withdrawn from refrigerated storage and allowed to equilibrate for two hours to room temperature. The fruit were then peeled and cored using a manual peeling machine (ginaca) and the unpeeled end skins sliced off. Commencing from the base end of the peeled 'slug', six slices (4mm thick) were taken, diced and a representative portion used for analysis of TSS (bench refractometer), titratable acidity (autotitrator, end point 8.1) and pH.

From the centre of the fruit, a further slice (12 mm thick) was taken, and immediately rated for flesh translucency (1 = opaque, 6 = very translucent) by a panel of five. The slice was analysed within five minutes for internal flesh ethylene concentration by vacuum extraction under an inverted water filled funnel fitted with a septum over the stem; gas chromatographic analysis with a 450 mm activated alumina column (90°C) with an FID detector. Following vacuum extraction the flesh colour of the now de-aerated slice was assessed by the same panel (1 = white, 6 = orange/yellow). Flesh colour has been found to be more accurately assessable in a de-aerated sample than in a fresh sample (Wassman pers. comm.).

Statistical analysis

The individual data were analysed to give a matrix of quadratic coefficients of determination (R^2) for the relationships between each of the eight parameters. Then, for each individual parameter in turn, the coefficients of determination between it and the other parameters were averaged, giving a numerical value of how well each parameter related to all of the other parameters; that is, 0 = no relationship, 1 = perfect relationship.

Subsequently, the coefficients of determination for each parameter of each experiment were numerically averaged to give an overall figure which although statistically has no value, indicates how well each parameter correlates to all others.

RESULTS AND DISCUSSION

The mean and range of each parameter was calculated and is presented in Table 1.

Table 1. The mean, standard deviation and range of nine parameters of physiological maturity measured in two Experiments in pineapples cv. Smooth Cayenne, using summer crop fruit

		Whole fruit		Flesh						
	Expt	Skin Colour*	Specific gravity	Juice pH	% TSS	Titrt acidity†	TSS/ acid	Ethylene conc.(ppm)	Colour‡	Trans- lucency§
Mean	1	2.8	0.98	3.60	17.6	0.84	23.4	0.314	3.79	2.1
	2	4.7	0.99	3.47	14.8	0.64	24.8	0.472	4.40	2.4
Std Dev.	1	2.9	0.03	0.23	2.15	0.25	9.6	0.306	1.56	1.1
	2	3.4	0.03	0.19	2.26	0.17	7.97	0.892	1.71	1.1
Minimum	1	0.0	0.92	3.25	7.5	0.28	11.2	1.55	1	1
	2	0.0	0.92	3.10	9.1	0.31	14.1	0.015	1	1
Maximum	1	8	1.03	4.30	21.3	1.60	66.4	0.061	6	6
	2	8	1.03	3.85	18.1	1.08	47.4	1.17	6	6

* 0 = green, 8 = full yellow.

† % anhyd. citric.

‡ 0 = white, 6 = orange/yellow.

§ 0 = opaque, 6 = very translucent.

The coefficients of determination computed for each experiment are shown in Table 2, as a matrix, presented as two diagonal blocks. The data above the diagonal; that is, in the upper RHS of the table is from Experiment 1 and below the diagonal from Experiment 2.

Table 3 shows the average of the values of the coefficients in Table 2 listed for each parameter for each experiment, and also shows the overall numerical average for each parameter. Note: The averages listed in Table 3 are derived from horizontal rows and/or vertical columns in Table 2, being means of the data elements within each diagonal-block matrix.

The most suitable parameter of physiological maturity will have both a high correlation coefficient of determination to each other parameter (the inter-correlation) and also a high degree of consistency using fruit samples from different sources.

With respect to the inter-correlation between parameters, the data on overall averages (Table 3) indicate that SG had the highest correlation over the two experiments, as indicated by the overall coefficient of determination.

Table 2. Quadratic coefficients of determination (R^2) from two experiments correlating each of eight parameters of pineapple physiological maturity with each other. Experiment 1 top RHS above diagonal; Experiment 2 bottom LHS and below diagonal

	Skin colour	Fruit SG	Flesh pH	Flesh %TSS	Flesh acidity	Flesh ethylene conc.	Flesh colour	Flesh translucency
Skin colour		0.30	0.24	0.15	0.04	0.32	0.39	0.34
Fruit SG	0.67		0.37	0.40	0.36	0.23	0.63	0.70
Flesh pH	0.31	0.36		0.03	0.69	0.11	0.36	0.32
Flesh TSS	0.51	0.38	0.05		0.04	0.12	0.28	0.16
Flesh acidity	0.12	0.47	0.62	0.03		0.23	0.23	0.28
Flesh ethylene conc.	0.37	0.36	0.07	0.25	0.16		0.15	0.23
Flesh colour	0.48	0.39	0.24	0.34	0.06	0.35		0.60
Flesh translucency	0.69	0.58	0.28	0.34	0.27	0.56	0.47	

Table 3. Averages of the coefficients in Table 2 for each parameter for Experiments 1 and 2, calculated from the rows and columns within the diagonal block of each experiment

	Whole fruit		Flesh					
	Skin* colour	Specific gravity	pH	%TSS	Titrt acidity†	Ethylene conc.(mg/kg)	Colour‡	Trans-lucency§
Experiment								
1	0.25	0.43	0.30	0.17	0.27	0.20	0.38	0.37
2	0.45	0.46	0.28	0.27	0.25	0.30	0.33	0.46
Overall	0.35	0.45	0.29	0.22	0.26	0.25	0.36	0.42

* 0 = green, 8 = full yellow.

