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THE RELATIONSHIP BETWEEN HARVEST MATURITY PARAMETERS AND THE STORAGE QUALITY OF COX APPLES

An analysis of two years' data

A REPORT FOR APRC (PROJECT SP 104)

M.S.Ridout & D.S.Johnson
Horticulture Research International
East Malling, West Malling
Kent. ME19 6BJ

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SUMMARY

1. This report is based on detailed analysis of data collected in 1994 and 1995 by participants in the Fruit Maturity Programme, which is currently funded by English Apples and Pears Ltd.

2. Cox apples were picked on 4 occasions, at approximately 10 day intervals, between 31 August and 3 October (the dates differed slightly in the two years). Fruit was picked from 30 orchards in 1994 and 32 orchards in 1995, and was subsequently stored in controlled atmosphere (1.2% O_2, < 1% CO_2 at 3.5°C) at HRI, East Malling. Samples of fruit were removed in the following January and April and assessed immediately, and following storage in air at 18°C for a further 7 days, to simulate marketing.

3. Delaying picking results in larger fruit with improved sugar content, red colour and aromatic flavour, and reduced acidity. However, greenness and firmness decrease over time and storage problems can arise if fruit are picked too late. Stored fruit may lack firmness and have an unsatisfactory background colour, and there is a greater risk that storage rots and certain types of physiological disorders will occur. Fruit picked on the second or third picking date was generally judged to have the best eating characteristics.

4. The possibility of predicting ex-store fruit characteristics from measurements taken at harvest, using regression models, was investigated. Useful regression models (explaining 50-70% of the overall variation in the two years) were found only for fruit greenness (Hunter 'a' colour) and fruit firmness.

5. The data showed that when ex-store firmness was adequate (6.0 - 6.5 kg immediately ex-store), ex-store greenness was almost always adequate as well (Hunter 'a' colour ≥ 10, corresponding to a score of less than 3 on the ENFRU colour chart). This indicates that attention should be focused on achieving adequate ex-store firmness.

6. Several alternative regression models were developed to predict ex-store firmness.

We favour the simplest of these, which uses harvest firmness as the only explanatory variable, because it predicts almost as well as alternative models and leads to straightforward recommendations.

7. The model predicts that to achieve an ex-store firmness of 6.5 kg it will be necessary to harvest fruit at a firmness of 9.4 kg for storage until January, and 10.2 kg for storage until April. However, to achieve these firmness values at harvest it would often have been necessary to pick fruit on or even (for storage until April) before, the first picking date, when fruit were small and eating quality was poor. It seems necessary, therefore, to relax the requirement for 6.5 kg firmness immediately ex-store.

8. To achieve an ex-store firmness of 6.0 kg, the model indicates that fruit should be picked at a firmness of 8.2 kg for storage until January and 8.7 kg for storage until April. This gives the optimum pick date as being generally pick 2 or pick 3 for storage until January and pick 1 or pick 2 for storage until April.

9. If the intention is to store until April, but firmness declines to the recommended level too early for satisfactory eating quality, the best strategy may be to leave the fruit on the tree and reduce the planned storage period.

10. Although these conclusions are based on careful and detailed statistical analysis, it is very important to emphasize that there are currently only two years of data. To estimate how reliable the predictions will be in future years requires a reasonable estimate of year-to-year variability. This will require data for several years. At that point it may be possible to identify climatic factors that cause some of the year-to-year variability. A necessary first step will be to study the data from this year's harvest.

INTRODUCTION

The poor performance of Cox apples on the UK market in 1992 and 1993, particularly late in the storage season, resulted in the formation of the Quality Fruit Group (QFG) whose primary function was to provide guidance to growers, store operators and marketeers as a means of improving the eating quality of Cox through the marketing chain and to effect a continuous supply of high quality fruit from September to April. Of primary concern to the QFG was the often poor texture of the fruit, and urgent consideration was given to ways of improving fruit firmness and juiciness. It was recognised that harvest date had a major influence on duration of storage and quality loss in store and an early decision of the QFG was to instigate a national programme to monitor changes in Cox maturity on approach to harvest as a means of providing detailed regional advice on when to harvest for long-term storage. The UK national maturity indexing programme was organised along the lines of those carried out for many years in the US and South Africa. At the outset the criteria used to make recommendations on start and end dates for long-term storage were based on the starch iodine test and on ethylene evolution to back up early prediction from full-bloom date and climatic data for the growing season. ADAS had a wealth of information which helped to categorise rate of maturation in a particular year but there was no storage data to facilitate a retrospective judgement on whether guidelines were correct. In the UK maturity programme, which began in 1994, provision was made for the storage of fruit harvested on four occasions, which were then assessed for quality in January and April. This information was of immediate use as a means of judging the accuracy of picking date guidelines given at harvest but more importantly provided a substantial body of data with which to study relationships between ex-store quality attributes and harvest maturity parameters.

Predictive models that result from analysis of these data should be regarded as tentative, since they are based on only two years of data. It is likely that there will be seasonal effects on relationships between fruit maturity characteristics at harvest and ex-store quality and these can be explored as data for the 1996 crop, and possibly for future seasons, become available.

EXPERIMENTAL METHODS

This study is based on data collected from 30 Cox orchards in 1994 and 32 orchards in 1995.

Fruit mineral analysis

Samples of 30 fruit were collected from each orchard one week before the picking date recommended by F.A.S.T. Ltd. The concentrations (mg $100g^{-1}$) of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca) and magnesium (Mg) in fruit from each orchard were determined by F.A.S.T. Ltd. Samples were also collected three weeks before the F.A.S.T.-recommended picking date, but we have not used these data because they are less complete. However, measurements of percentage dry matter were also made on this occasion and we have used these data.

Fruit attributes recorded at harvest

Fruit samples were taken on each pick date. Sampling and measurements were carried out jointly by F.A.S.T. Ltd and ADAS and full details of the methodology have been provided in Quality Fruit Group Reports for 1994 and 1995 (available from English Apples and Pears Ltd.) Measurements were made of fruit diameter and weight, background colour (ENFRU Card), firmness (hand-held penetrometer), starch (iodine test), titratable acidity and soluble solids (sugar) concentration (refractometer).

