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Indices of physiological maturity and eating quality in Smooth Cayenne pineapples. 2. Indices of eating quality

L. G. Smith

Department Primary Industries, Postharvest Group, 19 Hercules St., Hamilton, Q, 4007, Australia.

Abstract

A total of 220 Smooth Cayenne pineapples (*Ananas comosus* [L.] Merrill) were individually analysed in six experiments over 18 months including three different harvest seasons, to select which of nine parameters best predicts pineapple eating quality. Of the intact whole fruit, the parameters were skin colour and fruit specific gravity (SG); of the flesh they were percent total soluble solids (TSS), titratable acidity, TSS/acid (also known as the brix acid ratio), juice pH, ethylene concentration, colour, and translucency.

Flesh TSS not only gave the highest correlation to eating quality (R^2 = O.70) but TSS was the only parameter found suitable as a year-round index of pineapple eating quality. SG had a higher average coefficient than did skin colour and SG was considered the best index for grading whole, intact fruit for eating quality. A high correlation was found between skin colour and consumers expectations of eating quality, however, the correlation to the acutal eating quality was not statistically significant. It is recommended that only fruit having a TSS of 14% and above be marketed as fresh fruits.

INTRODUCTION

The eating quality of pineapples and many other fruits destined for the fresh fruit market is now receiving increased attention within the fresh fruit industry. Many consumers have indicated a disenchantment with fruit that looks attractive but fails to fulfill the expectations of eating quality engendered by the appearance. For pineapples, the eating quality at which the fruit is harvested is most important, because the pineapple, along with other non-climacteric fruits, does not improve in eating quality after harvest in spite of the colour change of the skin (Anon. 1971).

The eating quality of the Smooth Cayenne cultivar is both very seasonal and very variable. Skin colour is accepted as being a poor index of internal ripeness for pineapples and particularly for this cultivar (Anon. 1971; Teisson 1979; Bowden 1967, Smith 1987*b*) however, growers have little choice but to use skin colour when harvesting or grading fruit. Flatness of the fruitlets ('eyes') is also commonly used in some seasons, with fruit having very flat eyes regarded as being ripe or translucent. The accuracy of this criteria has not been established.

In Queensland, although consumer surveys have indicated that fresh pineapple eating quality is often poor and very variable, the fruit are still harvested mostly green skinned for a complex of reasons (Smith 1987*b*). One reason is that green-skinned pineapples develop less decay and thus keep longer, partly because the green skin has a natural defence to decay organisms. Also, in Queensland immature fruit develop less blackheart, an endemic chilling disorder which can develop either in the field during the latter stages of ripening or postharvest even when non-refrigerated (Smith 1987*b*). Additionally, for reasons that are not entirely clear, from time to time the flesh of green skinned Smooth Cayenne pineapples becomes very yellow and translucent and the fruit must be harvested or it will decay on the plant. Fourthly, some summer grown fruit are very palatable even when the flesh is hard, white and opaque and the skin dark blue-green (L. G. Smith unpub. data 1985), particularly fruit grown at Yeppoon (23° S), an area producing about a third of the Australian fresh market pineapples.

Consumers of pineapples are mostly not aware that the skin colour is a poor index of ripeness and that pineapple eating quality does not improve after harvest. To try to select a suitable fruit consumers use a variety of methods such as skin colour, smell, pulling the leaves and tapping the fruit. However, as even growers find it difficult to harvest or grade fruit consistently to an optimum stage of internal ripeness, most of these methods are useless.

Thus there is an important requirement within the Australian fresh market pineapple industry to be able to accurately monitor, and preferably to grade, pineapples for eating quality prior to consigning to the fresh market so that consumers are presented with a fruit of consistently acceptable eating quality.

Queensland Government market inspectors use percent total soluble solids (TSS) as an objective test for pineapples to regulate the fruit maturity, or, more accurately, the fruit eating quality. The basis for choosing this parameter and selecting the two particular TSS levels used (12% TSS for summer fruit and 10% for winter fruit) is not clear. Also, the use of the brix acid ratio (TSS/acid) has been raised by the Pineapple Sectional Group Committeee, the major Queensland pineapple-grower organisation, as possibly a superior alternative to TSS for estimating pineapple eating quality. Additionally, a method of separating whole intact fruit into grades of equal eating quality was recently investigated using the specific gravity (SG) of the fruit (Smith 1984). The internal ripeness of fruit samples graded using SG appears much more uniform than that graded by skin colour.

