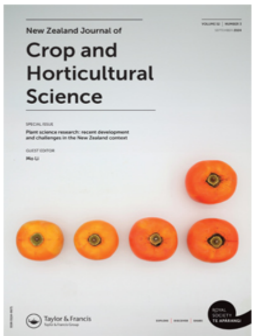

New Zealand Journal of Crop and Horticultural Science

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tnzc20

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To cite this article: Josephine M. Longuet-Higgins, Sebastian A. Rivera, Allan B. Woolf & Mo Li (2024) Exploration of fruit parameters for non-destructive identification of calyx cavity in ‘Fuyu’ persimmon (*Diospyros kaki* L.), New Zealand Journal of Crop and Horticultural Science, 52:3, 210-225, DOI: 10.1080/01140671.2024.2348134

To link to this article: https://doi.org/10.1080/01140671.2024.2348134

NEW ZEALAND JOURNAL OF CROP AND HORTICULTURAL SCIENCE
2024, VOL. 52, NO. 3, 210–225
https://doi.org/10.1080/01140671.2024.2348134

RESEARCH ARTICLE

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Exploration of fruit parameters for non-destructive identification of calyx cavity in 'Fuyu' persimmon (*Diospyros kaki* L.)

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ABSTRACT
Calyx cavity is a common physiological disorder in many persimmon cultivars. It is characterised by a separation between the calyx and the surrounding flesh. The presence of calyx cavity in export fruit can lead to phytosanitary risks and reduced storage potential due to more rapid softening and increased chilling injury. Manual detection of calyx cavity at packing is very time-consuming and uneconomic. This work investigated the ability of non-destructive evaluation, combined with modelling, to identify calyx cavity in 'Fuyu' persimmons. Fruit were evaluated at harvest, followed by a period of nine-week storage in modified atmosphere packaging at 0°C. The presence and severity of calyx cavity was related with higher red colouration and fresh weight before storage. Using colour index data and weight data, binary classification of calyx cavity by linear discriminant analysis (LDA) resulted 74.1% correct segregation. The model correctly identified 70.5% of calyx cavity fruit (29.5% false negatives) and 77.4% of no cavity fruit (22.6% false positives). The use of non-destructive calyx cavity classification based on the evaluation of quality parameters is a starting point in providing the ability to segregate healthy fruit before packaging and storage. Further work is necessary to improve model performance before implementation is viable.

ARTICLE HISTORY
Received 18 December 2023
Accepted 9 April 2024

HANDLING EDITOR
John Golding

KEYWORDS
Postharvest; persimmon; calyx cavity; disorder; modelling; quality

Introduction

Persimmon is a popular subtropical fruit known globally for its sweet flavour and potential health benefits (Giordani et al. 2011). However, persimmon fruit is also prone to developing a range of disorders which can cause fruit to be undesirable for consumption. Calyx cavity is a common physiological disorder seen in persimmon fruit. It is classified as a distortion disorder and is considered of major importance in persimmon production (George et al. 2005). The disorder results in a space, or cavity, developing around or

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/01140671.2024.2348134.

beneath the calyx of the fruit. In severe cases, this gap may encircle the entire calyx (Woolf and Ben-Arie 2011).

During fruit development, persimmon exhibits a double sigmoidal growth pattern consisting of two phases where the growth rate is rapid (stages I and III) with a period where the growth rate is slow in between (stage II) (Woolf and Ben-Arie 2011). Growth stage I corresponds to cell division and differentiation, and growth stage III is associated with cell expansion and maturation (George et al. 1997). The formation of calyx cavity occurs during phase III of fruit growth (Woolf and Ben-Arie 2011). During phase III, fruit size increases rapidly; the fruit tissue expands faster than the calyx which can result in the fruit flesh separating from the calyx tissue to form a cavity (Bellini and Giordani 2002). As fruit mature, size increases and therefore the potential to develop calyx cavity also increases. George et al. (1994) reported a moderate correlation between calyx cavity severity and fruit weight.

Calyx cavity has been linked to cultivar susceptibility as the development of the disorder varies between cultivars. The problem is more frequently seen in 'Fuyu' but occurs less in other cultivars such as 'Triumph', 'Jiro', and 'Suruga' (Woolf and Ben-Arie 2011). However, other preharvest factors also contribute to the formation of calyx cavity including the age of fruiting trees, poor early calyx growth, and the timing and quantity of rainfall in relation to the fruit growth pattern (Bignell et al., 2017; Woolf and Ben-Arie 2011; Yamada et al. 2002). The incidence of calyx cavity can be minimised through prevention strategies including crop load management, and correct nutrition and irrigation practices (Bignell et al., 2017).

The presence of calyx cavity disorder creates a variety of challenges for the persimmon industry. The calyx cavity acts as a refuge for unwanted 'hitchhiker' pests which may present a phytosanitary risk to importing countries (Lay-Yee et al. 1997). It also provides a desirable environment for fungal pathogens to develop in the cavity leading to fruit spoilage (Bignell et al., 2017). The presence of calyx cavity can promote rapid softening of fruit before storage and a greater incidence of chilling injury during cold storage (Woolf and Ben-Arie 2011). Thus, market restrictions are commonly enforced for fruit with calyx cavity. The tolerance of calyx cavity varies between markets with domestic markets often allowing calyx cavity compared to export markets which reject fruit with the disorder altogether. These consequences ultimately lead to significant quantities of unmarketable fruit, resulting in losses to the industry (Bignell et al., 2017).

