Project title:	Developing Practical Strategies to Improve Quality and Storage Potential of UK Apples
Project number:	TF225
Project leader:	Dr Richard Colgan - Natural Resources Institute, University of Greenwich
Report:	Annual Report October 2019 (for 2018)
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Location of project:	NIAB/EMR, FAST LLP, Selected Gala orchards in Kent
Industry Representatives:	Nigel Jenner, Paul Smith and Nigel Stewart
Date project commenced:	1 April 2016
Date project completed (or expected completion date):	31 March 2021

DISCLAIMER

The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headline

- Chlorophyll fluorescence can give 7-10 days advance warning of starch clearance patterns reaching 75-80%.

Background and expected deliverables

Fruit dry matter (FDM) content is considered a good indicator of high sugar and acid content (% Brixº) and eating quality of apples at harvest. Apples high in FDM tend to retain quality attributes over extended periods of storage. The extent to which orchard management practices during flower bud and fruit development affects FDM at harvest requires further attention. Moreover, the relationship between FDM and fruit ex-store quality throughout the storage season is of interest to the UK apple industry and may afford the opportunity to identify orchard consignments that can be stored for longer.

Several research groups, including the work of Palmer (1999) in New Zealand have linked high FDM at harvest to good quality and good storage potential. These studies were reviewed in AHDB-Horticulture Project TF 222, and although previous research highlighted the potential to use FDM as a proxy measure of fruit quality, much of this work was correlative.

The underlying basis of this relationship needs to be better understood so that it can be manipulated to deliver premium fruit quality. In this project, it is hoped to achieve this through a combination of a meta-analysis of existing data sets to obtain a greater understanding of the factors controlling both FDM and quality, and the development of practical strategies in terms of novel pruning strategies, reflective covers and manipulation of crop load through bud and fruit thinning to help growers to improve the quality of stored apples.

Year 3 of this study (2018) attempts to maximise Fruit Dry Matter (FDM) in Gala apples by manipulating crop load and increasing light interception through the canopy. Bud, flower and fruitlet thinning practices, using mechanical and chemical thinning treatments (Exilis and Brevis), were employed by the scientists to manipulate crop load. Parallel work utilised novel centrifugal pruning techniques to increase light interception throughout the tree in conjunction with positioning of reflective covers in alleyways to redirect light back into the lower canopy.

Summary of the project and main conclusions

Meta-analysis (Work package 1)

In the first two years of the project, meta-analysis of FDM data for commercial Gala and Braeburn orchards identified 56 Gala orchards where mineral analysis (soil or leaf) existed to allow some correlative analysis of FDM against soil and leaf quality attributes. Using multiple regression linear models revealed a weak positive relationship between fruit potassium and magnesium concentrations and FDM and a negative relationship with zinc.

Influence of light interception on FDM (Work package 2)

Conversion of tall spindle (TS) Gala trees to a centrifugal growth habit was undertaken in the winter of 2016 as part of WP2. In the 2018 season, centrifugal pruning and the positioning of reflective covers in the alleyways increased light interception through the canopy. Higher temperatures resulted, particularly in tall spindle trees where reflective covers raised internal canopy temperatures by 2.6ºC and led to a slightly faster rate of fruit expansion (non-significant). The exceptionally warm temperatures in 2018 with above average sunshine hours, led to fruit with high %FDM (~17.0%) across the canopy, so the experimental treatments did not increase %FDM. Yields per tree were not affected by the presence of reflective covers. Yields were raised in centrifugally pruned trees but the increase was not statistically significant. Centrifugally pruned trees in the trial plots are still recovering from initial conversion but it is anticipated by the 2019 harvest, yields from the centrifugal trees will at least equal the tall spindle trees.

Influence of bud, flower and fruitlet thinning on FDM (Work package 3)

In the third year of WP3, a repeat of bud, flower and fruitlet thinning practices carried out in 2017 was made on the same trees in 2018. The following treatments were applied:

T1: Untreated Control – no thinning

T2: Bud Thinning - buds were removed in late March at BBCH 52-54 (end of bud swelling to mouse ear)

T3: Mechanical Thinning – in April using a hand held Electroflor machine applied at BBCH 65-66 (60% first open flowers)

T4: Chemical Thinning - Exilis (6-benzyladenine) + Fixor applied in May at BBCH 70-72 (funded by Fine Agrochemicals Ltd)

T5: Chemical Thinning - Brevis (150 SG metamitron) applied in May at BBCH 70-71 & 71-72 (funded by FAST)

T6 Standard Hand Thinning – removal of fruitlets to doubles & singles within clusters, applied at BBCH 71-72 (fruit size 15mm to 25mm, pre/up to second fruit fall)

T7 Hand Thinning Size – removal of fruitlets based on size category starting at BBCH 73, event 1 fruit size 25mm to 30mm, event 2 fruit size 40mm (BBCH 74).

T8: Late Hand Thinning treatment - BBCH 73-74 (fruit size 30mm to 40mm, after second fruit fall)

The results from 2018 trial mirrored those of 2017 in that no treatment significantly ($p<0.05$) increased FDM, Application of Brevis and standard hand thinning led to a ~1% increase in FDM, measured using standard oven drying methods, but these increases were not statistically significant. Exilis and Brevis were equally effective at reducing fruit numbers, with 30.4% and 33.8% of fruit remaining on the tree respectively, when compared to ~500 fruitlets per tree counted prior to June drop. The numbers of fruit left on the tree after treating with Exilis and Brevis were similar to standard (34.3%) and late hand thinning (31.3) practices. Thinning to size removed the most fruitlets/fruits with 26.2% of the fruits remaining on the tree. Hand thinning treatments led to the highest amount of class 1 fruit (~85%). Fruits treated with Brevis and those subject to thinning to size had more advance maturity at harvest compared to un-thinned fruit. Fruits were harvested in the optimal harvest window for long-term storage which meant fruit firmness was retained throughout eight months storage in 3% CO_2, 1% O_2 (0.5-1.0ºC). No evidence of internal browning at the equator or in the stem bowl was observed throughout storage.

