FoodInfo Confidential Report No. 137

# Development of a non-destructive firmness tester for measurement of buttercup squash maturity

A report prepared for
**NZ Vegetable & Potato Grower's Federation Inc.**

W Harvey, A Lush & C Stuart
July 1995



*New Zealand Institute for Crop & Food Research Limited*
*Private Bag 4704, Christchurch, New Zealand*

CROP & FOOD RESEARCH
Mana Kai Rangahau

FoodInfo Confident Report No. 137
**Development of a non-destructive firmness tester for measurement of buttercup squash maturity**
W Harvey, et al.

# CONTENTS

# 1 EXECUTIVE SUMMARY


Industrial Research Ltd has developed KIWIFIRM, a new instrument for measuring kiwifruit maturity. This report describes research initiated by Crop & Food Research to assess the effectiveness of modifications to this instrument to measure the maturity of buttercup squash (*Cucurbita maxima* cv. Delica). KIWIFIRM is portable, operator independent and non-destructive of the fruit. This research shows that it can replace the Effegi penetrometer for harvesting decisions, since it can predict results from that device very precisely ($R^2 = 0.97$). KIWIFIRM is at the prototype stage of development and patents are applied for. It is intended that KIWIFIRM will be available as soon as contracts with a suitable manufacturer can be signed.

KIWIFIRM may well have applications to other fruit and vegetables (e.g., onions, cucumber) in the New Zealand economy. It also has value as a tool in research applications.

Further research is required to develop a non-destructive means for discriminating between buttercup squash fruit maturity on a moving grading line. KIWIFIRM is not robust enough in its present form for use in an on-line grading process.

# 2 INTRODUCTION

Buttercup squash (*Cucurbita maxima*) has become a major export to Japan from New Zealand over the past 5 years. In the 1994 season exports exceeded 80,000 tonnes with an FOB value of $70 million. A major goal for the industry has been to improve the consistency of the quality of the fruit arriving in Japan. Early season squash often receive premium prices on the Japanese market by filling a niche in January, when competing countries can supply only low volumes. While early harvested fruit are less likely to rot they may also be insufficiently mature and thus be of a lower quality when sold. Early season low quality fruit may depress prices for subsequent shipments. Over-mature fruit tends to be more prone to rot-inducing organisms.

A major hurdle for the industry has been finding a reliable, objective measure of fruit maturity. The Effegi fruit penetrometer with a specially produced 4 mm probe has been used. Unfortunately this tool tends to be operator specific, giving different readings depending on the strength and experience of the operator. It is also unsatisfactory because it makes holes in the fruit, rendering the fruit unsaleable once measured.

Over the past 5 years, Crop & Food Research has conducted research into the sensory quality of buttercup squash, particularly those aspects of quality influenced by the maturity of the fruit at harvest and the effect of this on the sensory and keeping quality of fruit arriving in Japan.

Squash fruit continue to ripen off the vine, but if picked too early this ripening does not progress sufficiently to develop acceptable sweetness and texture. The need for a non-destructive method of assessing maturity became apparent. We therefore approached Industrial Research Ltd (IRL) to determine whether a device called KIWIFIRM (developed for assessment of the firmness of kiwifruit by Andrew Lush and George Dawson of the Packaging Storage and Transport group of IRL, Auckland) would be suitable for measuring the maturity of buttercup squash.

This instrument is a small, hand-held, highly portable, non-destructive, prototype firmness tester which operates by applying a mechanical impulse to the fruit surface through a small non-penetrating tip. An in-built micro-processor converts characteristics of the resulting collision of the tip with the fruit surface into a value which is displayed on the body of the device. As with the Effegi penetrometer, KIWIFIRM values decrease as fruit soften. The output values displayed have a range 0.0 to 9.9, but intentionally at this stage do not equate with penetrometer values. The instrument is operator non-specific and can be used to assess growing fruit. Research funded from internal Crop & Food Research funding in the 93/94 season suggested that the output of the instrument has good correlation with penetrometer readings up to the 7.5-8.0 kg range, with decreasing resolution above this figure. We believed that to improve discrimination for squash firmer than 7.5 kg, the kinetic energy of the collision needed to be increased.