Thus a comparison of parameters of pineapple eating quality, examining at least, SG, TSS, TSS/acid and skin colour as means of monitoring or grading for eating quality is required. An accurate method for measuring and monitoring pineapple eating quality would be a major advantage to the Queensland pineapple industry. It would help encourage the development of farm practices producing commercial fruit of a higher standard of eating quality, which, in turn would better help establish new markets and increase the existing market share of pineapple sales.

This paper reports the results from six experiments over 18 months including three different harvest seasons, in which eating quality was correlated to each of nine parameters of physiological development to determine the best index of eating quality in Smooth Cayenne pineapples.

MATERIALS AND METHODS

The experiments used Smooth Cayenne pineapples (*Ananas comosus* [L.] Merrill) the major cultivar in Australia and came from several sources (Table 1). In the first experiment 13 parameters were measured on each of 50 fruit, some parameters being of academic interest only. Parameters which were found to correlate poorly to eating quality or be of little practical importance were not measured in subsequent experiments.

The wide variability within the pineapple fruit was taken into account when preparing samples for assessment. The pineapple fruit, botanically a sorosis, is a composite of fruitlets, each having a different stage of ontogeny. Consequently the fruit has wide variations in some of the parameters being assessed. An important variation in chemical composition exists from the top to the bottom of the fruit (Huet 1958, Smith 1985) and a variation of TSS also occurs around the fruit (Huet unpub. data 1958) most likely caused by differences in solar exposure. A method of producing multiple samples of equivalent quality from within the one fruit was devised (detailed in Experiment 1) for the experiments so that all the multiple subsamples, including those given to panelists and those used for chemical analysis, were virtually identical.

Included in the first experiment were two assessments to determine the usefulness of pineapple skin colour in predicting pineapple ripeness and pineapple eating quality by:

(i) Correlating the skin colour on whole intact fruit to panelists' expectations of internal ripeness and eating quality.

(ii) Correlating skin colour to the same two parameters in (i) measured on the same fruit after cutting, by the same panelists.

Table 1. The origin and the description of the fruit used in the 6 experiments used in the trial

Experiment	Harvest	Sample size	Origin; growing conditions
1	February 1982	50	Single farm block, optimum nutrition, Wamuran, south Queensland 27°30'S.
2	February 1983	50	Single farm block, overgrown, neglected. Elimbah, south Queensland 27°30'S.
3	May 1983	50	50 growers, South Queensland, purchased ex Brisbane Markets.
4	July 1983	30	2 growers, purchased Brisbane Markets Mutarnee north Queensland 18° S.
5	July 1983	28	8 growers, south Queensland Brisbane Market purchase.
6	August 1983	14	5 growers, south Queensland, Brisbane Market purchase.

Experiment 1

The fruit were selected in the field to encompass a very wide range of fruit physiological development as judged by skin colour and 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) and the SG of each fruit (including top) determined by apparent weight loss during water immersion. Of the 150 fruit harvested, ten subsamples each of five fruit were selected, with each subsample containing fruits of a wide and approximately similar range of skin colours and SG values. Following selection the fruit were placed under refrigeration at 10°C.

Twice a day for the next five consecutive days, one subsample was withdrawn, and held at ambient temperature to allow the condensation to evaporate. The whole intact fruits were then displayed to a panel of 18 laboratory staff who were asked to estimate, using only the external characteristics of the whole intact fruit, both the internal ripeness (called the anticipated ripeness, 1 = very unripe firm white opaque flesh, 6 = very ripe soft yellow translucent flesh) and the eating quality (called the anticipated eating quality, 1 = dislike extremely, 9 = like extremely). In their inspections, panelists were encouraged to use any method; for example, skin colour, smell, fruit firmness, pulling crown leaves, typical practices of them as fresh pineapple consumers.