Chlorophyll fluorescence as a means of measuring fruit maturity (Work package 4)

Chlorophyll fluorescence (CF) modelling was successful in predicting the onset of harvest maturity by 7 to 10 days in advance of starch clearance patterns reaching 75-80% in six commercial Gala orchards. Fruits harvested with CF -prediction as early or late maturing sites were tested for Internal Ethylene Concentration (I.E.C.) using a GC-FID which confirmed the early maturing sites had higher internal ethylene concentrations than those predicted by CF to be later maturing.

Advanced warning of the onset of starch clearance would allow growers more time to organise harvest and increase the likelihood of a greater proportion of the first pick Gala crop being harvested within the short window necessary to ensure fruit are suitable for long term storage. Chlorophyll fluorescence modelling was successful in predicting the onset of harvest maturity some 7 to10 days in advance of starch clearance patterns reaching 75-80%. Landseer monitored changes in CF profiles in six commercial Gala orchards starting from mid-July, at fruitlet stage, through August and again at harvest. While optimising harvest maturity is important for selecting orchards for long term storage, fruits need to have adequate balance of mineral nutrition and good FDM to improve the chances of fruits retaining quality for longer in store

Chlorophyll fluorescence affords an opportunity to provide information to growers regarding changes in fruit maturity in advance of changes in starch clearance patterns. Analysis of CF outputs from six commercial orchards found that on average CF outputs could predict the decrease in starch to 75% content 7 to 10 days before the event. Further work is ongoing to determine the impact of early warning and potentially more precise harvesting forecasting on the storage quality of fruit.

Main conclusions

- Statistical analysis of a large data set provided by FAST LLP; indicated a small positive correlation between higher fruit K and Mg content and higher FDM.
- In general, implementing thinning practices did not significantly increase FDM content. However, trees that had been thinned had significantly higher sugar (fructose and sucrose) content.
- Application of Exilis or Brevis was as effective as hand-thinning in reducing overall fruit numbers recorded at harvest. However, trees treated with Exilis produced a higher number of misshapen fruits
- Thinning to size produced the highest number of fruits in the 60-70mm size category and produced trees with the largest fruit.
- The use of a chlorophyll fluorescence and subsequent data modelling provided a 7-10 advanced warning in changes in starch clearance patterns when compared to traditional starch/iodine testing used by the industry as a measure of fruit maturity and the need to start harvesting.

Financial benefits

- No direct financial benefits have arisen from this work so far.

Action points for growers

- Harvesting fruits higher in the crop canopy separately will provide consignments with higher FDM.
- In general, the practice of thinning fruits increased the sugar (fructose and sucrose) content of fruit at harvest.

SCIENCE SECTION

Introduction

Improving the quality of stored apples and pears is an important priority area for AHDB Horticulture. A key indicator of fruit quality and storability is thought to be fruit dry matter content (FDM) as recent studies have suggested there is a good correlation between the FDM of apples and the ex-store sugar levels and eating quality (Harker et al., 2009; Jordan et al., 2000; Palmer et al., 2010).

Several research groups have linked high FDM at harvest to good quality and good storage potential; FDM reflects fruit carbohydrate content, where soluble solids content (SSC) and starch are the major constituents. The hydrolysis of starch into SSC during fruit ripening makes FDM a valuable and accurate indicator of potential postharvest SSC, or of actual SSC once hydrolysis is complete (Jordan et al., 2000; McGlone and Kawano, 1998; McGlone et al., 2003).

FDM is influenced by tree and fruit physiology and significantly affected by environmental conditions within and between seasons and cultural practices. Further research in this area is required to determine how environmental conditions and management practices employed during growth and development affect FDM at harvest and during storage and to determine the relationship between FDM and fruit ex-store quality for UK fruit.

Fruit and tree development are the result of the interaction of diverse cultural practices (e.g. pruning, thinning, pest and disease management), environmental inputs (e.g. water, nutrition, light, [CO2]) and physiological processes (e.g. light interception, photosynthesis, respiration, transpiration) (Wünsche and Lakso, 2000a), overlaid on the inherent genetic traits of the cultivar. These processes affect preharvest fruit development and influence how fruits at harvest appear, taste, and perform in storage (Kader, 2002). Increasing FDM in fruit must not be at the detriment to other quality parameters; consumer preferences for sweeter apples is only true where fruit firmness is retained (Harker et al., 2008).

Approximately 90 % of FDM is composed of soluble and insoluble carbohydrates (Suni et al., 2000). The main soluble carbohydrates determining SSC of apple juice contains a mixture of fructose, glucose, sucrose, sorbitol, organic acids, and inorganic salts (Kingston, 1992; Wills et al., 2007). The ratio of sugars varies depending on the cultivar (Wu et al., 2007) and influences taste. Fructose is sweeter that sucrose, which is sweeter than glucose (Kader, 2002). The proportion of sugars depends on the source/sink relationship between leaves and adjacent fruits and on the proportion of sorbitol and sucrose entering fruit. Sorbitol makes up 80% of the photosynthate entering fruit, the balance being sucrose. Sorbitol breaks down inside the cells to fructose, while the disaccharide sucrose breaks down to equal measures of fructose and glucose. Often glucose is more readily metabolised than fructose, leaving the concentration of available glucose (0.8 - 1.0% fresh weight (FW)) inside cells rather small compared to fructose (3.9 - 5.7% FW) with sucrose concentrations between 3.5 and 4.6% FW (Ackermann et al., 1992).