The research reported here was intended firstly to extend the range of the KIWIFIRM by increasing the kinetic energy of the ballistic collision. Key mechanical elements of the sensor structure would be modified resulting in greater resolution. Some software changes would also be made. Secondly, a crop of buttercup squash cv. Delica would be grown, fruit tagged at flowering, harvested at a range of maturities and the maturity of each fruit measured using days after flowering and penetrometer score as well as the modified KIWIFIRM to verify the success of the modifications.

The original brief for this project was to modify the KIWIFIRM so as to increase the ballistic collision and then to test this modified version on fruit of varying maturity. Because FRST funding had already been obtained to trial the original KIWIFIRM version for its effectiveness in predicting maturity of fruit, a broader approach to the problem could be taken. Not only was KIWIFIRM compared with measurements of time after flowering and Effegi penetrometer score (using the 4 mm NZBSC tip) but measurements of flesh colour, total solids, and Brix scores were made for fruit of a range of penetrometer scores so that these characteristics could also be compared with the KIWIFIRM results.

Three versions of the KIWIFIRM were able to be tested under this wider project. All results are presented here to give the complete picture even though these were not included in the proposal as funded by VegFed.

# 3 APPROACH

## 3.1 Modifications to KIWIFIRM

The version of KIWIFIRM (labelled KF#2-1.0/LIN) originally evaluated in preliminary squash trials in the 1993/94 season by Winna Harvey (Crop & Food) and Andrew Lush (IRL) has since been considerably modified and improved. The formerly custom engineered sensor element has been replaced by a proprietary sourced low-cost accelerometer that offers a much higher signal to noise ratio. Most of the mechanical components have had to be re-engineered to suit, as have the electronic hardware and software. As a result this newer version performs better than the earlier version of KIWIFIRM.

As well as these changes further modifications have increased the ballistic collision by approximately 25%. The arm mechanism of one KIWIFIRM was extensively re-engineered in order to increase its moment of inertia. This work entailed completely re-working the counter-balance masses that are the integral components of the arm assembly. The tip is attached to the arm, and it is necessary that this assembly is statically balanced in all planes to allow KIWIFIRM itself to make accurate measurements in any orientation in space. The collision energy was increased by approximately 25% which proved to be the maximum possible without completely redesigning the arm itself, and without using precious metals for construction (both possibilities well beyond the funding of this project). As it was, to achieve this gain it proved necessary to substitute the denser metal, tungsten (Density 18.84 x $10^3$ kg $m^{-3}$) for the lead (Density 11.34 x $10^3$ kg $m^{-3}$) that was originally used for the counterbalance masses. Tungsten is very hard and consequently very difficult to machine.

The performance of this modified probe (labelled KF#3-1.0/H/V7 LIN Acc) was then compared with the improved original version (labelled KF#2-1.0/V7 LIN Acc). The ability of the #3H version to discriminate was unexpectedly slightly diminished. We determined that this problem was due to an incorrect actuation spring being fitted to KF#3H which resulted in lower than expected impact velocity. This spring was replaced (on 1.3.95) by one which was more appropriate and this set-up (labelled KF#3-1.0/HSS/V7 LIN ACC) was then used in the remaining trials.

The results presented here are for two versions of the KIWIFIRM, KF#2 and KF#3HSS.

## 3.2 Production of fruit for testing

A crop of buttercup squash cv. Delica (sown 19/11/94) was grown at Crop & Food Research's Pukekohe Research station. Female flowers were tagged with the date of fruit set over the period from 10-18 January. Fruit developing from these flowers were harvested 26, 33, 37, 43 and 50 days after fruit set (days after flowering).

Ten fruit at each harvest were assessed non-destructively by each of three KIWIFIRM probes on the day of harvest. Ten marked sites around the equator of each fruit were measured and then re-measured using a drill press mounted penetrometer at 5 of these sites. This enabled 1:1 (i.e. spot) correlations to be obtained between the output of each of the KIWIFIRM probes and the penetrometer.

The season advanced very rapidly this year with fruit ripening faster than usual. To ensure that fruit with penetrometer scores at the lower end of the range were included in this trial, extra fruit were harvested of unknown flowering date and the results from these fruit added to the tagged fruit.