The fruit were then peeled and cored using a ginaca (manual peeling machine). From the centre of the fruit, a 12 mm slice was taken, immediately rated by a panel of five for flesh translucency (1 = opaque, 6 = very translucent), and 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. Following vacuum extraction the flesh colour of the now de-aerated slice was assessed by the same panel for flesh colour (1 = white, 6 = orange/yellow). Visual flesh colour has been found to be more accurately assessable in a de-aerated sample than in an untreated sample (Wassman pers. comm.). The remainder of the peeled fruit was rated for ripeness by a panel of five (0 = very unripe 6 = very ripe or overripe).

Six slices, 4 mm thick, were cut off the remaining bottom half of the peeled cylinder using a machine slicer, each slice being placed alternately into one of two stacks, with each stack having each slice rotated 120° to the previous one to average out the variation around the fruit. Each stack was then cut into 10 pieces and tooth picks inserted to hold each of the composite samples together (20 samples total). The same 18 panelists who previously rated the fruit for anticipated eating quality were each given one sample to assess for eating quality (hedonic scale units, 1= dislike extremely to 9 = like extremely). Two samples were crushed and the juice analysed for: percent total soluble solids (TSS) using a bench refractometer; titratable acidity (to pH 8.1 using an autotitrator); and pH.

Experiment 2

Experiment 2 was carried in a similar manner to that of Experiment 1 except the parameters ripeness, anticipated ripeness and anticipated eating quality were not determined in this or subsequent experiments.

Experiment 3

The fruit were assessed in a similar manner to Experiment 2 except that the parameters flesh colour, flesh translucency, and flesh ethylene concentration were not measured in this or subsequent experiments.

Experiments 4, 5 and 6

Fruit were assessed during winter months (June to August) when the average eating quality is at a minimum, and in a manner similar to Experiment 3. Flesh pH was not measured in Experiment 6.

Treatment of results

The data of Experiment 1 were used to measure the coefficients of determination for the curve of best fit between pineapple skin colour and anticipated ripeness, anticipated eating quality, eating quality, and ripeness. The resultant curves of best fit were found to be all linear allowing a direct comparison between all the coefficients without further computation.

For each experiment the measured eating quality was correlated to each of the other parameters measured in that experiment and also to TSS/acid. The curves of best fit for the various parameters were found to be a mixture of linear and quadratic, preventing a precise comparison of the respective coefficients. As a consequence, quadratic coefficients of determination (R^2) were computed between eating quality and all the parameters.

Six parameters were also analysed for statistical poolability across all experiments. This analysis determines if the data could be regarded as coming from the one sample population unaffected by season. The correlation coefficient was determined between TSS and eating quality using the pooled data over both the complete range, and also over the TSS range of 8–14 % TSS.

RESULTS AND DISCUSSION

The mean, standard deviation and range of the parameters measured in the experiments are presented in Table 2.

Table 2. The sample size, mean, standard deviation and range of data collected in each of six experiments used to determine the best parameter of eating quality in Smooth Cayenne pineapples grown in Queensland

Expt. no.	Mean	Std. dev.	Range	Expt. no.	Mean	Std. dev.	Range
	% TSS				**Titratable acidity** (% anh. citric)		
1	17.6	2.2	7.5 - 21.3	1	0.84	0.25	0.28 - 1.6
2	14.8	2.3	9.1 - 18.1	2	0.64	0.17	0.31 - 1.1
3	14.5	2.3	8.0 - 19.8	3	1.1	0.25	0.46 - 1.6
4	11.8	1.1	9.8 - 14.0	4	1.1	0.14	0.86 - 1.4
5	9.7	1.6	7.1 - 13.4	5	1.3	0.14	1.02 - 1.5
6	10.1	1.1	8.3 - 12.2	6	1.2	0.13	1.06 - 1.5
	Skin (shell) colour (0 = green 8 = full yellow)				**Specific gravity**		
1	2.8	3.0	0 - 8	1	0.98	0.03	0.92 - 1.03
2	4.7	3.4	0 - 8	2	0.99	0.03	0.92 - 1.03
3	4.0	2.6	0 - 8	3	0.96	0.03	0.89 - 1.02
4	3.8	1.5	1 - 7	4	0.96	0.02	0.86 - 0.98
5	2.4	1.6	0 - 6	5	0.97	0.01	0.95 - 0.98
6	0.7	1.1	0 - 4				
	TSS/acid ratio				**pH**		
1	23.4	9.7	11.2 - 66.4	1	3.60	0.23	3.25 - 4.3
2	24.8	8.0	14.1 - 47.4	2	3.47	0.19	3.10 - 3.85
3	13.9	4.5	6.1 - 29.4	3	3.34	0.14	3.10 - 3.61
4	10.5	1.5	8.0 - 14.2	4	3.33	0.10	3.17 - 3.56
5	7.5	1.0	5.4 - 9.5	5	3.27	0.09	3.01 - 3.36
6	8.2	1.1	6.4 - 10.6				
	Flesh ethylene concentration (ppm)				**Eating quality** (1 = dislike extremely, 9 = like extremely)		
1	0.314	0.306	0.061 - 1.55				
2	0.472	0.892	0.015 - 1.17				
				1	6.2	1.2	1.5 - 7.6
				2	5.5	1.3	2.8 - 7.7
				3	5.3	1.0	2.8 - 7.4
				4	6.0	0.4	5.1 - 6.8
				5	3.4	0.78	2.0 - 4.6
				6	3.6	0.65	2.3 - 4.3