The balance between crop load and vegetative growth is key to maximising FDM. However, root biomass and the influence of carbohydrate reserves in roots should not be overlooked. Castle (1995) reviewed the literature on the impact of rootstocks on fruit quality for citrus and deciduous fruit crops; rootstocks will influence canopy management and nutrition uptake and thus will impact on crop load and fruit size and storage potential of fruit. The impact of thinning, pruning or rootstocks on fruit quality attributes is often difficult to estimate without considering the impact of crop load; statistical techniques such as analysis of covariance have helped to quantify the influence of rootstock on fruit quality, considering the variability in trees crop load. Drake (1988) compared cv. Gold Spur apples grafted onto various rootstocks; M9 and M27 produced the firmness fruit and the highest % Brix in juice samples.

Some of these studies were reviewed in AHDB Horticulture (TF 222) and although previous research highlights the potential to use FDM as a proxy measure of fruit quality, much of this work was correlative.

The underlying basis of this relationship needs to be better understood so that it can be manipulated to deliver premium fruit quality. This is being achieved through a combination of a meta-analysis of existing data sets to obtain a greater understanding of the factors controlling both FDM and quality, a series of field-based experiments at NIAB-EMR and FAST LLP, trials on commercial grower sites and the development of practical strategies to help growers to improve the quality of stored apples.

Many studies have been undertaken on both thinning and pruning of apple trees, such that both the optimum crop load for good yield and pruning techniques to increase light interception are well known. We will take full advantage of this knowledge in designing our experiments and trials to understand the mechanisms for optimising quality for long-term storage.

The impact of dry matter accumulation on fruit maturity is less well documented; many of the factors that influence FDM (light intensity, rootstock, pruning and crop load) can influence the rate of fruit maturation.

Fruit maturity at harvest is vital in dictating post-harvest storage life and future eating quality (Kader, 2002), therefore it is important to have a better method for predicting maturity on the tree. Gala destined for long-term storage should be picked at 85-90% starch content (based on iodine staining of equatorial slices). In many instances once fruit start to ripen and starch clearance starts, then a rapid decline in zonal starch patterns of 2% a day is often observed, giving growers little time to pick orchards at optimum maturity as they often have only 1 to 2 days' warning that fruits are starting to ripen. Identifying non-destructive techniques that allow growers and advisors the ability to assess maturity changes across orchards and even within the canopy of individual trees affords opportunities to have greater control of harvesting schedules and practices.

Chlorophyll fluorescence has been used in many instances to measure crop health. The fluorescence yield depends both on the concentration of chlorophylls and the state of the photosynthetic apparatus (Chloroplasts). Thus, in some cases physiological stress can lead to an increase in fluorescence yield as the mechanisms of photosynthesis within the chloroplasts become less efficient and therefore less absorbed light energy can be used to drive the process, while on the other hand as fruit tissues mature or green vegetables senesce the loss of chloroplasts leads to a decrease in fluorescence yield. It is this reduction in fluorescence yield that is being investigated in this project as an indicator of apple fruit storage potential. The same techniques to measure changes in fruit maturation have been reported previously (Rees et al. 2005).

Recent work on fruit quality commissioned by AHDB

AHDB commissioned a series of reviews on the relationship between FDM and fruit quality on thinning methods and on future research needs for improving the storage quality of UK apples and pears. The objectives of this proposal have been developed based on these reviews and from the findings of a series of projects commissioned by AHDB over the past few years that have focused on improving quality of apples and pears.

TF 213, 221 "Extend the marketing period of Gala apples" (led by NRI) studied the relationship between quality characteristics and volatile components on consumer acceptability as well as factors affecting quality after storage. Over a two-year period, consumer acceptability of UK Gala from a selection of Gala orchards found that fruit with higher FDM at harvest equated to higher %Brixº at harvest and to a better %Brixº coming out of store. Fruit with %Brixº more than 13.5% were considered in many cases to have equal overall acceptability with imported fruit in late April/early May. UK fruits generally have better firmness and acidity and, where % Brixº was equal to imported fruit (13.5%), were considered more acceptable despite being lower in the complement of volatiles. Taste-odour interactions lead to complicated changes in perceived flavour. Increasing sucrose concentrations can reduce perceived levels of bitterness and sourness and in addition increased sweetness can increase the perception of fruity aromatic flavours. The ability to market fruit into late May and early June is dependent on selecting the high FDM yielding orchards and storing them in regimes that maximise taste and flavour. Within project TF 221 alternative regimes were investigated that preserve taste. Several alternative CA regimes such as 3% CO_2 2% O_2 (+ Smart Fresh^{TM}) and 3% CO_2 (0.6-0.4% O_2) scored more highly than conventional regimes in taste panel assessments, despite having similar firmness, %Brix° and acid ratios. Storage in oxygen <1% retained selected volatiles compared to conventional storage in 5% CO_2 and 1% O_2 where high CO_2 is known to restrict the esterification of alcohols to respective acetate esters.

TF 198 "Developing water and fertiliser saving strategies to improve fruit quality and sustainability of irrigated high-intensity, modern and traditional Conference pear production" (led by EMR) investigated the potential to develop water and fertiliser saving irrigation strategies that would also optimise Class 1 yields and fruit quality. Results over two seasons showed that FDM varied significantly between the four different growing systems in the AG Thames Concept Pear Orchard (CPO) at EMR, and that marketable yields and fruit quality were maintained or improved by alternate wetting and drying treatments. The scientifically-derived irrigation scheduling guidelines developed in TF 198 are now being tested in a project funded by Worldwide Fruit Ltd and Marks and Spencer plc on a commercial pear farm in North Kent to optimise production efficiency of high intensity Conference pear production. The potential of using deficit irrigation strategies to manipulate resource partitioning and fruit FDM was being investigated in 2016. TF 210 and TF 214, led by NIAB-EMR, investigated the potential to use precision irrigation and targeted fertigation to improve marketable yields, consistency of cropping and fruit quality of Gala and Braeburn.

Description of Work Packages

In order to deliver 'Best Practice' to the top-fruit industry to improve FDM a series of work packages have been set up initially working on discrete aspects of husbandry with the aim of bringing together different components of each WP in the later stages of the project to form a single trial plot.