All fruit were then assessed destructively to give further information as to their individual maturity. The colour of the flesh was measured using a Hunterlab reflectance spectrophotometer. The soluble solids in the expressed juices were measured using a digital refractometer. The dry matter of the flesh was also measured.

# 4 RESULTS

## 4.1 KIWIFIRM as a predictor of penetrometer score

Figures 1 (KF#2) and 2 (KF#3HSS) show the mean penetrometer scores for each fruit compared with the mean KIWIFIRM scores. Only graphs for KF#2 and KF#3HSS are given as results for KF#3H before the spring was modified were not as discriminating.

The relationship between the penetrometer score and the KIWIFIRM score was as follows for each of the two modifications:

Penetrometer score(kg) = $4.6 \times 10^{-2}$ (KF#2 score)$^{2.43}$

Penetrometer score(kg) = $5.9 \times 10^{-2}$ (KF#3HSS score)$^{2.35}$

Both probes gave excellent prediction of penetrometer score with $R^2$ values of 0.96 (KF#2) and 0.97 (KF#3HSS).

## 4.2 Penetrometer as a predictor of maturity

Figures 3, 4 and 5 show how soluble and total solids and flesh colour changed with penetrometer score.

Penetrometer score increased as soluble solids increased. This increase in soluble solids is very dependent on site and season. In this warm season soluble solids were higher at lower penetrometer scores than in previous seasons. At more southern sites, soluble solids were lower at the same penetrometer score (Harvey et al, 1995). Because of the variation with site and season, soluble solids are not a dependable absolute measure of maturity for harvest decisions.

Penetrometer score increased as total solids increased. As the fruit reaches its optimum harvest point, solids reach a peak and then level out and begin to decrease as the fruit begins to use up its starch reserves. Penetrometer score does not drop off in the same way. Total solids alone are therefore not a reliable indication of maturity. Total solids also vary considerably with site and season. If a measure is sought for use in harvest decisions, and the fruit is hardening off as it reaches its peak solids content, the later reduction in solids does not influence the usefulness of the penetrometer at this earlier stage.

Penetrometer score also increased as flesh colour increased. Flesh colour and sweetness are of major importance to buyers of the fruit. Flesh colour changes both on and off the vine and much of the development of the desirable colour occurs after harvest. Thus, flesh colour at harvest is very different from flesh colour after shipment. While flesh colour gives a good indication of the maturity of the crop, an understanding of the changes of the fruit post-harvest is required before a rejection of fruit by flesh colour can be made. This characteristic also varies considerably with site and season.

Penetrometer score was strongly correlated with soluble solids($R^2 = 0.8$), total solids ($R^2 = 0.69$) and the a* component of flesh colour ($R^2 = 0.84$). This relationship remains highly correlated but changes with site (a more southern site will give a paler flesh colour and a higher total solids at the same penetrometer score) and season (a warm season will produce higher soluble solids at the same penetrometer score). The setting of an appropriate harvest standard for soluble solids or flesh colour is difficult because of this variation and because of the large changes which occur in both of these characteristics during post harvest storage and shipment.

Figures 3, 4 and 5 show that the fruit assessed was of a good range of maturities as indicated by the variation in penetrometer score and the range of sweetness (as indicated by the soluble solids measurements), total solids and flesh colour.