These variables were used as possible predictors of ex-store quality. In addition a maturity (Streif) index was calculated from these data using the formula

$$\text{Streif index} = \frac{9.81 \times \text{Firmness}}{\text{Sugar} \times (100 - \text{Starch})}$$

where Sugar and Starch values are percentages and the constant 9.81 converts the units of firmness from kg to Newtons. The formula cannot be used when the Starch value is 100% and in these instances a value of 99% was substituted. The more usual calculation of the Streif index requires that percentage starch is entered as an integer value between 1 (100% starch) and 10 (0% starch). However, the relationship between percentage starch and starch score is not linear and, for greater accuracy in statistical analysis, use of the percentage starch values would seem to be preferable. A consequence of this is that the Streif index values given in this report (*e.g.* in Table 2) differ from those given in the harvest information provided by the QFG.

Storage

Two boxes of fruit (nominally 14 kg) were picked from each orchard on 1, 12, 22 September and 3 October in 1994, and on 31 August and 11, 21, 29 September in 1995 and delivered to HRI, East Malling on the same day. On arrival, fruit were sampled to obtain four netted samples of 20 fruit for each site, for storage in controlled atmosphere (1.2% O_2, < 1% CO_2) at 3.5°C until January or April. Samples were weighed, dipped in fungicide ('Ridomil mbc') at the recommended rate, and loaded into 0.5 tonne storage cabinets. Carbon dioxide was removed from the storage cabinets using external hydrated lime scrubbers and oxygen concentration was controlled by an automatic control system which admitted air as necessary and maintained 1.2% O_2 (±0.1%). The low oxygen atmosphere was generated by the fruit, generally within two weeks of sealing the cabinets.

Assessment of stored fruit

Two of the four netted samples were removed in January (9 and 10 January 1995, 8 and 9 January 1996) and the other two in April (10 and 11 April in 1995, 9 and 10 April in 1996). On each occasion, one sample was examined immediately and the other was stored in air at 18°C for a further 7 days, to simulate 'shelf-life', before examination.

The samples were weighed, to enable the calculation of weight loss during storage, and ten apples were removed for measurement of colour using a Hunter colorimeter. This colorimeter measures three colour components labelled 'L', 'a' and 'b'. The 'L' value measures black ('L'=0) to white ('L'=100). The 'a' value is larger the greener the fruit and the 'b' value increases with increasing yellowness. (The Hunter 'a' values that are recorded are actually negative, but we ignore the negative sign throughout this report.) The firmness of the same ten fruits was measured with an automated penetrometer fitted with an 11mm probe. The number of rots per sample was recorded, and all fruit were cut and examined internally for the presence of physiological disorders. After the simulated 'shelf-life', firmness and colour were again measured, and, in addition, a few apples from each sample were tasted by Mr John Chapman of F.A.S.T. Ltd and scored for taste (sugar/acid balance), texture and Cox flavour. Mr Chapman uses a similar system in monitoring commercial stores. Maximum scores achievable for taste, texture and flavour were 5, 5 and 10 respectively.

STATISTICAL METHODS

This section describes the statistical methods that we have used, and gives some guidelines on interpretation of the output.

Tables of means

Tables of means calculated over orchards are generally accompanied by the standard error of the difference (s.e.d.) for comparing any two means. Observed differences in means may arise because of a genuine difference, or as a chance result of the particular fruit that were sampled. The s.e.d., which is based on orchard to orchard variation, allows one to estimate the likelihood that the difference is due to chance. Differences greater than twice the s.e.d. have a probability of less than 1 in 20 of being due to chance and are conventionally regarded as being 'statistically significant'. To simplify the presentation we have sometimes, when this is justified statistically, pooled separate s.e.d.s to obtain a single s.e.d. that can be used to compare all values in a Table. The abbreviation d.f. in Tables denotes degrees of freedom.

Predictive models

The predictive models that we present are derived by the statistical technique known as multiple regression analysis. This technique is aimed at modelling a particular *response variable* (*e.g.* ex-store firmness) in terms of one or more *explanatory variables*. The potential explanatory variables in this study were harvest measurements of fruit weight, diameter, colour, firmness, acidity, sugar and starch coverage, the Streif index, fruit N, P, K, Ca and Mg measured one week before the suggested optimal harvest date, and fruit dry matter percentage measured three weeks before the suggested optimal harvest date, a total of 14 variables.

An important, and difficult, problem in regression analysis is the problem of *variable selection*, that is choosing which of the possible explanatory variables should be included in any particular model. We used a modern, computer intensive, technique known as cross-validation to try to select models with good predictive ability based on harvest measurements. Then we investigated whether these models could be improved by adding mineral analysis variables or fruit dry matter.

Cross-validation works as follows. The data are partitioned randomly into two parts. One part is used to fit models involving different combinations of explanatory variables. Predictions from these fitted models are then tested on the other part of the data, which was not used in deriving the model. Different models can therefore be ranked in terms of their predictive ability. This is then repeated for many different random partitions of the data (we used 5000 repetitions) and models are ranked in terms of their *average* predictive ability. Usually there are several different combinations of explanatory variables that have similar predictive ability and we have then preferred those that involve the fewest explanatory variables.

Details of regression models are given in tables such as the following:

Explanatory variable	Firmness, January ex-store
Constant	4.34 (5.06)
Diameter	-0.021 (1.91)
Firmness	0.37 (14.4)
r.s.d. (d.f.)	0.51 (241)
$\bar{R}^2$	61.9

The main entries in the table (4.34, -0.021, 0.37) are the *regression coefficients*. These indicate that the model is as follows:

$$\text{Ex-store firmness} = 4.34 - 0.021 \times \text{Diameter} + 0.37 \times \text{Firmness}$$

where the diameter and firmness on the right hand side of the equation are the measurements taken at harvest. The figures in brackets after the coefficients are the *t-values*. Roughly speaking, the larger the t-value, the closer the explanatory variable is correlated with the response variable. At the bottom of the table, the *residual standard deviation* (r.s.d, calculated as the square root of the residual mean square) is a measure of the variability that remains in the data after fitting the regression model. The figure in brackets after the r.s.d. is the residual degrees of freedom. These values are included primarily for those who have some familiarity with regression analysis. The final line gives the *percentage variance accounted for* ($\bar{R}^2$), a measure of how much of the overall variation in the data is explained by the regression model. Large values of $\bar{R}^2$ are desirable.

Well over one hundred regression models were examined in total, but only the most useful or interesting of these are presented here.