Work package 1: Meta-analysis of Fruit Dry Matter

WP 1 2016 - 2017 Year 1 NRI University of Greenwich Chris Atkinson, Stephen Young with support from Richard Colgan and Debbie Rees, Julien LeCourt NIAB-EMR.

Background

Meta-analysis can be described simply as "carrying out research about previous research" in a systematic manner of review. The concept is based on combining the outputs of several diverse studies which have measured similar factors and aggregating these outputs provides more reliable and precise statistical descriptors that can help to inform appropriate outputs, e.g. crop management strategies. Meta-analysis can also help to identify causes of inconsistency between results from various studies (e.g. due to different sampling approaches) to develop new hypotheses from patterns that were not previously apparent, to find sources of disagreement in results from diverse sources and to identify potential modes of action. The latter can be particularly important in determining future route.

Materials and methods

Data sets from FAST LLP supplied over 3 consecutive seasons (2015/16, 2016/17 & 2017/2018) were used to conduct a series of multiple correlation and regression analyses to identify links between mineral analysis data of fruits at harvest with the propensity to accumulate dry matter.

Initial correlation tests were performed on the 2015/2016 and 2016/2017 data sets using fruit, leaf and soil mineral analysis data correlated against FDM using a Pearson test ($p<0.05$). The analysis was performed using GGally package (ggplot2); an extension package "from RStudio" (R Core Team, 2014). Correlation coefficients were determined from Lindley and Scott (1995).

Following on from Pearson's correlation analysis a linear model using Library Lattice in RStudio was conducted. In the first instance a linear model (lm) including all minerals (lm (DM ~ Ca + N + KCA + Cu + Fe + K + Mg + Mn + P + Zn + B)) was undertaken. To assess the contribution of individual mineral elements within combined model, ANOVA (analyses of variance) was used to perform an analysis of the relative contributions from explained and unexplained sources of variance in a continuous response variable. Significant effects were tested with the F statistic, which assumes random sampling of independent replicates, homogeneous within-sample variances, and a normal distribution of the residual error variation around sample means (Doncaster and Davey, 2007). ANOVA was carried out to determine whether there were significant differences between minerals using RStudio (R Core Team, 2014). The mineral elements identified as having a significant effect on FDM were added in different combinations in a second series of restricted linear models. The regression models were tested against the Akaike Information Criterion (AIC) to confirm the best fit.

Work package 2: Centrifugal pruning and reflective mulches

WP 2 2016 - 2020 Years 1-5 EMR Julien Lecourt

Background

Compared to many areas of tree fruit production, the productivity of UK orchards is limited by light levels (Palmer 1999). The close relationship between the amount of light intercepted by the tree canopy and fruit production is well known (e.g. Lakso, 1996, Figure 2.1a) and increased light interception promotes dry matter accumulation (e.g. Palmer et al. 1992, Figure 2.1b), TSS, fruit colouration and profitability (Jackson 1970; Robinson and Lakso 1988; Kappel and Neilsen 1994; and Lakso 1996; Kappel and Brownlee 2001). Therefore, optimising light interception in high-density orchards is critical and although different strategies are available to growers (see below), scientifically derived guidelines are needed to optimise their use in UK commercial intensive apple and pear orchards.

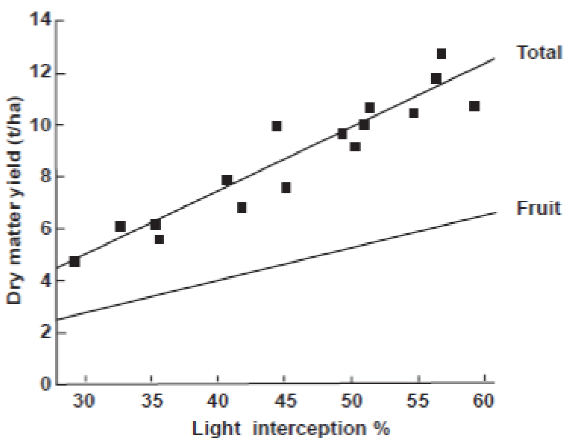


Figure 2.1a. Relationship between light interception (%) and total dry matter production and FDM yield (t/ha) of Golden delicious/M9 at East Malling (Modified from Palmer, 1999).

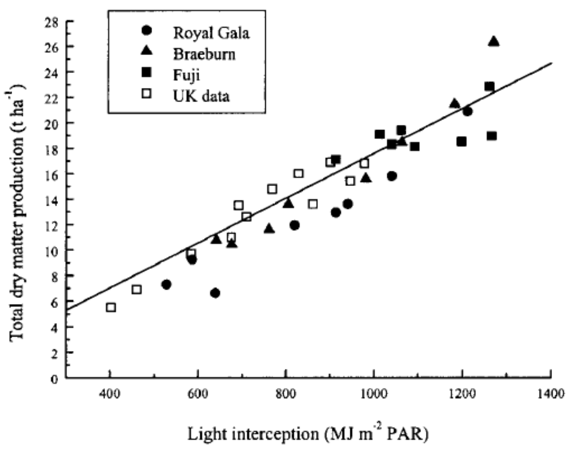


Figure 2.1b. Relationship between seasonal intercepted PAR (MJ/m^2) and total dry matter production (t/ha) of Royal Gala, Braeburn, Fuji and averaged seasonal data for the UK

For apple, new training systems have been developed abroad and have shown promising results regarding yield and quality. For pear, the different training systems in the AG Thames/EMR CPO have delivered a threefold increase in yield in comparison to commercial orchards, due in part to improved canopy light interception. Reflective covers or mulches can improve the amount of light intercepted by the tree canopy by up to 30% in all types of weather, with corresponding improvements in apple and pear quality and yield (Iglesias and Alegre 2009; Privé, Russell et al. 2011; Guo 2013).