The New Zealand persimmon supply chain requires fruit to be stored for extended periods (up to 9 weeks at 0°C) during transport to export countries by sea freight (New Zealand Horticulture Export Authority 2022). Fruit is generally packaged in sealed modified atmosphere packaging (MAP) in trays containing approx. 4 kg of fruit (Bignell et al., 2017). The commercial recommendations are to remove fruit with calyx cavity during packing (Bellini and Giordani 2002). While instances of severe cavity may be easily identified visually, detection of moderate and mild cases of calyx cavity can be difficult as the view of potential cavities is obstructed by the leafy calyx lobes. In fruit destined for high-value markets, like Japan, packhouses may employ the strategy of air-blasting beneath the calyx lobes to remove any hidden pests (Woolf and Ben-Arie 2011).

In terms of calyx cavity evaluation, previous studies categorised the severity of calyx cavity by the degree of separation between the calyx and the surrounding flesh using an arbitrary visual observation scale. Yamada et al. (1987) rated the degree of separation on a scale from 0 to 10, while George et al. (1994), calculated the volume of the cavity to assess severity. In addition, Akagi et al. (2020) categorised the disorder into five scores (levels 0–4) based on visual observation of dissected fruit. This study also reported that fruit with severe calyx cavity may exhibit increased external colouration in the flesh adjacent to the cavity.

The important quality attributes of persimmon include size, colouration, firmness, and soluble solids content (SSC) (George et al. 2005). Market quality 'Fuyu' persimmon should be between 230 and 250 g weight in grams with a minimum weight of 150 g (Bignell et al., 2017). Flesh texture should be slightly firm and the flavour sweet (SSC of ~14%). The fruit is also required to have a bright orange peel; colour rating 5 or above on the Japanese industry colour chart (see Figure A in supplementary material). For 'Fuyu' fruit, this corresponds to a colour index between 10 and 40; below ~10 corresponds to an immature (or poor colour persimmon) and a colour index value above ~40 for an overmature persimmon (Tessmer et al. 2016). Changes in these fruit quality attributes have been linked to disorders in persimmon. Calyx cavity is associated with larger fruit size and darker colouration, as mentioned previously (George et al. 2005; Akagi et al. 2020). Other significant persimmon disorders such as chilling injury are also associated with quality attribute changes including the development of gelatinous flesh consistency, large reductions in fruit firmness and evolution of a deep red colouration (Woolf and Ben-Arie 2011).

Published literature on the relationships between fruit quality attributes and the presence of calyx cavity is limited. Therefore, this research sought to investigate the relationships between quality attributes and calyx separation using non-destructive methods of evaluation and to assess the potential for this data to be used to classify and segregate fruit with calyx cavity. With these investigations, it may be possible to develop a rapid, non-destructive method of classification that would allow the segregation of affected fruit from export-quality fruit and minimise the chance of pests and rotten fruit in export consignments.

Materials & methodology

Plant materials and storage

Persimmon fruit (*Diospyros kaki*, cv. Fuyu) were sourced from commercial orchards located in Gisborne and transported overnight at ~1°C to Massey University Postharvest Laboratory in Palmerston North. Fruit were harvested from different orchards and harvest times to provide variation within the fruit sampling population. A sample of ~120 fruit was selected from each of seven harvest times (batches) over a 1-month period, resulting in a total of 839 fruit. Individual fruit were assessed using non-destructive and destructive methods of evaluation. At harvest, all sampled fruit ($n = 839$) were evaluated using non-destructive methods and half of the fruit from each sample ($n = 395$) were then evaluated using destructive assessments. The remaining fruit ($n = 444$) were stored in New Zealand industry-standard 60 µm polyethylene MAP at 0°C for 9 weeks to mimic the long-term storage required during transport. Following the completion of storage, fruit were assessed again using the non-destructive and destructive methods as described below. A diagram of the experimental flow can be found in Figure B in the supplementary material.

Non-destructive methods of evaluation

Non-destructive quality assessment methods included weight, colour, acoustic firmness, and non-destructive compression. Fruit weight was measured by a digital balance (PR50003DR, Mettler Toledo, USA).

The skin colour was evaluated using a spectrophotometer (CM-2000d, Konica Minolta Sensing, Osaka, Japan) in four locations, including two measurements on the shoulders (one for each shoulder) and two measurements around the equator separated by 90°. Colour is expressed as a colour index, where L* represents lightness (range 0–100); a* represents the colours red to green (range +60 to – 60); and b* represents the colours yellow to blue (range +60 to – 60) (Carreño et al. 1995).

$$\textit{Colour index} = \frac{1000\ a*}{L*b*} \tag{1}$$

Non-destructive fruit firmness was evaluated as firmness index (FI in $Hz^2g^{2/3}$) using AWETA acoustic firmness sensor (AFS, Aweta™ Impact & Acoustic Firmness System, Nootdorp, The Netherlands). Each fruit was measured twice at the equator, and the average of these readings was recorded. Non-destructive fruit firmness was also measured by compression using a texture analyser (TA-XT2, Stable Micro Systems, UK) equipped with a 5 kg cell and fitted with a 60 mm diameter compression plate probe. For each fruit, a single compression to a target force of 4 N at a loading speed of 1 mms^{-1} was completed, following methods adapted from (Schotsmans and Mawson 2004). Results were expressed as deformation strain (% of equatorial diameter) to 4 N force.