RESULTS

Fruit mineral analysis and dry matter

Table 1 shows mean values of fruit N, P, K, Ca and Mg concentrations across all orchards, one week before the F.A.S.T.-recommended harvest date. Concentrations of all nutrients were higher in 1995 than in 1994. Percentage dry matter, measured three weeks before the recommended harvest date, was also higher in 1995 than in 1994.

Fruit measurements taken at harvest

As expected, fruit weight, diameter and sugar content increased over successive picks whilst firmness, greenness (ENFRU colour score), acidity, starch coverage and the Streif index decreased (Table 2).

At Pick 4, fruit was slightly less green in 1994 than in 1995, but otherwise fruit weight, diameter and colour were very similar in the two years at all picks. In contrast, sugar and starch coverage was higher in 1995 than in 1994 at all picks. Firmness and acidity were also higher in 1995 at pick 1 and, to a lesser extent at picks 2 and 4. At pick 3 there was no significant difference between years.

Because of the way it is calculated, the Streif index is very sensitive to small changes in starch percentage when this is close to 100%. For example, if the starch value changes from 99% to 98%, and the firmness and sugar content are unchanged, the value of the Streif index is halved. This underlies the large difference between values of the index in 1994 and 1995 at pick 1. Thereafter, differences were smaller, though 1995 values were higher at all picks.

Post-harvest measurements

Percentage weight loss

At the January ex-store inspection, Pick 2 fruit had a lower percentage weight loss than Pick 1 fruit, but weight loss increased again for Pick 3 fruit (1995) or Pick 4 fruit (1994) (Table 3). This pattern remained, though with smaller differences, after 7 days 'shelf-life'. At the April inspection, pick date had little effect on percentage weight loss.

Regression analysis did not yield any useful predictive models of percentage weight loss.

Hunter 'L' colour

Hunter 'L' colour increased with increasing pick date and during 'shelf-life' (Table 4). At the April inspections values were generally higher in 1994 than in 1995, but the two years gave similar results at the January inspections.

Regression models accounted for only 21-30% of the variation at each inspection (Table 5). Fruit colour at harvest was the only variable that occurred in the model for every assessment time.

Hunter 'a' colour

Hunter 'a' values decreased, implying that the fruit became less green, with increasing pick date and during 'shelf-life' (Table 6). Fruit were also less green at the April inspections than at the January inspections.

Regression models based on fruit measurements taken at harvest accounted for 55-61% of the variation at each inspection (Table 7). Fruit colour at harvest appeared to be the most important explanatory variable, though the Streif index also appeared in all models. At each assessment, a slightly improved fit was obtained by including fruit N as an additional explanatory variable (Table 8).

Figure 1 shows greenness ex-store (Hunter 'a' value) plotted against greenness at harvest (ENFRU card score). The correlation is negative because the higher the ENFRU card score, the *less* the green is the fruit, whilst the higher the Hunter 'a' values the *more* green is the fruit.

Hunter 'b' colour

Hunter 'b' values increased, implying that the fruit became more yellow, with increasing pick date and during 'shelf-life' (Table 9).

Regression models accounted for 20-40% of the variation at each inspection (Table 10). Fruit colour at harvest was again selected as an explanatory variable for all assessment times.

Fruit firmness

Fruit firmness decreased with increased pick date and during shelf life (Table 11). At the April inspections fruit was less firm than at the corresponding January inspections.

Because firmness models are of particular importance, we present several alternative models. Our cross-validation selection procedure pointed to models based on fruit firmness and diameter at harvest. These models, which explained 48-62% of the variance, are presented in Table 12. Table 13 gives models which include fruit P and K concentrations as additional explanatory variables. These models have slightly improved percentage variance accounted for, ranging from 55-65%. We also investigated the effect of adding fruit dry matter concentration into the model, since this has shown previously an association with ex-store firmness. The estimated regression coefficient was negative for all assessments, but was statistically significant only for the January shelf-life assessment.

Table 14 presents regression models in which harvest firmness is the sole explanatory variable. The percentage variance explained by these models is 3-11% less than the corresponding models in Table 13, but there is clearly some convenience in having a model that is based on only a single explanatory variable. Figure 2 shows the relationship between firmness immediately ex-store and harvest firmness.

Percentage of fruit with rots

The percentage of fruit that had rots increased with increasing pick date and during shelf life (Table 15). The percentage was also higher in fruit inspected in April than in fruit inspected in January. At the January inspection, the percentage of fruit with rots exceeded 5% only for Pick 4 fruit in 1994 whereas at the April inspection more than 5% of fruit from

Picks 3 and 4 in both years had rots.

Regression analysis did not yield any useful predictive models of percentage rotting.

Taste, texture and flavour

In both years the taste (sugar/acid) score was highest for Pick 2 and Pick 3 fruit and the Cox flavour score was highest for Pick 3 fruit (Table 16). There was a large difference between the January and April scores for Pick 1 in 1995 for both of these variables. The texture score was highest at Pick 2 in 1994 and at Picks 1 and 2 in 1995.

Regression analysis did not yield any useful predictive models for the taste or texture scores. Regression models for January and April assessments of Cox flavour explained 25 and 45% of the variance respectively (Table 17).

Physiological disorders

One of the criteria for selecting orchards for this study was that fruit should have good storage potential. As a result, the incidence of physiological disorders was low and there were many zeros in the data. This limits the possibilities for developing models to predict the occurrence of these disorders.

Bitter pit and late storage corking

The incidence of bitter pit and late storage corking was generally low (<2%) in January but had increased by the April assessment in both years (Table 18). There was a further increase during shelf-life in April, particularly in the first year.

Regression models for the incidence of bitter pit and late storage corking explained less than 15% of the variance, except for the April shelf-life assessment where a model based on harvest weight and fruit K (positive regression coefficients) together with diameter, sugar content, Streif index and fruit N (negative regression coefficients) explained 23.5% of the variance. However, this is not sufficient to obtain any useful predictions.

Core flush

The incidence of core flush was low (<2%) in the January assessments and remained so for the April assessments of the 1995 crop (Table 19). However, for the 1994 crop, incidence was 7-10% immediately ex-store in April, except for pick 1 fruit, and increased further during shelf life.

Regression models for the incidence of core flush explained less than 15% of the variance at all assessments.

Breakdown

Breakdown was a general term used to describe abnormalities of the flesh that were not considered to be either bitter pit or late storage corking. Its incidence was less than 1% in January assessments in both years, except for pick 4 in 1994 (Table 20). Incidence was higher in April and again incidence for pick 4 in 1994 was considerably higher than elsewhere.