Materials and methods

In the Autumn of 2016, innovative centrifugal pruning and training systems were initiated and compared with a standard tall spindle tree within a 4-year-old Gala/M9 orchard at EMR (Figures 2.2 and 2.3). Within the orchards reflective mulches were laid either side of the rows after flowering to determine the effects of improved light penetration and on Class 1 yields, FDM and components of quality fruit quality (TSS, colour). The impact of pruning systems on tree architecture and canopy development are being monitored using LiDAR which can estimate tree row volume, porosity, specific leaf area and light levels studied using AccuPAR.

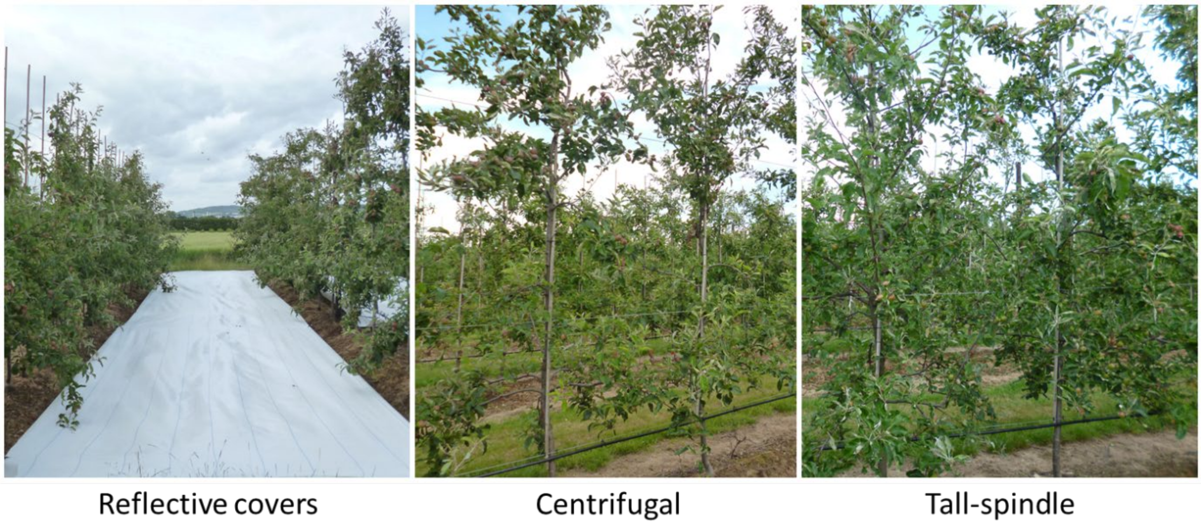


Figure 2.2. Pictures of the treatments applied during the experiment. The training and reflective mulches have been applied to a 4-year-old (2016) M9 Gala orchard located at NIAB EMR.

Fruits were harvested in September 2017. Fruit was sampled from each experimental tree and categorised into 3-4 sub samples by position within the tree. Analysis of fruit quality attributes was carried out to quantify the effects of manipulating light interception on fruit FDM and quality attributes at harvest and following storage. For selected parts of the experiment in project Years 1 & 2, a more detailed categorisation will be undertaken in terms of light interception by the fruit bearing branch. Analysis of fruit quality attributes is described in WP4. Where applicable, high throughput phenotyping tools currently being developed in other IUK projects will be used to quantify treatments.

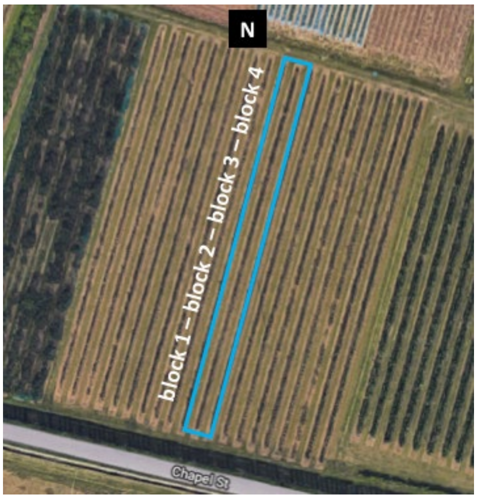


Figure 2.3. Satellite view of the area effects on aspects of fruit quality.

- **Post-Harvest Handling and analysis**

Apples from the top and bottom of the trees under reflective covers and pruning regimes were harvested on 20 September 2017 and transferred to the Produce Quality Centre (PQC) where fruits were sampled for dry matter content. Apples were sampled for dry matter, taking segments from opposite eighths, removing the core. Tissue was chopped into 1 cm pieces, 50 g of tissue was weighed to 2 decimal places, dried in an oven for 48 hours and reweighed. Tissue was then placed back into the oven for a further 24 hours and reweighed. Additional samples were frozen and freeze dried for 5 days at -80 °C and then reweighed.

The bulk of the remaining harvested fruit was randomised within their orchard treatments and stored in 3% CO_2,1% CO_2 (0.5-1.0 °C) for 5 months, after which fruits were assessed immediately ex-store and again after 7 days at 18 °C.

Results

Five Decagon loggers with 2 VP4 sensors per logger installed on 22 August, provided data on air temperature and humidity. The temperature recorded was transformed into growing degree days (GDD) accumulated during a period of 4 weeks. The treatments with reflective covers showed an average accumulation of an extra 5.4 degrees than the treatments without reflective covers at the time of the harvest, on 14 September (Figure 2.4).