Destructive methods of evaluation

Destructive quality assessment methods included calyx cavity evaluation, SSC, and flesh firmness measurements.

To destructively assess the presence and severity of calyx cavity, the calyx lobes of each fruit were removed to expose the area between the calyx and fruit tissue where separation occurs. The degree of separation was visually observed and then scored based on the size and depth of the cavity (Figure 1). Each fruit was assigned a scale value of 1 (no calyx cavity present), 2 (minor separation), 3 (moderate separation), or 4 (severe separation). This arbitrary scale was created based on previous work by Akagi et al. (2020). Calyx cavity was also expressed as a binary (no cavity = score 1; cavity = score 2, 3, and 4). In the following sections, at-harvest and after-storage calyx cavity data is combined into one data set. The calyx cavity severity assessment was completed only after storage in the stored fruit due to the destructive nature of the method. It is assumed that calyx cavity severity does not change during the storage period.

Flesh firmness (kg_f) was destructively measured using an electric penetrometer (Willowbank Electronics, New Zealand) equipped with a 7.9 mm probe, following the removal of 1 mm of fruit skin from opposite sides of the fruit equator. The SSC was

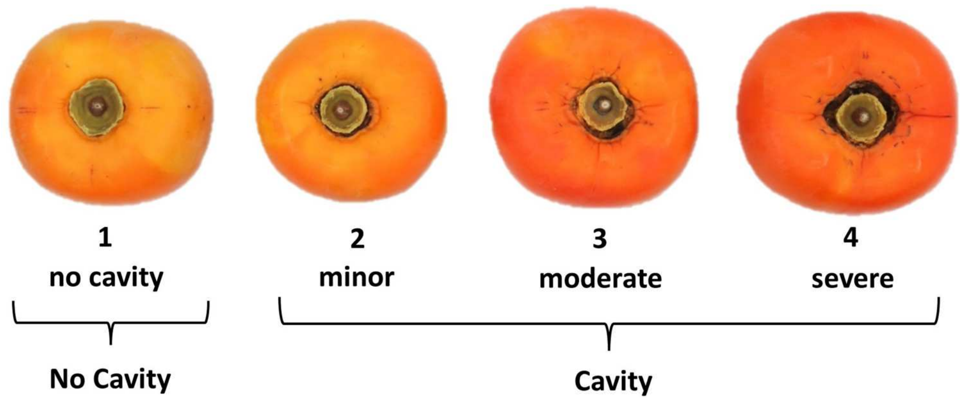

Figure 1. Diagram of the visual scale created to segregate different levels of calyx cavity in 'Fuyu' persimmon ranging from score 1 (no calyx cavity present) to score 4 (severe calyx cavity present). The scale is also expressed as a binary where score 1 = absence of calyx cavity ('No cavity'), and scores 2–4 = presence of calyx cavity ('Cavity'). (Calyx lobes have been removed).

measured by removing two cylindrical cores (from the outer pericarp at the shoulder and equator of fruit) of approximately 20 g of flesh, using a 12 mm diameter corer. The core was cut to approx. 2 cm in length and placed in a garlic press with a cloth layer as a filter (Suntudprom 2014). The extracted persimmon juice was measured as °Brix by a hand-held digital refractometer (Pocket PAL-1, Atago, Japan).

Statistical analysis

Significant differences in means between calyx cavity presence and severities were indicated by t-tests at *P*-value <0.05. Means of quality variables followed by a common letter are not significantly different by the HSD-test at the 5% level of significance. HSD = Tukey's honestly significant difference at 5% level of significance. A principal component analysis (PCA) biplot was generated to display the relationship between response variables (loading plot) and the presence of calyx cavity (score plot). PCA was performed using the correlation matrix (rescaled values) of the response variables of fresh weight, colour, non-destructive compression, acoustic firmness, flesh firmness, and SSC. Linear discriminant analysis (LDA) was carried out using the response variables of (at-harvest) weight and colour index as continuous predictors of either calyx cavity presence or severity. Statistical analysis and plotting of figures were conducted and figures were plotted in RStudio (R Foundation for Statistical Computing, Vienna, Austria) using R (version 4.2.1) and Minitab version 21.3.1 (Minitab Inc., Pennsylvania, USA).

Modelling

Linear discriminant analysis (LDA) was carried out to predict calyx cavity. This classification technique is commonly used to segregate objects into two or more classes by finding a linear combination of characterising features (Sharma and Paliwal 2015). Confusion matrices were created to visualise and summarise the performance of the classification models. In a confusion matrix (Table 1), the columns represent the true (observed)

Table 1. Confusion matrix visualisation displaying experimental observations compared to predicted outcomes.

		Observation	
		Absent	Present
Prediction	Absent	True Negative (TN)	False Negative (FN)
	Present	False Positive (FP)	True Positive (TP)

Note: The table summarises the performance of a classification model by comparing its predicted categories to the true categories observed in the sample dataset. It shows the number and/or percentage of true positives (TP), true negatives (TN), false positives (FP), and false negatives (FN) predicted by the model.

class, and the rows display the classes predicted by the model. Where the model classifier correctly predicts the outcome of a cavity when it is present, this is termed a true positive. Where the classifier accurately predicts the outcome of no cavity when it is absent, this is termed a true negative. On the other hand, when the model incorrectly estimates the outcome of no cavity when it is present (and vice versa), this is termed a false negative (or false positive) (Chicco and Jurman 2020).