Sample size

Experiment	1	2	3	4	5	6
Fruit nos	50	50	50	30	28	14

The quadratic coefficients of determination (R^2) measured between eating quality and each of the parameters assessed are presented in Table 3.

Skin (shell) colour as an index of ripeness and eating quality

A high correlation was found between skin colour and both (a) the anticipated ripeness and (b) the anticipated eating quality (R^2 = 0.94 ($P<0.01$) and 0.81 ($P<0.01$) respectively). However there was much less correlation between the skin colour and the actual ripeness (R^2 = 0.42) ($P<0.05$) indicating that skin colour can be a poor index of fruit ripeness.

Table 3. Quadratic coefficients of determination (R^2) determined between eating quality and nine parameters of physiological maturity

Experiment no.	Skin colour	Specific gravity	TSS	Titrt. acidity	TSS/ acid	Juice pH	Flesh ethylene concentration	Flesh Colour	Flesh Translunency
1	0.01	0.70**	0.48**	0.02	0.05	0.01	0.02	0.07	0.17
2	0.54**	0.41**	0.53**	0.03	0.11	0.02	0.17	0.31	0.32
3	0.06	0.33**	0.49**	0.12	0.16	0.03	n.a.‡	n.a.	n.a.
4	0.13	0.16	0.04	0.21*	0.16	0.13	n.a.	n.a	n.a.
5	0.05	0.06	0.44**	0.15	0.49**	0.34**	n.a.	n.a.	n.a.
6	0.05	0.02	0.27	0.07	0.21	n.a.	n.a.	n.a.	n.a.
Numerical average	0.14	0.28	0.38	0.10	0.20	0.09	0.09	0.19	0.25
Data pooled	n.p.†	n.p.	.70**	n.p.	n.p.	n.p.	n.a.	n.a.	n.a.

*$P < 0.05$.

**$P < 0.01$.

† n.p. = not statistically poolable.

‡ n.a. = not determined.

The correlation between skin colour and actual eating quality was very small (R^2 = 0.012 ($P > 0.05$)) and not statistically significant. Thess results indicate that the average consumer uses skin colour almost exclusively to predict the internal ripeness and eating quality of pineapples, but that the predictions are erroneous.

The data in Table 3 shows that in two of the three experiments where fruit had a very wide and evenly distributed range of skin colours (Experiments 1 to 3), there was no significant relationship between skin colour and eating quality. That is the data clearly show that skin colour can often be valueless as an index of eating quality. This result confirms the opinions of workers in the industry.