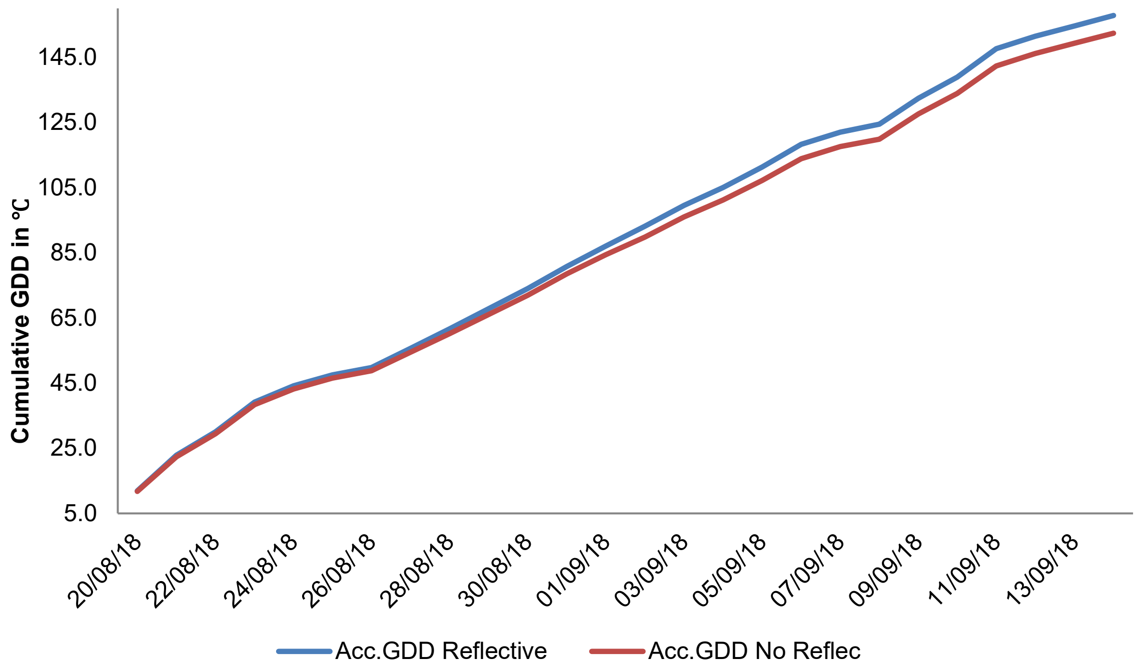


Figure 2.4 Effect of reflective covers on the temperature calculated as accumulated growing degree days (GDD)

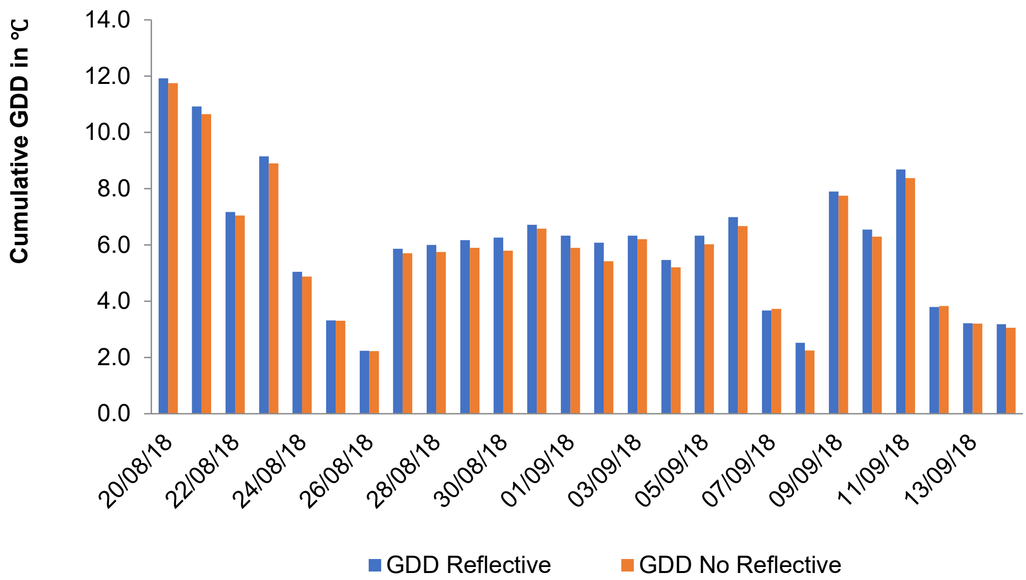


Figure 2.5 Effect of the reflective covers on the air temperature calculated as daily growing degree days (GDD)

Daily calculation of GDD (Figure 2.5) showed higher GDD values on the areas with reflective covers. Differences range from 0.1 degrees on 22 and 31 August, to 0.7 degrees on 7 September. No statistically significant difference was shown.

The use of reflective covers showed a tendency to decrease the percentage of humidity in the air in comparison with the areas without reflective covers. Out of the four weeks, only five days from 27 August to 31 August showed a higher humidity in the zones with reflective covers.

- **Effects of the treatments on light interception**

The reflective covers resulted in 29.45 % of the incident light to be reflected to the canopy against 4.27 % in the zones without (Figure 2.6). The results as shown below represent the mean of twenty measurements per treatment showing statistically significant differences between the treatments, LSD = 1.

The Centrifugate System (CS) shows a greater amount of light penetrating the canopy in the with 19.8 % against 12.5 % in Tall Spindle (TS) (Figure 2.7). However, this difference was not statistically significant due to the large inter-tree variability.