Results & discussion

Fruit quality and harvest timing

Differences in fruit quality parameters were observed between fruit harvested at different timings during the season (Table 2). The general trend was increasing harvest times resulted in increasing fruit weight and decreasing flesh firmness. An exception was observed with the last harvest due to fruit being sourced from different orchards each time. The other variables (including acoustic firmness, compression, colour index, and soluble solids content) displayed no direct trend with increasing harvest time. However, many Harvests that exhibited a higher colour index had a corresponding lower flesh firmness and SSC.

Calyx cavity incidence & severity

The presence of calyx cavity refers to instances where fruit displayed any level of calyx cavity (scores 2–4); the absence of calyx cavity includes only score 1 (as illustrated by Figure 1). Out of a total of 839, 396 fruit (47%) had a calyx cavity compared to 443 (53%) of fruit without calyx cavity. Out of the total population, calyx disorder was most commonly score 2 (or minor severity) with an incidence of 28%. Meanwhile, incidence of moderate (score 3) and severe (score 4) calyx cavity, was less prevalent, between 13% and 6%, respectively (Table 3). Zooming into the affected population (i.e. 47% of the total), 58% of the affected fruit exhibited minor calyx cavity, 28% exhibited moderate calyx cavity, and 14% exhibited severe calyx cavity (Table 3). Overall, approximately half of all persimmon fruit sampled exhibited some degree of calyx cavity, while the other half of fruit was healthy. In fruit with calyx cavity, a minor form of the disorder was most common, with few severe cavities observed.

In the literature, there are large differences in reported rates of calyx cavity; an incidence of 75% was noted in New Zealand 'Fuyu' (Glucina 1987) compared to < 25% found in Japanese 'Fuyu' (Akagi et al. 2020). Yamada et al. (1988) observed an incidence

Table 2. Mean values and standard errors of quality variables by harvest timing of 'Fuyu' persimmon fruit.

Harvest	1	2	3	4	5	6	7
Weight (g)	$217.3^{d,e} \pm 3.5$	$235.8^{c,d} \pm 3.7$	$253.9^{b,c} \pm 4.0$	$262.3^{b} \pm 4.5$	$267.4^{b} \pm 3.6$	$298.5^{a} \pm 4.2$	$202.9^{e} \pm 3.1$
Acoustic firmness index	$9.5^{c} \pm 0.2$	$12.3^{a} \pm 0.2$	$12.3^{a} \pm 0.2$	$12.8^{a} \pm 0.3$	$10.1^{c} \pm 0.2$	$11.3^{b} \pm 0.2$	$10.5^{b,c} \pm 0.2$
Compression strain (%)	$0.29^{b} \pm 0.02$	$0.22^{c,d} \pm 0.006$	$0.23^{c} \pm 0.008$	$0.19^{d} \pm 0.006$	$0.34^{a} \pm 0.01$	$0.23^{c} \pm 0.01$	$0.28^{b} \pm 0.01$
Flesh firmness (kg_f)	$5.5^{c,d} \pm 0.2$	$6.9^{a} \pm 0.08$	$6.4^{a,b} \pm 0.09$	$6.0^{b,c} \pm 0.09$	$4.7^{e} \pm 0.15$	$5.2^{d,e} \pm 0.12$	$4.9^{e} \pm 0.13$
Colour index	$14.6^{c} \pm 0.3$	$11.7^{d} \pm 0.2$	$13.7^{c} \pm 0.2$	$14.0^{c} \pm 0.2$	$18.4^{a} \pm 0.2$	$17.4^{a} \pm 0.3$	$16.2^{b} \pm 0.3$
Soluble solids content	$14.6^{a} \pm 0.1$	$13.6^{b} \pm 0.1$	$12.2^{c} \pm 0.09$	$12.3^{c} \pm 0.08$	$14.7^{a} \pm 0.1$	$12.7^{c} \pm 0.09$	$12.3^{c} \pm 0.08$

Note: Means that do not share a letter are significantly different at <0.05 significance. n = 395

Table 3. The presence and severity of calyx cavity in sampled persimmon fruit based on visual assessment scores.

Calyx cavity	Severity	Count	Total severity incidence (%)[a]	Severity incidence in symptomatic fruit (%)[b]
no cavity	1	443	53	0
minor	2	232	28	58
moderate	3	110	13	28
severe	4	54	6	14
	Total	839		

[a]Total severity incidence refers to the percentage of fruit affected at each level of severity from the total sample population. [b]Severity incidence in symptomatic fruit refers to the percentage of fruit with each severity of calyx cavity as a fraction of the fruit that have calyx cavity disorder (excluding healthy fruit).

between 5.4% and 56.2% in fruit from a variety of different phenotype crosses. Differences in the occurrence of calyx cavity have been attributed to size, cultivar, poor early calyx growth, stress during fruit development, fruiting tree age, genetic inheritance, and environmental conditions including excessive soil fertility and accentuated rainfall (Bellini and Giordani 2002; Bignell et al., 2017; Woolf and Ben-Arie 2011).