Regression models for the incidence of breakdown explained less than 15% of the variance at all assessments.

Superficial scald

Fruit picked in 1995 developed superficial scald during the April shelf-life period at 18°C. The incidence for fruit from picks 1 to 4 was 22.0%, 2.5%, 0.5% and 0.7% respectively. A regression model based on harvest weight, diameter, sugar content and Streif index together with fruit N explained 18% of the variance, but this is too low to yield useful predictions.

USING FIRMNESS MODELS TO PREDICT OPTIMUM PICKING DATE

In this study, Cox apples were found to eat well at a firmness of 5.7-6.1 kg. To provide this, ENFRU recommends that fruit should have a firmness of at least 6.5 kg immediately ex-store. Table 21 shows that this recommendation is usually successful in achieving fruit of satisfactory firmness. The Table shows the relationship between ex-store firmness, classified as <6.5 kg or ≥6.5 kg, and firmness after shelf-life, classified as <5.7 kg, 5.7-6.0 kg or >6.0 kg. At the January assessment 82% of samples that had ex-store firmness >6.5 kg had firmness >6.0 kg after shelf-life. A further 11% had firmness 5.7-6.0 kg after shelf life. At the April assessment, the corresponding figures were 74% and 21%. In contrast, at both assessments, most samples that had firmness <6.5 kg immediately ex-store had firmness <5.7 kg after shelf-life.

We now consider the effect of using the various models to *predict* whether ex-store firmness exceeds 6.5 kg. Table 22 shows the extent to which the different prediction models agree with the actual data, and with each other. The pattern of results was similar at both assessments. There was a high degree of agreement, around 95%, between the different predictions from the different models and the predictions agreed with the observed values about 80% of the time. Agreement was only slightly worse for the model based solely on harvest firmness than for the more complex models. We therefore prefer the simple model, because it is easier to interpret.

In this model one needs a firmness of 9.4 kg to ensure an ex-store firmness of 6.5 kg in January and 10.2 kg at harvest to give an ex-store firmness of 6.5 kg in April. The upper half of Table 23 shows the distribution of predicted optimum pick dates, based on this model. The 'optimum' pick date is defined as the last pick date on which the harvest firmness is predicted to exceed the critical value. The Table shows that the requirement of 6.5 kg ex-store is often too stringent. Particularly for storage until April, fruit was often too soft at Pick 1, which would itself be considered too early for quality attributes other than firmness. We have therefore shown, in the lower half of Table 23, the distribution of pick dates to achieve 6.0 kg, rather than 6.5 kg, ex-store. This gives a more satisfactory picture, with the optimum pick date generally being pick 2 or 3 for storage until January and pick 1 or 2 for storage until April. For January ex-store firmness of 6.0 kg the target harvest firmness is 8.2 kg and for April the target is 8.7 kg.

Table 24 presents some data on greenness of fruit picked on the optimum predicted picking date to achieve adequate firmness after storage. Hunter 'a' values need to be in excess of 10 to conform to less than 3 on the ENFRU colour chart. The Table shows that most fruit had satisfactory greenness (Hunter 'a' value $\geq$ 10) when picked according to the predicted dates to achieve an ex-store firmness of 6 or 6.5 kg. It therefore appears unnecessary to develop a separate model to predict ex-store greenness, since picking for firmness will also provide fruit of the required background colour. In other words, delaying harvest has a greater adverse effect on texture than on loss of greenness.

Table 25 shows the total fruit quality score of fruit picked on the optimum predicted picking date. We have doubled the taste and texture scores, which were originally on a 0-5 scale, and added these to the Cox flavour score, which is on a 0-10 scale, to give a combined score on a 0-30 scale, in which all three components have equal importance. Table 25 shows the mean total score over all available orchards. For storage until January, fruit picked later, for a target of 6.0 kg rather than 6.5 kg, have a higher mean quality score. However, for fruit stored until April, the target firmness had no significant effect on the quality score.

TABLE 1

Fruit mineral concentrations (mg $100g^{-1}$) one week before the picking date recommended by F.A.S.T. and percentage dry matter three weeks before picking data. Data are means of up to 30 orchards in 1994 and 32 orchards in 1995. Values for individual orchards were determined from samples of 30 fruit.

Element	1994	1995	s.e.d. (56 d.f.)
Nitrogen (N)	58.8	63.3	1.33
Phosphorus (P)	12.6	13.1	0.18
Potassium (K)	132.5	146.4	2.22
Calcium (Ca)	5.48	5.75	0.115
Magnesium (Mg)	6.05	6.42	0.075
% Dry matter	16.0	17.6	0.15

TABLE 2

The effect of pick date on fruit characteristics at harvest. The tabulated values are means of up to 30 orchards in 1994 and 32 orchards in 1995. The individual values for each orchard were themselves means of 20 fruit samples, apart from the Streif index which was derived from the mean values of firmness, sugar and starch.

		Pick			
Variable	Season	1	2	3	4
Weight (g)	1994	109	117	126	131
s.e.d.=4.6 (237 d.f.)	1995	105	116	127	132
Diameter (mm)	1994	62.3	64.1	66.0	66.9
s.e.d.=0.87 (237 d.f.)	1995	61.5	64.1	66.1	67.1
Colour (ENFRU score*)	1994	1.2	1.6	2.2	3.1
s.e.d.=0.12 (237 d.f.)	1995	1.1	1.5	2.1	2.7
Firmness (kg)	1994	10.3	9.3	8.9	7.1
s.e.d.=0.28 (237 d.f.)	1995	11.0	9.6	8.6	7.6
Acidity (g kg^{-1})	1994	10.4	9.8	9.4	8.2
s.e.d.=0.24 (237 d.f.)	1995	11.4	10.3	9.2	8.8
Sugar (%soluble solids)	1994	11.9	12.6	13.6	14.5
s.e.d.=0.24 (237 d.f.)	1995	12.8	14.1	14.8	15.9
Starch (% black)	1994	83.4	69.5	48.8	31.3
s.e.d.=3.29 (237 d.f.)	1995	97.8	77.5	55.9	44.1
Streif Index	1994	1.35	0.42	0.14	0.08
	1995	5.89	0.54	0.19	0.11

* ENFRU card, 1 = green, 4 = yellow

TABLE 3

The effect of pick date and duration of storage on weight loss, as percentage of harvest weight. Tabulated values are means of up to 30 orchards in 1994/5 and 32 orchards in 1995/6.