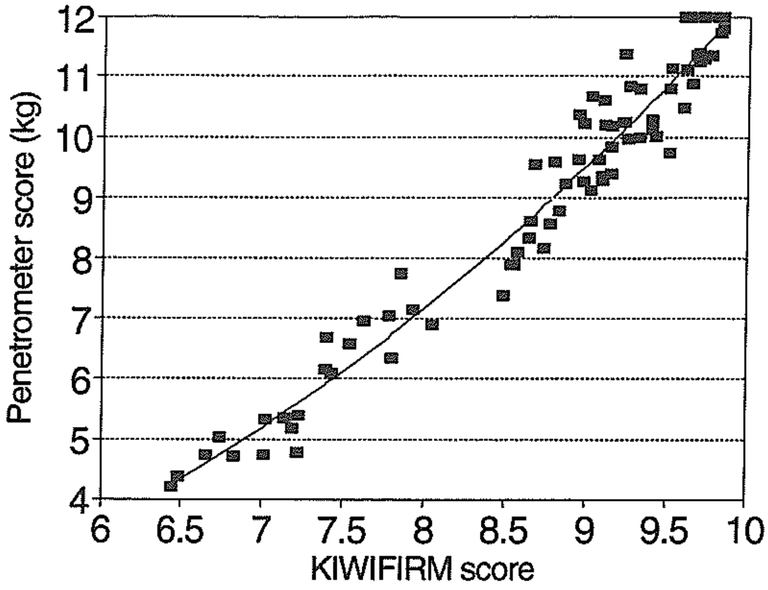


**Figure 1** Relationship between KIWIFIRM pressure tester (version KF#2) and Effegi penetrometer score. Dots are data points and the solid line is the fitted relationship described in the text.