Variation in the severity of calyx cavity was observed between fruit from different harvest timings (Figure 2). In most harvests, affected fruit was most commonly score 2 (minor separation), followed by score 3 (moderate separation), then score 4 (major separation). A considerable deviation from this trend can be seen in harvest 6 where 85% of fruit had some amount of separation around the calyx. In this harvest, more fruit were classified as score 3 than score 2, and there was a much higher number of severely affected fruit (score 4) compared to all the other harvests. The higher incidence of severe calyx cavity in Harvest 6 is likely related to the high average weight of fruit (298 g compared to 203–267 g, respectively).

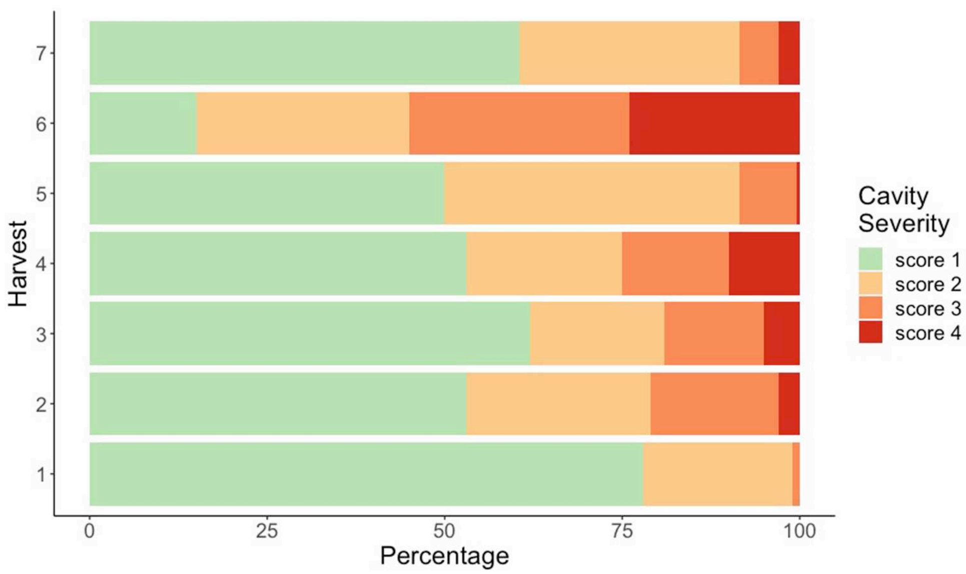

Figure 2. Stacked bars representing the percentage of each calyx cavity score across the different harvest batches after visual evaluation and scoring of the severity of calyx separation. Score 1 represents fruit without a calyx cavity, and scores 2, 3 and 4 represent fruit with cavities of increasing severity.

The general trend is an increase in calyx cavity severity with later harvest timing (apart from Harvest 7). Persimmon fresh weight increases steadily with fruit maturity, with slight increases observed in ‘Fuyu’ up until late maturity (Tessmer et al. 2016). It is likely that Harvest 1 fruit were less mature than Harvest 6, with fruit maturity, and therefore size, increasing over the harvest window (see Figure C in supplementary material). As calyx cavity is also linked to fruit size (George et al. 1994), the corresponding increase in calyx cavity incidence with harvest time is consistent. The abnormality observed in Harvest 7 may be explained by weight as these fruit had a lower average weight compared to the previous Harvests. The potential link between the incidence of calyx cavity and maturity implies that this disorder may also be associated with increased colour and softening. This could complicate the ability to attribute subsequent differences in quality characteristics to calyx cavity, rather than such difference being a result of variation in harvest maturity.

Relationships between quality attributes and calyx cavity

Principal component analysis

A PCA (principal component analysis) model was applied to the data to explore quality attributes that may be related to the presence of calyx cavity. In this analysis, calyx cavity is a binary variable where no cavity includes fruit scored as score 1 and cavity includes fruit scored as scores 2, 3 and 4. The first three principal components explained 78.2% of the overall variance (Table 4). The first principal component (PC1) accounted for 39.3% of the total variance. The variable that correlated most with PC1 was flesh firmness. Weaker correlations include non-destructive compression, colour, and acoustic firmness. Since both colour and firmness are good predictors of maturity in persimmon fruit (Tessmer et al. 2016), it is likely that this component is primarily a measure of the maturity of the fruit. The second principal component (PC2) explained 27.3% of the overall variance. PC2 is more closely associated with fruit weight and the presence of calyx separation, and both correlations are positive. Hence, PC2 is mainly a descriptor of fruit size. The third principal component (PC3) explains 11.6% of the overall variance. PC3 was positively associated with SSC, indicating that this component is largely a measure of fruit flesh SSC.

Table 4. Eigenvectors for each parameter for the first three principal components and the proportion of variance accounted for by each component.