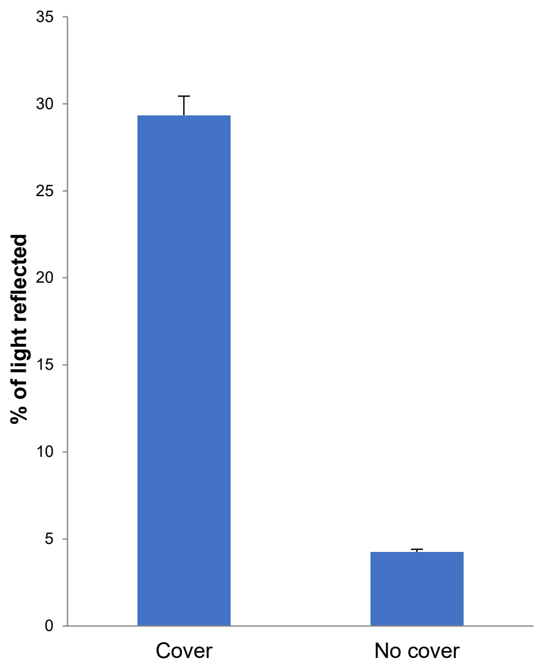


Figure 2.6. Effect of the reflective cover on light reflection by the ground

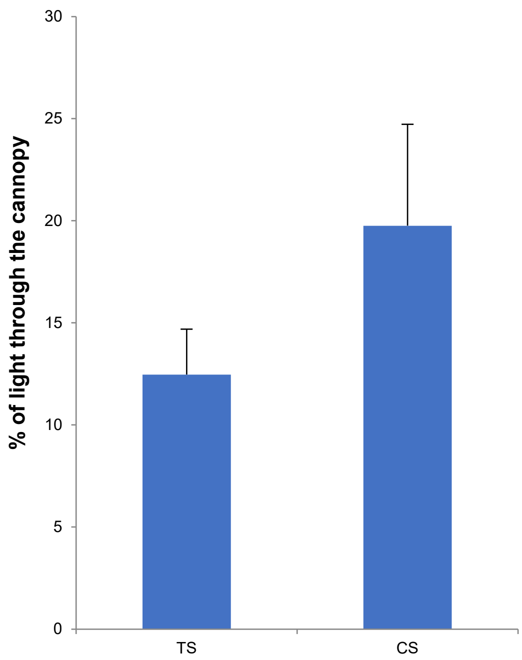


Figure 2.7 Effect of the training system on light interception (TS = Tall Spindle, CS = Centrifugate System)

Data of the temperature of the apples was recorded with a thermal camera FLIR ThermaCam P25 at two different days, on the 7th (cloudy day) and 13th (sunny day) of September just before the harvest (Table 2.1). For both days, reflective covers resulted in higher temperature in the canopy. On the 7th September, the apple temperature of the CS and TS training system was 0.28 °C and 2.66 °C higher with reflective covers, respectively. On the 13th of September, the apple temperature of the CS and TS training system was 1.15 °C and 0.41 °C higher with reflective covers, respectively. Results are means of 9 fruits per treatment. The training systems treatments did not significantly affect fruit temperature (Table 2.1).

Table 2.1. Effects of the two training systems and reflective covers on ‘Gala/M9’ fruit temperature.

Treatment	07/09/2018	13/09/2018
Centrifugal no reflective cover	25.43	25.77
Centrifugal reflective cover	25.71	26.92
Tall Spindle no reflective cover	23.08	26.06
Tall Spindle reflective cover	25.74	26.47
F-prob	n.s.	n.s.
LSD	2.61	1.72

Effects of the training systems and reflective covers on the rate of fruit expansion

Fruit height and diameter were measured weekly and the Fruit Expansion Rate (FER) between two successive measurements was calculated to determine whether these parameters were affected by the treatments (Figure 2.8, 2.9). Fruit size was similar between the two training systems. However, reflective covers induced a slightly higher average fruit height and diameter for the two training systems. Differences were however not statistically significant.

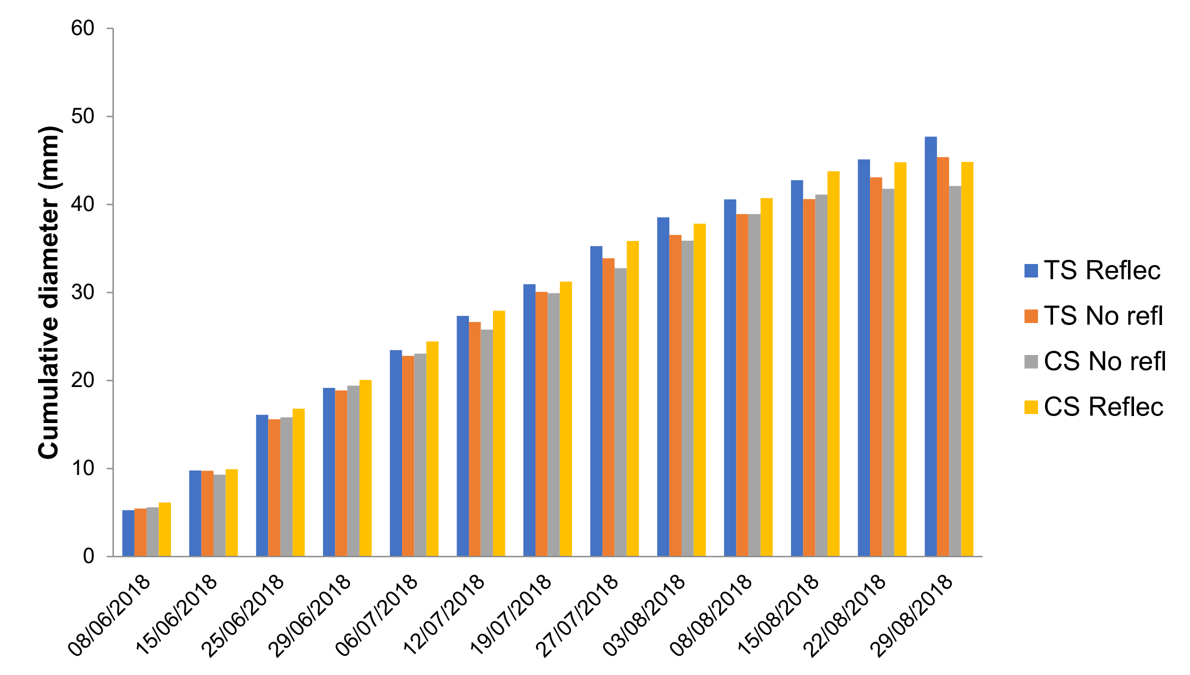


Figure 2.8 Fruit expansion rate (FER) cumulative diameter (TS = Tall Spindle, CS = Centrifugal, No refl = no cover, Reflec/Refl = cover)