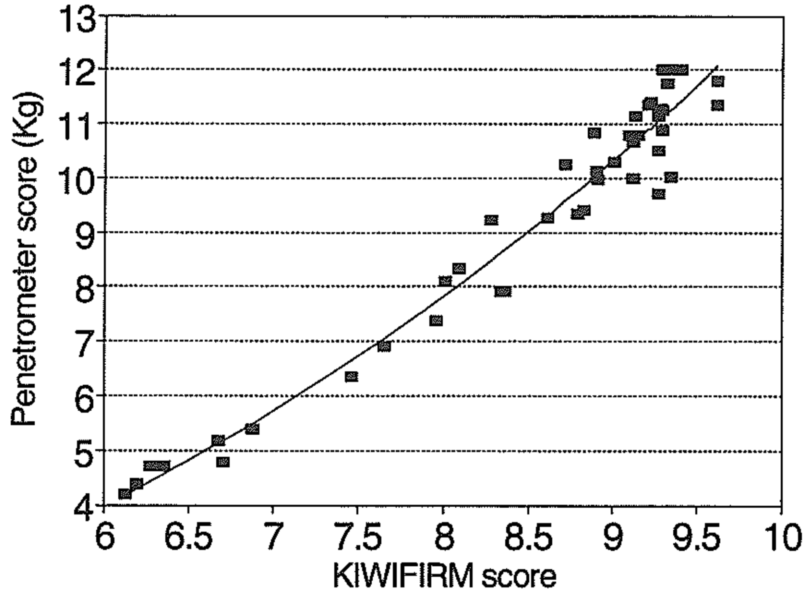


**Figure 2** Relationship between KIWIFIRM pressure tester(KF#3HSS) and Effegi penetrometer score

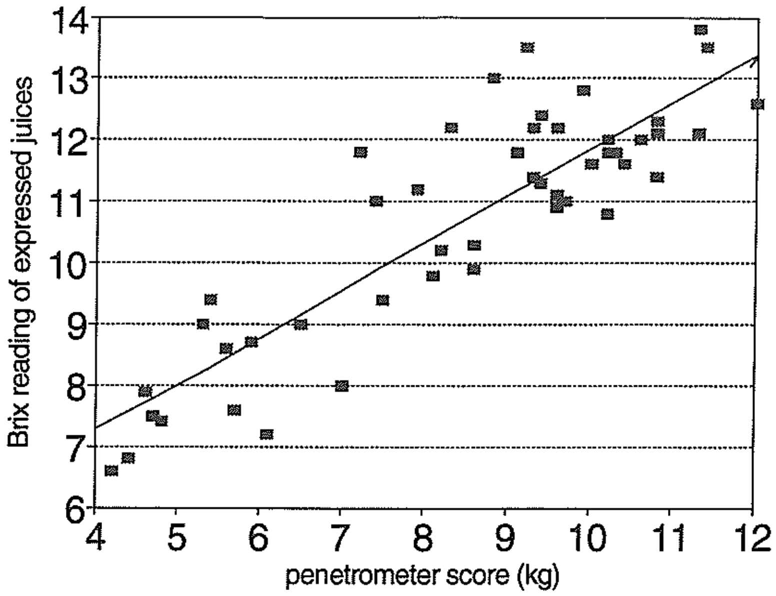


**Figure 3** Relationship between penetrometer score and Brix reading of expressed juices

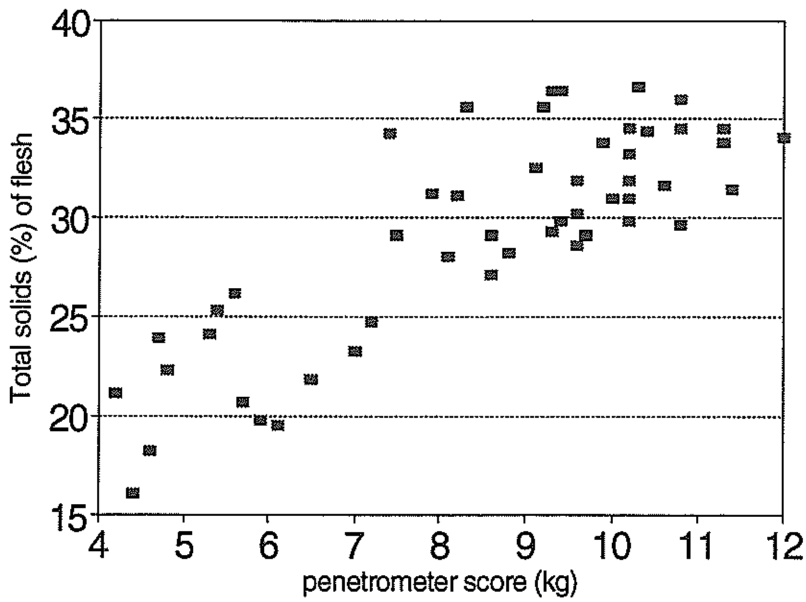


**Figure 4** Relationship between penetrometer score and total solids

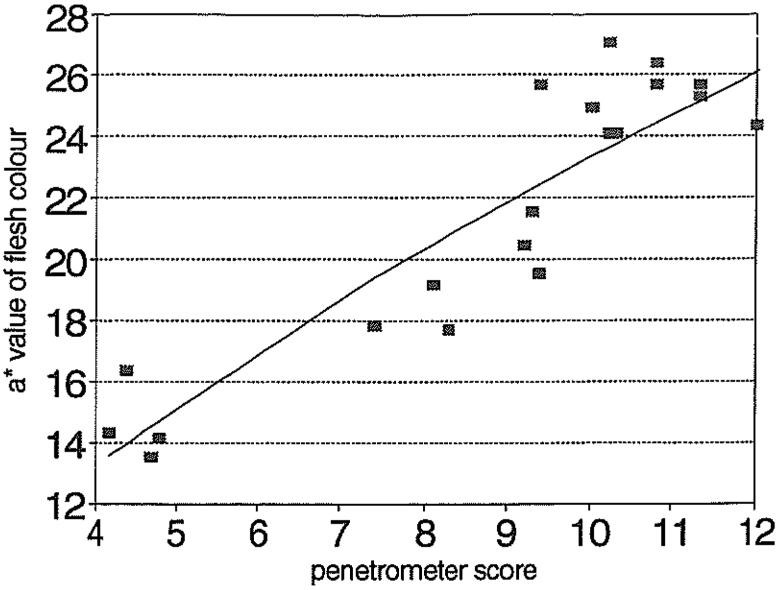


**Figure 5** Relationship between penetrometer score and flesh colour(a*)

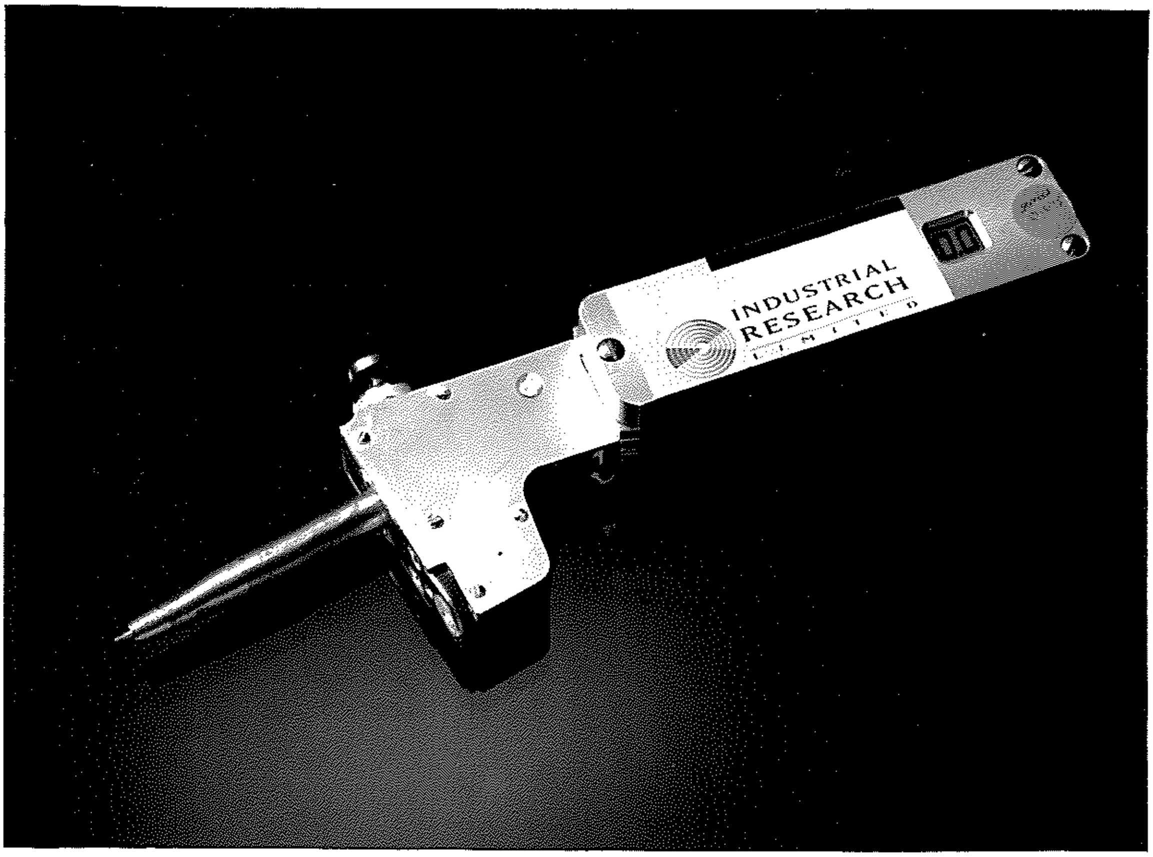


**Figure 6** KIWIFIRM pressure tester

# 5 CONCLUSIONS AND RECOMMENDATIONS

A major need of the buttercup squash industry is an understanding of maturity and ripeness and the need for a reliable means of measuring maturity.

From previous research (Beever, Hawthorne & Wishart, 1991; Harvey et al, 1995) we believe penetrometer score to be the most reliable method of determining fruit maturity for harvest decisions. As the KIWIFIRM has such a strong correlation with penetrometer score we recommend its use in harvest decisions in place of the penetrometer. KIWIFIRM'S major advantages are its non-destructive mode of action which means that more fruit can be measured without damage, and its operator independent operation, which ensures compatibility of measurements between sites, seasons and crops.

We believe this tool would provide a reliable means of measuring fruit maturity at harvest.

KIWIFIRM is also a valuable research tool, allowing fruit of exact maturity to be harvested for experimental purposes. This allows for improved cultivar selection where fruit of equivalent maturity are compared. As further research into the physiological development of buttercup squash in the field is an urgent requirement of the industry, this tool could be a valuable asset in determining the progress of maturation of fruit on the vine in relation to site, season and plant characteristics.

# 6 REFERENCES

Harvey, W.J.; Grant, D.G.; Burgmans, J.; Lammerink, J.P.; Hannan, P. Squash maturity: sensory and physical changes in fruit before and after harvest. *New Zealand Journal of Crop & Horticultural Science (in preparation)*

Beever, D.J.; Hawthorne, B.T.; Wishart, G. 1991. The penetrometer as a guide to crop maturity. *Report to the New Zealand Buttercup Squash Council - 1990-91 Research and Development Programme.*