Parameter	Eigenvector PC1	PC2	PC3
Weight (g)	0.058	0.635	−0.048
Calyx cavity	−0.103	0.571	−0.320
Compression strain (%)	−0.500	−0.192	0.015
Acoustic firmness index	0.391	0.309	0.330
Flesh firmness (kg_f)	0.533	0.005	0.208
Soluble solids content	−0.329	0.149	0.861
Colour index	−0.436	0.341	−0.046
		Proportion	
Proportion of variance	0.3933	0.2732	0.1158
Cumulative proportion	0.3933	0.6665	0.7823

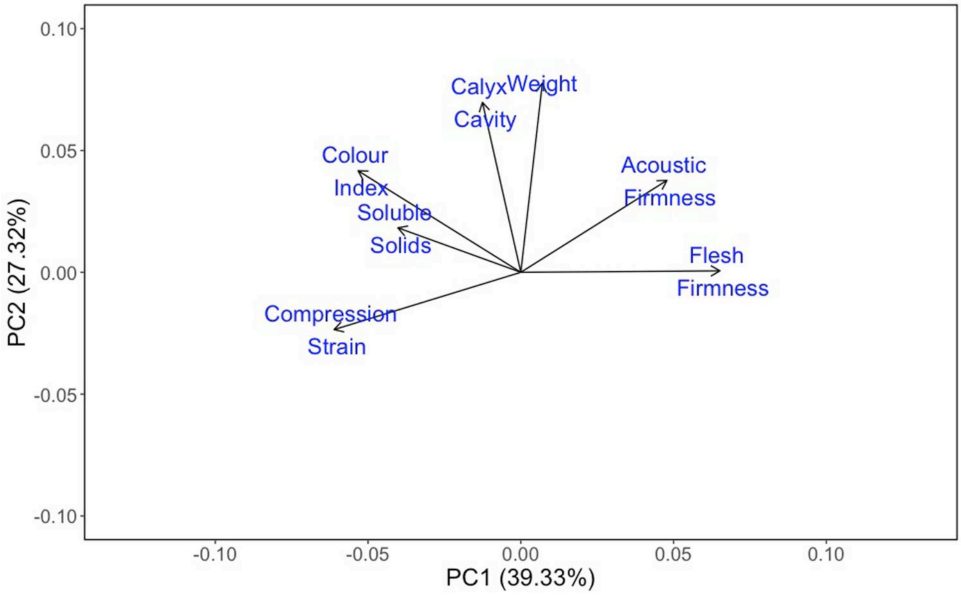

Figure 3. Loading plot of principal components 1 and 2, representing the relationship between seven postharvest response variables of 'Fuyu' persimmons. Data includes only after storage measurements.

Various relationships among quality attributes can be identified from the PCA loading plot in Figure 3. Based on the position of the loadings, the main variables that correlated with calyx separation are the weight and the colour index. The acute angle between the loadings of calyx cavity and weight, and calyx cavity and colour index suggest a positive relationship between the two variables and the presence of calyx cavity. This association indicates that heavier fruit and darker orange-red fruit more commonly had some degree of calyx separation.

From this exploratory analysis, an association between skin colour and weight and the presence of calyx cavity was identified. Hence, the parameters of colour and size were selected, and further analysis was conducted to determine the strength of the relationship.

Fresh weight and calyx cavity

The rate of calyx cavity was higher in larger fruit and lower in smaller fruit (Figure 4). The average weight of fruit without a calyx cavity was 218.0 g, significantly lower (*p*-value <0.05) than fruit with a cavity which weighed on average 280.6 g. The severity of the observed calyx separation also increased with fruit weight. Persimmons with higher weights often had a higher incidence of severe separation; medium-weight fruit tended to have moderate-sized cavities, and smaller fruit were mostly without a cavity (Figure 4). The average weight increased by approx. 40 g between each sequential score. This suggests that the larger fruit are more likely to have more severe calyx separation. This agrees with previous research that established a link between fruit size and the likelihood of calyx cavity development where larger fruit were more prone to developing the disorder than smaller fruit (Yamada et al. 1987).

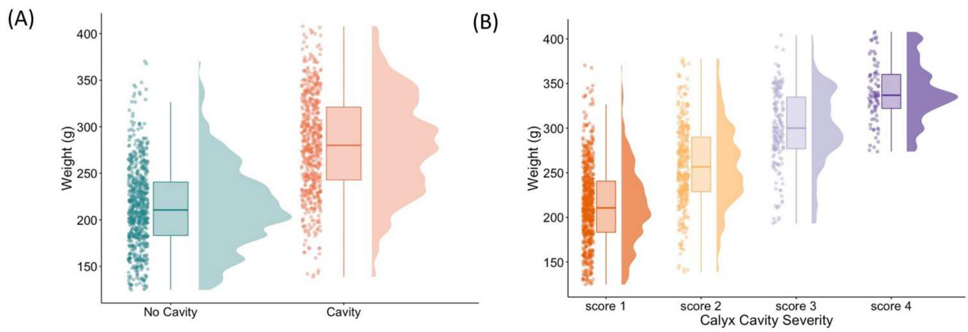

Figure 4. A, Distribution of individual fruit weights based on the presence or absence of calyx cavity 'No cavity' includes fruit scored as score 1; 'Cavity' includes fruit scored as scores 2, 3 and 4. **B**, Distribution of individual fruit weights based on the visual scale severity of the observed calyx cavity, where score 1 represents fruit without a cavity, and scores 2, 3 and 4 represent fruit with cavities of increasing size. The differences in mean weight between no cavity and cavity and each cavity score are statistically significant (p-value <0.001).

The development of calyx cavity occurs during the last phase of the double sigmoid growth curve (cell expansion) late in the season (Woolf and Ben-Arie 2011). The fruit flesh expands more rapidly than the calyx and separates from around the calyx and forms a cavity (Bignell et al., 2017). Potentially, larger fruit at harvest had more severe calyx separation due to greater expansion (as persimmon fruit size increases up until harvest), allowing the degree of separation to worsen (Bellini and Giordani 2002). Although, it has been noted that the magnitude of the disorder is highly environmentally influenced (Yamada et al. 1987).