		Pick			
Assessment time	Season	1	2	3	4
January, ex-store	1994/5	4.2	1.2	1.1	4.3
	1995/6	3.6	1.1	1.9	2.3
January, shelf life	1994/5	5.8	3.6	3.7	8.0
	1995/6	4.4	3.2	4.5	4.8
April, ex-store	1994/5	4.7	4.6	2.8	7.8
	1995/6	3.6	3.4	3.5	3.1
April, shelf life	1994/5	6.4	6.9	6.7	-
	1995/6	4.3	5.9	6.4	5.1

s.e.d. = 0.54 (914 d.f.)

TABLE 4

The effect of pick date and duration of storage on Hunter 'L' colour. Tabulated values are means of up to 30 orchards in 1994/5 and 32 orchards in 1995/6.

		Pick			
Assessment time	Season	1	2	3	4
January, ex-store	1994	59.9	61.1	62.5	-
	1995	60.5	61.4	62.7	63.8
January, shelf life	1994	61.3	63.7	64.8	-
	1995	64.1	64.6	65.2	65.5
April, ex-store	1994	61.7	62.4	62.4	-
	1995	59.1	60.8	62.1	-
April, shelf life	1994	64.6	65.8	65.7	-
	1995	61.7	62.7	63.2	-

s.e.d. = 0.60 (715 d.f.)

- red colour had developed to an extent that precluded measurement of background colour

TABLE 5

Regression models for Hunter 'L' colour. The Table shows regression coefficients with t-values in brackets, the residual standard deviation (r.s.d.) and its degrees of freedom, and the percentage variance accounted for ($\bar{R}^2$). See the Statistical Methods Section for more details.

Explanatory variable	January assessment		April assessment	
	Ex-store	Shelf-life	Ex-store	Shelf-life
Constant	54.4 (43.1)	56.3 (43.2)	60.1 (118.5)	70.3 (42.6)
Colour	1.61 (5.92)	1.09 (3.93)	1.04 (3.67)	1.54 (4.57)
Sugar	0.33 (3.17)	0.44 (4.07)	-	-0.64 (4.81)
Streif index	-	1.01 (1.94)	-2.19 (4.08)	-2.37 (3.96)
r.s.d. (d.f.)	1.74 (184)	1.80 (192)	1.86 (177)	2.02 (174)
$\bar{R}^2$	30.1	24.2	21.1	22.3

TABLE 6

The effect of pick date and duration of storage on Hunter 'a' colour. Tabulated values are means of up to 30 orchards in 1994/5 and 32 orchards in 1995/6.

		Pick			
Assessment time	Season	1	2	3	4
January, ex-store	1994	13.7	12.6	11.0	-
	1995	14.3	13.0	11.7	11.2
January, shelf life	1994	11.2	10.8	10.0	-
	1995	12.1	10.5	9.0	8.0
April, ex-store	1994	12.8	11.4	10.5	-
	1995	13.0	12.1	10.6	-
April, shelf life	1994	11.0	9.3	8.4	-
	1995	11.9	10.1	9.3	-

s.e.d. = 0.35 (715 d.f.)

- red colour had developed to an extent that precluded measurement of background colour

TABLE 7

Regression models for Hunter 'a' colour. The Table shows regression coefficients with t-values in brackets, the residual standard deviation (r.s.d.) and its degrees of freedom, and the percentage variance accounted for ($\bar{R}^2$). See the Statistical Methods Section for more details.

Explanatory variable	January assessment		April assessment	
	Ex-store	Shelf-life	Ex-store	Shelf-life
Constant	12.7 (23.6)	15.9 (20.2)	14.2 (56.8)	12.6 (43.9)
Colour	-1.18 (7.05)	-1.41 (8.42)	-1.61 (11.6)	-1.76 (11.0)
Sugar	-	-0.25 (3.83)	-	-
Starch	0.024 (4.96)	-	-	-
Streif index	0.68 (2.26)	1.04 (3.33)	1.09 (4.13)	1.66 (5.42)
r.s.d. (d.f.)	0.92 (183)	1.09 (192)	0.91 (177)	1.05 (175)
$\bar{R}^2$	60.6	55.0	55.4	56.6

TABLE 8

Regression models for Hunter 'a' colour, with fruit mineral analysis variables included. The Table shows regression coefficients with t-values in brackets, the residual standard deviation (r.s.d.) and its degrees of freedom, and the percentage variance accounted for ($\bar{R}^2$). See the Statistical Methods Section for more details.

Explanatory	January assessment		April assessment	
variable	Ex-store	Shelf-life	Ex-store	Shelf-life
Constant	10.8 (14.4)	15.9 (18.4)	13.1 (26.0)	10.7 (18.5)
Colour	-1.09 (6.49)	-1.22 (7.09)	-1.54 (11.0)	-1.71 (10.7)
Sugar	-	-0.35 (5.08)	-	-
Starch	0.027 (5.52)	-	-	-
Streif index	0.68 (2.19)	0.99 (3.07)	1.20 (4.38)	1.73 (5.54)
Fruit N	0.026 (3.96)	0.020 (2.64)	0.016 (2.36)	0.029 (3.82)
r.s.d. (d.f.)	0.89 (171)	1.04 (178)	0.89 (165)	1.01 (163)
$\bar{R}^2$	63.4	57.3	56.6	59.8

TABLE 9

The effect of pick date and duration of storage on Hunter 'b' colour. Tabulated values are means of up to 30 orchards in 1994/5 and 32 orchards in 1995/6.

		Pick			
Assessment time	Season	1	2	3	4
January, ex-store	1994	30.2	31.5	31.5	-
	1995	30.4	31.9	32.5	32.9
January, shelf life	1994	32.7	33.8	34.7	-
	1995	32.9	33.2	34.2	34.4
April, ex-store	1994	30.7	31.5	32.5	-
	1995	30.3	31.5	32.7	-
April, shelf life	1994	33.1	34.3	34.1	-
	1995	32.6	33.4	34.4	-

s.e.d. = 0.39 (715 d.f.)

- red colour had developed to an extent that precluded measurement of background colour

TABLE 10

Regression models for Hunter 'b' colour. The Table shows regression coefficients with t-values in brackets, the residual standard deviation (r.s.d.) and its degrees of freedom, and the percentage variance accounted for ($\bar{R}^2$). See the Statistical Methods Section for more details.