† % anhyd. citric.

‡ 0 = white, 6 = orange/yellow.

§ 0 = opaque, 6 = very translucent.

The variability between each experiment in Table 3 indicates that skin colour showed the most variability between the experiments (R^2 = 0.25 Experiment 1, 0.45 Experiment 2) while pH and acid, closely followed by SG, showed the least.

Thus, SG not only gave the highest average coefficient in each experiment but also showed only slight variation between the fruit samples from the very different origins (Experiments 1 and 2). Hence it is concluded that SG is the best parameter of the eight tested to use as a index of physiological maturity. The low averages of the coefficients for TSS, titratable acidity, pH, and internal ethylene concentration suggest that these parameters are each poor indices of physiological maturity. Although these parameters change in a consistent pattern during fruit development as shown by Gortner *et al.* 1967, the absolute values change substantially from sample to sample (Table 1; also Part I, Table 2). The TSS concentrations in the flesh of the fruit would most likely depend on the total light available to the plant over the ontogeny of the fruit. Additionally some variation in the TSS would be caused by variations in fruit size and water supply to the plants. Thus although the values of TSS may change as a fruit develops, the absolute value of the TSS at a particular time does not reflect its stage of physiological maturity. The coefficients of determination in Table 2 are computed using the absolute values, rather than based on changes with time as reported by Singleton and Gortner (1965). Apparently, environmental factors alter the absolute levels of titratable acidity, pH and internal ethylene concentration in a similar fasion to those affecting TSS.

Overall, flesh colour and flesh translucency gave higher average coefficients than skin colour. This is in agreement with the subjective opinions held by researchers in the Queensland pineapple industry regarding physiological maturity in pineapples, namely, flesh translucency and flesh colour are reasonably good indicators, but skin colour is quite variable. In previous years at this laboratory Bowden (1967) used flesh translucency to grade fruit from new clonal selections as a way of comparing fruit qualities at an equal stage of ripeness. The results of the work in this paper suggest SG would be a superior index.

The reason why SG should correlate to physiological maturity could be explained as follows. The pineapple is botanically a sorosis and at the flower stage, the immature fruit has an open porous structure. Cell division is completed prior to anthesis (Bartholomew and Paull 1986). As a consequence, the fruit as a whole has a low SG measured at this stage. As the fruit grows the cells of the fruitlets expand and gradually fill the air spaces, increasing the SG. This cellular expansion continues until the fruit is very ripe and thus the increase in SG parallels the ontogeny of the fruit. As fruit becomes very ripe the cell contents leak into the intercellular spaces displacing air and further increasing the overall SG of the fruit. Also, as Singleton (1957) reported, an increase in the TSS of the fruit accounts for some of the increase in SG in that a 22% TSS syrup has a density of 1.088 compared to a 6% TSS sap having a density of 1.022. Thus the increase in SG parallels the growth and development of the fruit, explaining why SG can be an index of physiological maturity in the pineapple.

Just why skin colour should be such a variable index of physiological maturity invites comment. The development of skin colour is in fact the reduction of chlorophyll rather than an increased synthesis of carotenoids (Gortner *et al.* 1967). French workers regard green skinned ripe fruit as having a physiological disorder named jaune, (Py *et al.* 1985). In Queensland it is seen as a natural phenomenon, being a very common occurrence in fruit harvested in spring.

Grading pineapples for physiological maturity using SG has the major practical advantage of being non-destructive. Also, it can separate green-skinned fruit which are often regarded as being equally immature but which, when cut, can commonly be seen to be of a wide range of stages of flesh ripeness. Experience at this laboratory shows that SG can be quickly and accurately measured using a wire cage enclosing a single fruit suspended in a 100 litre tank beneath an accurate balance ($\pm$ 0.1g). The simplicity and accuracy of the method warrants wider use for postharvest work on pineapples, particularly as these fruit are otherwise difficult to grade when intact. No increase of postharvest rots has been observed in stored fruit as a result of submerging the fruit, although a fungicide could be included as a precaution.

The accurate determination of SG is most applicable to a laboratory but field measurements would be feasible with a portable accurate balance shielded from wind. Alternatively, whole intact fruit could be graded in the field according to SG by using two tanks, one containing water and the other 2.5% salt brine. Such a combination would separate fruit into three grades of physiological maturity: fruit floating in water (the least physiologically developed), fruit sinking in water but floating in salt, and fruit sinking in the salt (very ripe fruit).

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