In Experiment 2 where the fruit had been grown under overgrown and nutrient-deficient conditions the skin colour was found to be reasonably well correlated to eating quality (R^2 = 0.54 $P < 0.01$). Whether this result was due to the poor growing conditions, or just natural variation is unresolved. Personal observation suggests that the problem of green skinned ripe fruit does not occur with poor overgrown neglected farm blocks. Growers and market agents commonly believe the 'green-ripe' effect results from the use of increased nitrogenous fertiliser. Alternatively, high skin temperatures may be a major cause, the process of degreening in many fruits; for example, tomatoes, mangoes, bananas, is often affected by temperatures above 30°C. However, this explanation would not explain why fruit from neglected blocks seem immune. One explanation could be that with good nutrition plants develop a very extensive and healthy root system which rapidly takes up water following rain to such an extent that the fruit turgor pressure causes cell membranes to leak, accelerates flesh colour development, and fills interstitial spaces with exudate. Local cannery field staff and some growers have suggested a relationship between heavy rain during the 20 days prior to ripening and the green-ripe phenomenon. The topic needs to be addressed further as it is an important problem in Smooth Cayenne fruit destined for the fresh fruit market.

TSS as an index of eating quality

TSS was the only parameter found to be statistically poolable for all six experiments (Table 3) with the pooled data giving a linear curve of best fit with a coefficient of determination (R^2 = 0.70). For any single experiment, the highest coefficient of determination between TSSand eating quality was 0.53 (Table 3, Experiment 2). The marked numerical difference is due to both the increased number of samples and the wider range of both TSS and eating quality values of the combined data compared to those of any individual experiment. The slope and intercept for the resultant curve of the pooled data, was 0.36 and 0.10 respectively.

Over the TSS range of 8 to 14%, a range more closely encompassing the existing cut off points of unacceptable eating quality. The coefficient of determination was substantially less, (R^2 = 0.43) but with slope and intercept of similar magnitude to the data of the whole range (0.39 and 0.29 respectively). The R^2 value of the restricted data set is important when considering different TSS 'cut-off' levels, and also when calculating sampling sizes for regulating maturity over this range.

The analysis of the combined data indicated that TSS accounted for 70% of the variability (R^2 = 0.70) of the pineapple eating quality of six experiments over three seasons. This indicates that TSS is a good overall index of pineapple eating quality, independent of the effect of season of the year, and the best of nine major parameters of pineapple physiology.

Of the individual experiments; TSS was found to give the highest numerical average coefficient of determination to eating quality (average R^2 = 0.38) (Table 3), indicating that TSS is not only the best index when averaged over all seasons, but is generally the best in any particular season.

From the data of intercept and slope over the range 8 to 14% TSS, the TSS level corresponding to average eating quality of 14 on the hedonic scale (dislike slightly) is 11.0, and is 10.9 using the full range data. For an average eating quality of 6, the corresponding figures are 16.1 and 16.6. These data suggest that to endeavour to market a higher quality fresh pineapple the average minimum TSS level of the fruit should be substantially increased above the existing Queensland minimum.

Specific gravity as an index of eating quality

SG gave the next highest average coefficient after TSS (numerical average R^2 = 0.28) and SG has the advantage of being non-destructive. SG is not suitable by itself to grade for eating quality because the non-poolability of this parameter confirms that the relationship to eating quality varies widely with season as previously reported (Smith 1984). The relationship between SG and eating quality at any one time will also vary from farm to farm and farm-block to farm-block to a greater or lesser degree, but the method does grade fruit into classes of near-uniform ripeness. The degree of uniformity of the TSS (and thus of the eating quality) of fruit graded using SG will depend on the uniformity of the fruit in each farm block.

It is of interest to note that in Experiment 4, TSS was very poorly related to eating quality (R^2 = 0.04, Table 3). An inspection of the individual data shows the datum values reasonably spread with no spurious out-lying point causing the suspicious result. The explanation lies in part with the small range of TSS values recorded (9.8 to 14, Table 1), and the balance must be a natural variation of data.

The data above indicate that TSS is well correlated to eating quality, and, as the TSS in pineapples is nearly all sugar (Singletonand Gortner 1965), the major factor influencing eating quality is thus the sugar concentration of the juice.

TSS acid ratio as an index of eating quality

As an index of eating quality TSS/acid was found to be mostly very inferior to TSS, as judged by the magnitude of the numerical average (of the coefficients of determination) shown in Table 3. For fruit harvested in summer and autumn (Experiments 1 to 3) the superiority of TSS over TSS/acid was very marked. For fruit harvested in winter (Experiments 4 to 6) this result tended to be reversed but even so, TSS/acid was never substantially better than TSS. It should be noted that the eating quality of the fruit harvested in winter was low (see eating quality, Table 2, Experiments 4 to 6). A major reason why there are so few fruit in these experiments was the inability to get tasters to continue tasting fruit of such low eating quality. Thus although TSS/acid may in some instances be slightly better than TSS as an index of eating quality in winter fruit, this only applies when the eating quality is so low that the fruit are objectionable to eat. The use of brix/acid ratio is not recommended as an index of pineapple eating quality.