The mean weight difference between each adjacent category of calyx cavity severity was significant. The distribution of weights was also large within all levels of calyx cavity; within each level of calyx cavity, there were fruit of a large range of different weights. These factors suggest that there was a general trend of larger fruit being more prone to calyx cavity, but weight alone is likely not an accurate indicator of calyx cavity susceptibility. Weight requires coupling with complementary maturity indicators or exploration under different growing conditions (and other pre-harvest factors) to determine the pertinence of using it as an indicator of calyx cavity.

Peel colouration and calyx cavity

Fruit with calyx cavity had a greater average skin colouration than fruit with no calyx cavity (Figure 5A). The mean colour index value was 16.4 in fruit with calyx cavity, significantly higher compared to 14.1 in fruit without calyx cavity. An increase in the average skin colour index between consecutive scores was also observed; the average colour index increased by 1–2 units with each score (Figure 5B). Fruit with more severe cavities had darker orange-red colourations on average compared to fruit without calyx cavity which tended to have lighter orange skin colouration. The higher colour index values in fruit with calyx cavity may have been attributed to the potential association between calyx separation and maturity. As a result, the observed differences may be due to fruit maturity at harvest rather than the presence of calyx cavity. On the other hand, Akagi et al. (2020) detected specific patterns of uneven colouration in fruit

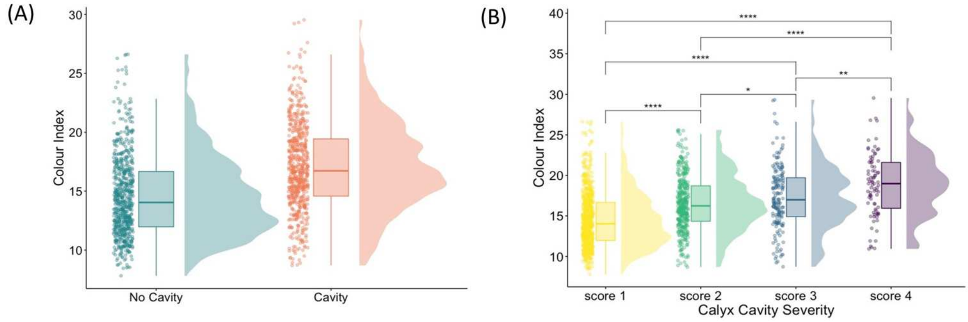

Figure 5. **A**, Distribution of fruit skin colour index values based on the presence or absence of calyx cavity 'No cavity' includes fruit scored as score 1; 'Cavity' includes fruit scored as scores 2, 3 and 4. **B**, Distribution of individual fruit skin colour index values based on the visual scale severity of the observed calyx cavity where score 1 represents fruit without a cavity, and scores 2, 3 and 4 represent fruit with cavities of increasing size. Colour measurements were taken at the fruit shoulder and equator; averages were used to calculate the colour index from equation 1. The mean colour index of no cavity and cavity fruit was significant ($p < 0.001$); significant differences between mean colour index scores of calyx cavity severity scores are indicated by asterisk ($p < 0.05$;*), ($p < 0.01$;**), ($p < 0.001$;****).

with the disorder. A darker reddish colouration in the pericarp from the point of separation between the calyx and fruit tissue in the more severe cases of calyx cavity was described. This indicates the observed colour differences were a feature of calyx cavity rather than maturity alone.

Modelling to predict calyx cavity

Linear discriminant analysis was completed using at-harvest weight and colour index data as continuous predictors of calyx cavity severity. Of the quality variables evaluated, weight and colour index were chosen as predictors to estimate the degree of calyx cavity due to the patterns of increase in these parameters observed between the levels of calyx cavity.

Two LDA models were created to classify fruit by the presence or severity of calyx cavity. The first model segregated fruit into either no cavity or cavity (including minor, moderate, and severe cavities) using at-harvest weight and colour index data with calyx cavity as a binary factor. As shown in Table 5, model predictions were fairly accurate for the second model in terms of estimation of both fruit with no cavity and with a cavity. The rate of true positives was 77.4%, and the rate of true negatives was 70.5%. A second model was created to classify fruit by score of severity (1, 2, 3, or

Table 5. Classification table of predictions based on linear discriminant analysis of at-harvest weight and colour index data where calyx cavity data is used as a binary (No cavity = calyx cavity severity of score 1; Cavity = calyx cavity severity of scores 2, 3 and 4).

		Predicted				
		No cavity	Cavity	Correct (%)	Error (%)	Risk
Observed	No cavity	343	100	77.4	22.6	Export packout loss
	Cavity	117	279	70.5	29.5	Rejection
	Total			74.1	25.9	

4). This model exhibited relatively poor performance compared to the first model (see Table A in the supplementary material). The second model faced challenges segregating fruit between the different intermediate severities. This may have been due to larger differences in weight and colour index in the least and most affected fruit; these differences were less pronounced between fruit in scores 2 and 3. Akagi et al. (2020) carried out similar work that used colour differences to predict the degree of calyx separation and noted prediction problems stemming from imbalanced class weights, as group sizes were significantly smaller at higher severities.