Explanatory	January assessment		April assessment	
variable	Ex-store	Shelf-life	Ex-store	Shelf-life
Constant	25.0 (28.0)	30.9 (50.7)	26.4 (32.6)	30.8 (40.0)
Colour	0.82 (4.27)	1.24 (6.96)	0.75 (4.47)	1.16 (5.06)
Sugar	0.38 (5.13)	-	0.30 (4.69)	-
Starch	-	0.012 (2.07)	-	0.016 (2.25)
Streif index	-	-0.77 (2.18)	-0.98 (3.30)	-1.29 (3.14)
r.s.d. (d.f.)	1.23 (184)	1.08 (192)	1.02 (176)	1.22 (174)
$\bar{R}^2$	30.9	27.1	39.3	19.7

TABLE 11

The effect of pick date and duration of storage on fruit firmness (kg). Tabulated values are means of up to 30 orchards in 1994/5 and 32 orchards in 1995/6.

		Pick			
Assessment time	Season	1	2	3	4
January, ex-store	1994	7.3	6.5	6.1	5.5
	1995	7.2	6.2	6.0	6.0
January, shelf life	1994	6.8	6.0	5.7	5.3
	1995	6.3	5.7	5.4	5.3
April, ex-store	1994	7.0	6.4	5.9	5.3
	1995	6.6	5.9	5.8	5.7
April, shelf life	1994	6.3	5.6	5.4	-
	1995	6.1	5.7	5.5	5.1

s.e.d. = 0.17 (916 d.f.)

TABLE 12

Regression models for post harvest firmness (kg) based on harvest firmness (kg) and diameter (mm). The Table shows regression coefficients with t-values in brackets, the residual standard deviation (r.s.d.) and its degrees of freedom, and the percentage variance accounted for ($\bar{R}^2$). See the Statistical Methods Section for more details.

Explanatory variable	January assessment		April assessment	
	Ex-store	Shelf-life	Ex-store	Shelf-life
Constant	4.85 (4.85)	6.61 (7.27)	6.90 (6.77)	6.88 (6.77)
Size	-0.027 (2.16)	-0.046 (3.98)	-0.049 (3.87)	-0.050 (3.98)
Firmness	0.36 (13.1)	0.24 (9.60)	0.26 (9.41)	0.22 (7.15)
r.s.d. (d.f.)	0.52 (225)	0.47 (226)	0.52 (222)	0.48 (198)
$\bar{R}^2$	62.3	55.0	54.9	48.3

TABLE 13

Regression models for post harvest firmness (kg) based on harvest firmness (kg) and diameter (mm), and on fruit P and K concentrations (mg $100g^{-1}$). The Table shows regression coefficients with t-values in brackets, the residual standard deviation (r.s.d.) and its degrees of freedom, and the percentage variance accounted for ($\bar{R}^2$). See the Statistical Methods Section for more details.

Explanatory	January assessment		April assessment	
variable	Ex-store	Shelf-life	Ex-store	Shelf-life
Constant	3.49 (3.38)	5.35 (5.80)	5.84 (5.54)	5.44 (5.39)
Size	-0.014 (1.11)	-0.030 (2.65)	-0.034 (2.63)	-0.030 (2.52)
Firmness	0.38 (14.0)	0.27 (10.9)	0.29 (10.5)	0.25 (8.62)
Fruit P	0.102 (3.81)	0.097 (4.03)	0.079 (2.92)	0.105 (4.21)
Fruit K	-0.0071 (3.47)	-0.0088 (4.82)	-0.0087 (4.24)	-0.0102 (5.4)
r.s.d. (d.f.)	0.50 (223)	0.45 (224)	0.50 (220)	0.44 (196)
$\bar{R}^2$	64.9	59.7	58.2	55.4

TABLE 14

Regression models for post harvest firmness (kg) based solely on harvest firmness (kg). The Table shows regression coefficients with t-values in brackets, the residual standard deviation (r.s.d.) and its degrees of freedom, and the percentage variance accounted for ($\bar{R}^2$). See the Statistical Methods Section for more details.

Explanatory variable	January assessment		April assessment	
	Ex-store	Shelf-life	Ex-store	Shelf-life
Constant	2.73 (14.2)	3.10 (17.1)	3.03 (15.2)	2.93 (13.3)
Firmness	0.40 (19.2)	0.31 (15.8)	0.34 (15.6)	0.30 (12.7)
r.s.d. (d.f.)	0.52 (226)	0.49 (227)	0.53 (223)	0.49 (199)
$\bar{R}^2$	61.7	52.1	52.1	44.4

TABLE 15

The effect of pick date and duration of storage on the percentage of fruit with rots. Tabulated values are means of up to 30 orchards in 1994/5 and 32 orchards in 1995/6.

		Pick			
Assessment time	Season	1	2	3	4
January, ex-store	1994	0	0.5	0.7	20.5
	1995	0	1.1	1.3	3.7
January, shelf life	1994	0.7	1.3	1.2	35.3
	1995	1.1	2.5	3.6	3.1
April, ex-store	1994	1.7	2.2	7.7	75.3
	1995	0.8	1.6	6.7	18.7
April, shelf life	1994	1.2	1.8	18.3	-
	1995	1.3	3.9	9.8	19.5

TABLE 16

The effect of pick date and duration of storage on fruit taste, texture and flavour. Tabulated values are means of up to 30 orchards in 1994/5 and 32 orchards in 1995/6.

		Pick			
Assessment time	Season	1	2	3	4
Taste (sugar/acid) (maximum 5)					
January, shelf life	1994	2.5	4.7	4.9	3.6
	1995	2.4	4.6	4.9	4.4
April, shelf life	1994	2.7	4.7	4.4	-
	1995	3.9	4.8	4.8	-
Texture (maximum 5)					
January, shelf life	1994	2.7	4.3	3.3	2.3
	1995	4.2	4.1	3.5	3.0
April, shelf life	1994	3.4	4.3	2.5	-
	1995	4.3	4.2	3.4	-
Cox flavour (maximum 10)					
April, ex-store	1994	2.3	5.4	6.4	6.3
	1995	2.3	4.7	5.6	4.0
April, shelf life	1994	1.9	4.6	5.9	-
	1995	3.7	5.8	6.2	-

Taste (sugar/acid), s.e.d. = 0.24 (413 d.f.)