The other parameters of eating quality

In each of the six experiments (Table 3) titratable acidity was found to be negatively correlated to eating quality but only weakly. This weak relationship would explain why TSS/acid is not a better index of eating quality than TSS alone. The data on TSS and acidity indicates that the poor palatability of winter fruit is not due to their high acidity but due to their low TSS content.

Internal ethylene concentration was not significantly correlated to eating quality (Table 3, Experiments 1 and 2). This result is of interest as the ethylene production rate in many, if not all, fruits increases as they develop and ripen. The result is discussed further, below.

Flesh pH was generally poorly correlated to pineapple eating quality. This result is in agreement with previous work (Bowden 1967), the parameter being included in the experiments here for the sake of completeness. It was the one statistically significant relationship between pH and eating quality (Experiment 5) which gave a negative coefficient.

Flesh colour, flesh translucency and internal ethylene concentration were all poor indicators of pineapple eating quality (Table 3, Experiments 1 and 2) as judged by the magnitude of the average coefficient of determination. At first glance this seems unreasonable as these are all indicators of fruit ripeness. However, all three parameters relate directly to the physiological state of fruit development commonly described by Australian fruit physiologists as the physiological maturity (Wills *et al.* 1981). The three parameters are only indirectly related to the eating quality. Fruit which are at optimum physiological ripeness; that is, the flesh yellow and semi-translucent, can still have low TSS levels and thus poor eating quality for a number of reasons:

(1) Reduced light intensity during winter or periods of cloudy weather.

(2) If the fruit is large relative to the size of the plant or the exposed leaves, the plant will have only a small amount of photosynthate to distribute throughout the large fruit and thusthe percentage of sugar; that is, the % TSS will be reduced.

(3) If the plant is shaded by other plants or by trees the sugar level of the fruit will be reduced due to reduced photosynthetic activity.

(4) If plants have more water, the concentration of sugars will be diluted.

(5) Conversely, if the plant roots are damaged, water uptake will be reduced resulting in a smaller fruit but one of a increased TSS content.

A large fruit-weight to exposed-leaf-area ratio is particularly common in pineapple plantations where artificial flower-induction results in a proportion of small plants prematurely induced to bear a fruit, particularly when the planting material is poorly graded for equality of size. The final size of a fully developed pineapple directly relates to the temperature during the time of initial fruit development (Bartholomew and Paull 1986) rather than to the capacity of the plant to produce a fruit of a predetermined TSS level. Thus a fruit initiated in late summer when the temperature is high will be large in size but because it matures through winter when light levels are substantially reduced, the final TSS of the fruit will be low. Fruit with the highest TSS are ones which are initiated in winter, giving a small fruit, but maturing through spring and early summer when light levels are high, giving a large production of TSS. The variation of the fruit size to the amount of photosynthate explains the very seasonal nature of pineapple eating quality even when the fruit consumed is at optimum ripeness.

TSS is currently used by Queensland marketing authorities as an index of pineapple maturity. TSS cannot be used to grade fruit directly on the farm, being a destructive index, but it could be used in conjunction with SG which is non-destructive.

It has already been proposed that fresh market pineapples could be commercially graded using SG (Smith 1984). However, this paper suggests that it is not enough to grade for just SG. To ensure consistently high eating quality in the pineapples, the TSS of the fruit must be high.

TSS could be used by growers on subsamples to spot check fruit from different parts of a farm, or by industry inspectors to assess fruit from different farms or at various points along a marketing chain. TSS (and eating quality) decrease only marginally during the postharvest life of the fruit (Huet 1958; L. G. Smith, unpub. data). The data in this paper suggests that TSS is the most suitable parameter to monitor pineapple eating quality but the data also indicate that consumer quality would be substantially increased if the average TSS level was above 14%.

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