The potential use of these classification models to segregate calyx cavity fruit in the industry only reduces the problem by about half. As displayed in Figure 6, the amount of cavity fruit is 47%, and after segregation, the amount of cavity fruit in the exported sample is 25%. In this situation, no cavity fruit was also unnecessarily removed by misclassification, causing a 26% export packout loss or reduced profits if redistributed to local markets. Thus, the model creates the potential for no cavity fruit to be removed, and for cavity fruit to be left in with the no cavity fruit population. This would likely result in undesirable consequences for exports. When cavity fruit are not identified and segregated, entire consignments of fruit could be put at risk of rejection from the presence of pests in the cavity. As 4 kg to 10 kg fruit are stored per packaging unit during export shipping, this creates a risk of allowing the spread of pests between fruit (Bignell et al., 2017). When healthy fruit are wrongly classified as calyx cavity fruit,

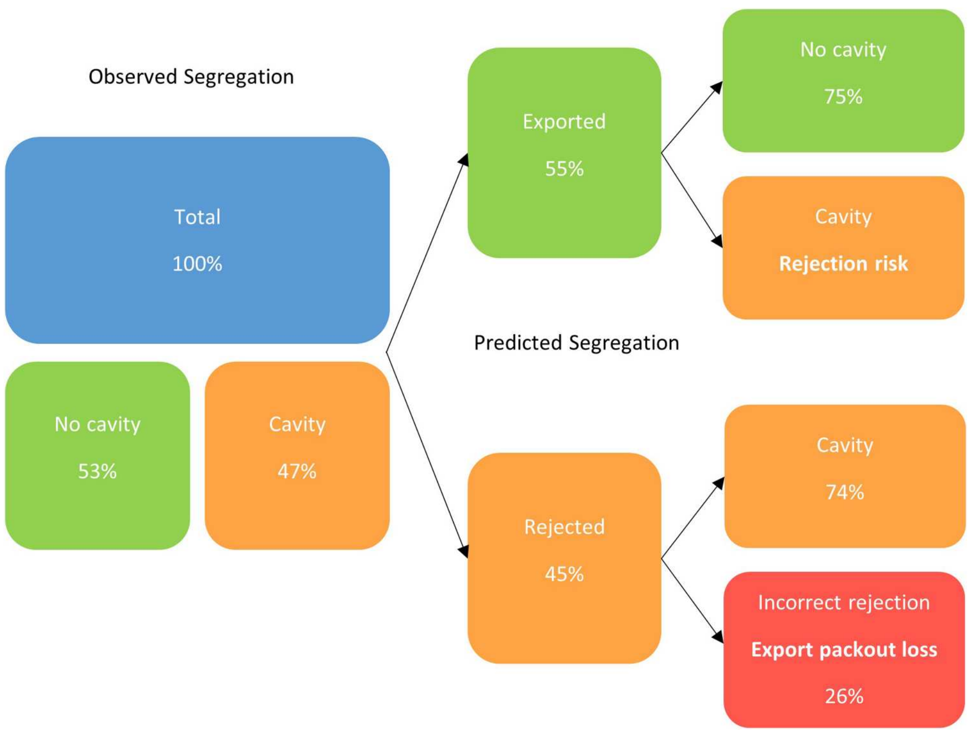

Figure 6. Flowchart showing an example of the use of the classification model to segregate fruit including potential commercial implications. ‘No cavity’ refers to fruit without calyx cavity and ‘Cavity’ includes fruit with a calyx cavity severity from scores 2, 3, and 4.

export packout loss is increased. Additionally, larger fruit are more likely to be sorted out by being wrongly categorised as calyx cavity when healthy, leading to high export packout losses. The potential rejection risk and high export packout losses mean the benefit to the industry is limited.

However, the use of a calyx cavity segregation model could still provide several advantages to the persimmon export industry. Possible commercial benefits include increasing the quality of fruit by minimising the amount of fruit with calyx cavity as this disorder is considered a disorder of major importance to importers (Bignell et al., 2017). Fewer fruit with calyx cavity in a consignment could reduce the amount of spoilage that occurs due to rots that develop inside the calyx cavity and spread to the surrounding fruit (George et al. 2005). Segregating affected fruit may also reduce the likelihood of shipments of fruit being rejected due to the presence of quarantine pests.

The accuracy of the segregation model requires improvement before consideration for industry implementation. The influence of harvest maturity on quality parameters suggests that using samples with more similar harvest maturities could reduce any effects due to more mature fruit rather than the presence of calyx cavity. Increasing the amount of data collected could also help increase model performance, as well as considering the use of other non-destructive variables. Additionally, models would likely only be useful for each season and cultivar and require adjustments to account for changes in these parameters. Model testing on fruit obtained from different regions, growing conditions and cultivars would provide an indication of variance in model performance and may help provide information for adjustments. Further study is required for the optimisation and validation of a segregation model of calyx cavity in persimmon.

Conclusions

This work has found the presence and severity of calyx cavity is correlated with fruit weight and colouration. Fruit with calyx cavity were on average heavier and had darker orange-red colouration compared to healthy fruit, and this trend increased with larger degrees of separation. A classification model using fruit weight and colour index can discriminate between fruit with and without incidence of calyx cavity with an accuracy of 70.5% (29.5% false negative). Future work is required to optimise the performance of the calyx cavity segregation model including more data from multiple seasons and incorporating other quality input variables. Improvements in model accuracy could lead to improvements in export storage quality.

Acknowledgements

The authors would like to thank First Fresh NZ for supplying the fruit used in this study and the financial assistance provided by the Lois Turnbull Scholarship through Massey University.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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