Texture, s.e.d. = 0.24 (413 d.f.)

Cox flavour, s.e.d. = 0.26 (413 d.f.)

- fruit was not tasted due to high incidence of rots

TABLE 17

Regression models for Cox flavour score. The Table shows regression coefficients with t-values in brackets, the residual standard deviation (r.s.d.) and its degrees of freedom, and the percentage variance accounted for ($\bar{R}^2$). See the Statistical Methods Section for more details.

Explanatory variable	January assessment		April assessment	
	Ex-store	Shelf-life	Ex-store	Shelf-life
Constant	-	2.15 (1.13)	-	-2.66 (1.90)
Diameter	-	0.12 (4.62)	-	-
Acidity	-	-0.53 (6.97)	-	-0.30 (3.68)
Sugar	-	-	-	0.78 (10.9)
r.s.d. (d.f.)	-	1.53 (234)	-	1.30 (183)
$\bar{R}^2$	-	24.7	-	45.3

TABLE 18

The effect of pick date and duration of storage on the incidence of bitter pit and late storage corking. Data are the mean percentage of affected fruit from up to 30 orchards in 1994 and 32 orchards in 1995. Individual orchard percentages were based on samples of approximately 20 fruit.

		Pick			
Assessment time	Season	1	2	3	4
January, ex-store	1994	0.3	0.2	0.2	-
	1995	0	0	0.5	0.7
January, shelf life	1994	1.3	0.3	0	1.0
	1995	0.5	1.1	0.2	2.3
April, ex-store	1994	3.2	4.1	1.3	0.5
	1995	1.3	4.1	3.0	1.2
April, shelf life	1994	4.4	10.5	8.7	-
	1995	1.4	7.0	5.2	2.7

TABLE 19

The effect of pick date and duration of storage on the incidence of core flush. Data are the mean percentage of affected fruit from up to 30 orchards in 1994 and 32 orchards in 1995. Individual orchard percentages were based on samples of approximately 20 fruit.

		Pick			
Assessment time	Season	1	2	3	4
January, ex-store	1994	0	1.3	0.3	0
	1995	0	0	0	0
January, shelf life	1994	0.2	1.6	0.2	1.3
	1995	0	0.3	0	0.2
April, ex-store	1994	2.6	9.9	8.2	7.2
	1995	0	0	0.3	0.6
April, shelf life	1994	6.7	12.5	14.5	-
	1995	0.8	1.0	0.8	1.2

TABLE 20

The effect of pick date and duration of storage on the incidence of senescent breakdown. Data are the mean percentage of affected fruit from up to 30 orchards in 1994 and 32 orchards in 1995. Individual orchard percentages were based on samples of approximately 20 fruit.

		Pick			
Assessment time	Season	1	2	3	4
January, ex-store	1994	0	0.2	0	2.5
	1995	0	0	0	0.5
January, shelf life	1994	0	0.2	0.7	3.6
	1995	0	0	0.5	0.5
April, ex-store	1994	0.5	1.7	1.0	6.5
	1995	1.3	0.9	1.7	1.1
April, shelf life	1994	0.5	1.7	2.3	-
	1995	0.3	1.4	2.3	3.7

TABLE 21

Relationship between firmness immediately ex-store and firmness after shelf-life. Data for both years and all picking dates were combined to give 228 values from the January assessments and 201 values from the April assessments. The Table shows these values classified by their firmness immediately ex-store and after shelf-life.

	Firmness (kg) after shelf-life		
Ex-store firmness (kg)	< 5.7	5.7-6.0	> 6.0
January assessment			
< 6.5	101	19	9
≥ 6.5	6	11	82
April assessment			
< 6.5	89	22	16
≥ 6.5	4	16	54

TABLE 22

The percentage agreement between observed values of ex-store firmness and predictions from different models. Observed and predicted data were classified as being below or above 6.5 kg and the percentage of samples for which the classification agreed was calculated. The total number of samples was 228 for the January assessment and 201 for the April assessment.

		Observed	Predicted		
			Model 1	Model 2	Model 3
January ex-store					
Observed		100			
	Model 1	80	100		
Predicted	Model 2	80	95	100	
	Model 3	82	94	95	100
April ex-store					
Observed		100			
	Model 1	77	100		
Predicted	Model 2	79	96	100	
	Model 3	80	92	94	100

Model 1 - based on harvest firmness only (Table 14)

Model 2 - based on harvest firmness and diameter (Table 12)

Model 3 - based on harvest firmness and diameter and fruit P and K (Table 13)

TABLE 23

Distribution of optimum pick dates for 1994 and 1995 seasons. The optimum pick date is the last occasion on which harvest firmness is sufficiently great to predict that ex-store firmness will be at least 6.5 kg (upper part of Table) or 6.0 kg (lower part of Table). The table shows the number of orchards for which the optimum pick date was pick 1, 2, 3 or 4. For some orchards, and particularly to achieve a firmness of at least 6.5 kg after storage until April, fruit was too soft even at the first pick. The number of orchards for which this occurred is shown in the column headed 'Before pick 1'.

			Pick			
Store until	Season	Before pick 1	1	2	3	4
To achieve 6.5 kg ex-store						
January	1994	5	16	2	4	3
January	1995	1	17	8	2	4
April	1994	17	9	2	1	1
April	1995	8	17	4	2	1
To achieve 6.0 kg ex-store						
January	1994	0	0	7	19	4
January	1995	0	1	9	16	6
April	1994	1	13	4	8	4
April	1995	0	10	14	4	4

TABLE 24

Classification of ex-store greenness (Hunter 'a' colour) of fruit picked at the predicted optimum harvest date to achieve ex-store firmness of 6.5 kg (upper half of Table) or 6.0 kg (lower half of Table) in either January or April. The Table shows the number of orchards for which the Hunter 'a' value was below or above 10. Some orchards are excluded because the optimum predicted pick date was before the first actual harvest.

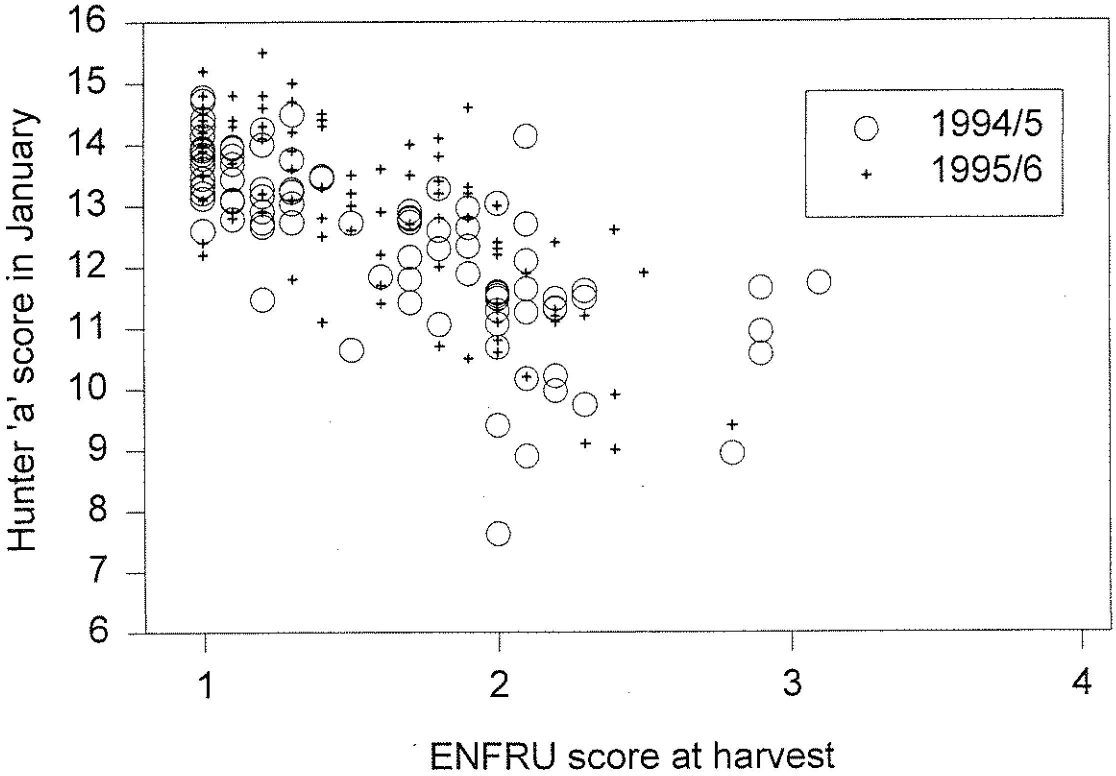
		Hunter 'a' colour	
Store until	Season	< 10	≥ 10
To achieve 6.5 kg ex-store			
January	1994	2	23
January	1995	0	31
April	1994	0	13
April	1995	1	23
To achieve 6.0 kg ex-store			
January	1994	6	24
January	1995	0	32
April	1994	5	24
April	1995	1	31

TABLE 25

Overall fruit quality score (maximum 30) of fruit picked at the predicted optimum harvest date to achieve ex-store firmness of 6.5 kg (upper half of Table) or 6.0 kg (lower half of Table) in either January or April. Some orchards are excluded because the optimum predicted pick date was before the first actual harvest.

Store until	Season	Number of orchards	Overall quality score Mean (s.e.)
To achieve 6.5 kg ex-store			
January	1994	25	15.8 (1.09)
January	1995	31	19.3 (0.78)
April	1994	13	16.9 (1.37)
April	1995	24	21.4 (0.74)
To achieve 6.0 kg ex-store			
January	1994	30	22.4 (0.52)
January	1995	32	22.1 (0.62)
April	1994	29	17.2 (0.74)
April	1995	32	22.6 (0.57)

Figure 1. Ex-store versus harvest greenness



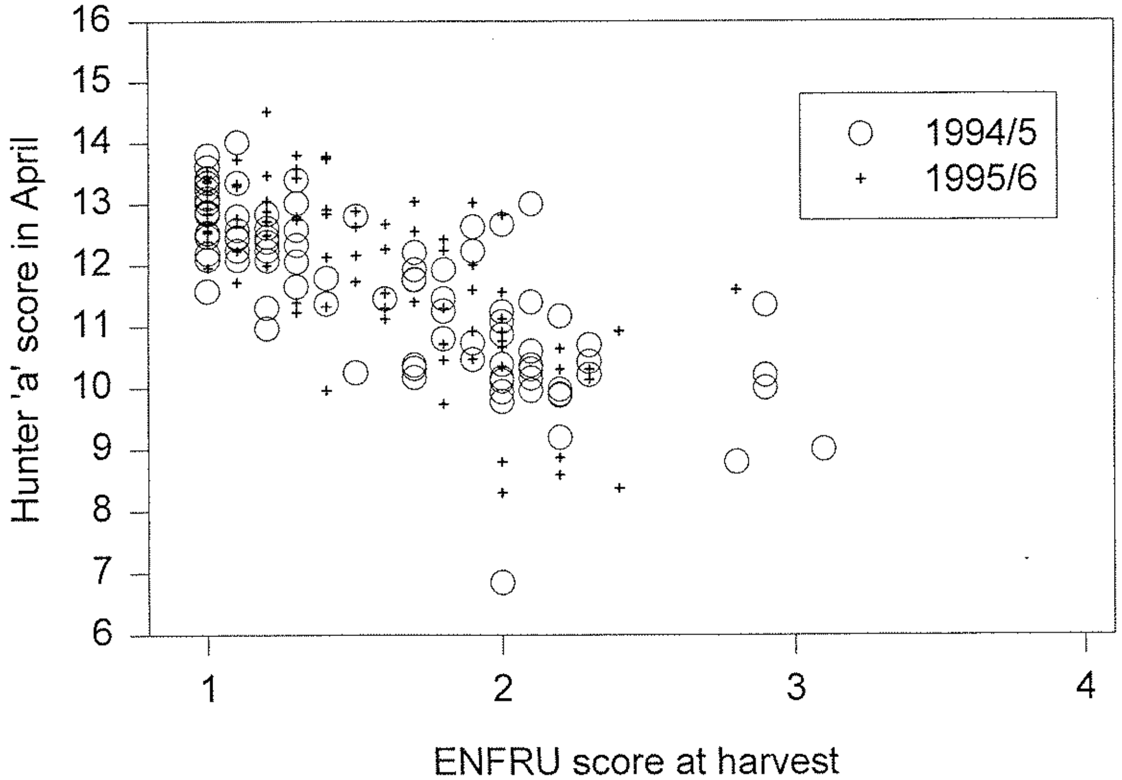


Figure 2. Ex-store versus harvest firmness