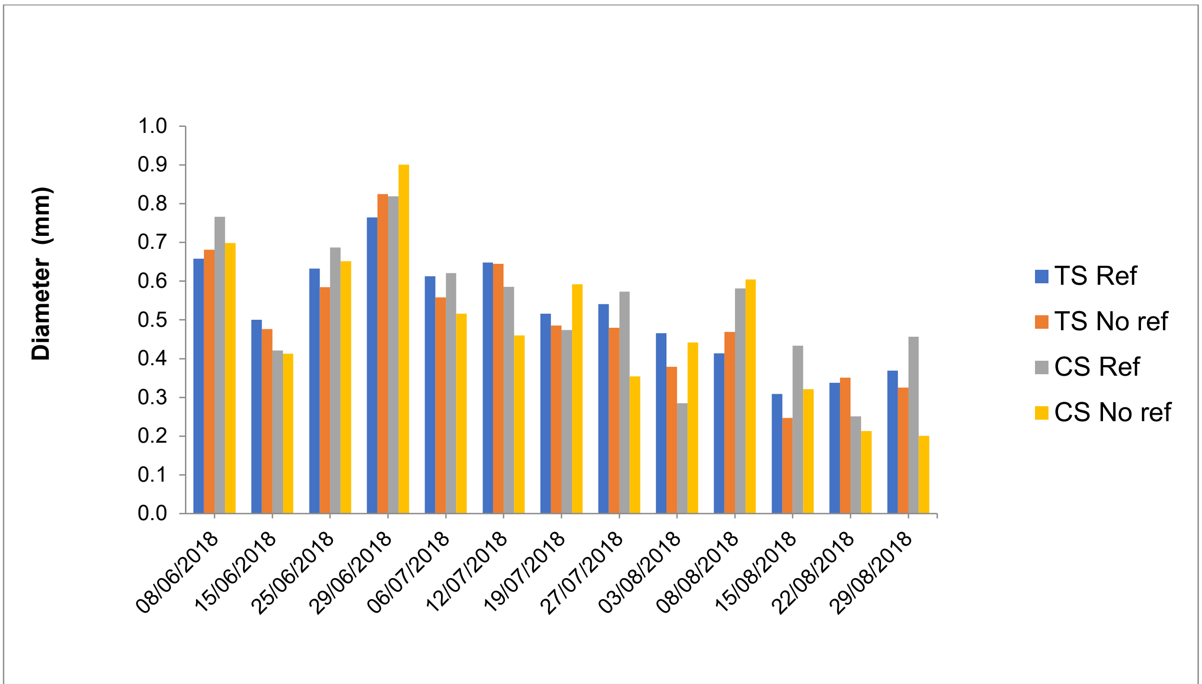


Figure 2.9 Fruit expansion rate (FER) diameter daily growth (TS = Tall Spindle, CS = Centrifugal, No ref = no cover, Ref = cover)

- **Fruit size and yield at harvest**

Yield was higher for the tall spindle trees, but CS trees are recovering from their conversion and now produce yield close to TS. Average fruit fresh weight from the CS treatments was

10.1 kg with reflective covers and 8.74 kg without covers (Table 2.2). From the TS treatments, fruit fresh weight was 11.75 kg with reflective covers and 10.88 kg without. The detailed yield records from the selected experimental trees showed that the total percentage of marketable fruit from each tree in CS was 90.03% with reflective covers and 88.43% without. Total percentage of marketable fruit from the TS treatments, was 91.79% with reflective covers and 89.58% without (Table 2.3). These differences were not statistically significant. The treatments did not result in significant changes in fruit size either.

Table 2.2. Effects of the two training systems and reflective covers on 'Gala/M9' fruit weight. From experimental selected trees.

Treatment	Yield per tree (kg)	Marketable fruit (%)
Centrifugal no reflective cover	8.74	88.43
Centrifugal reflective cover	10.1	90.03
Tall Spindle no reflective cover	10.88	89.58
Tall Spindle reflective cover	11.75	91.79
F-prob	n.s.	n.s.
LSD	5.09	6.04

- **Harvest Analysis- NRI**

Apples were harvested on 28 September 2018 and transferred to the PQC where fruits were sampled for firmness, starch and % Brix, followed by taking apples tissue for fruit dry matter using opposite eighths method, fruits were sectioned into 1 cm cubes weighed and frozen for later analysis. Apple tissue for dry matter content was measured using oven drying and freeze-drying methods; following freeze-drying tissues were powdered using a spice grinder and the powdered tissue used for sugar extraction in 80% ethanol and analysis of the supernatant by HPLC.

Analysis of harvest data found that fruit from centrifugal pruned trees were generally higher in starch content (Table 2.4) than those in standard tall spindle trees and were 4 N firmer ($p<0.05$). Centrifugal pruned trees had lower yields (9.42 kg/tree) compared to tall spindle (11.3 kg/tree) and crop loads are still recovering from conversion pruning in 2017. With the resultant lower fruit numbers, it is likely that fruit maturity would have been retarded, leading to firmer fruit. Overall, centrifugal pruning failed to increase % Brix°, %FDM or sugars (Table 2.4).

Table 2.4 Overall effect of implementation of reflective covers from fruit set to harvest on the harvest maturity, Fruit Dry Matter and sugar content of Gala apples at harvest

	Pruning			
	Tall Spindle	Centrifugal	fprob	$LSD_{0.05}$
% Starch	40.9	52.5	0.042	11.03
% Brix°	13.5	13.8	0.161	0.44
Firmness (N)	71.5	75.2	0.047	3.65
% FDM (Oven)	17.1	17.5	0.120	0.56
% FDM (FD)	17.4	17.9	0.284	1.23
Fructose (µL/µL)	31.9	32.5	0.642	3.18
Sucrose (µL/µL)	22.3	22.2	0.913	1.19

Table 2.5 Overall effect of pruning technique on the harvest maturity, Fruit Dry Matter and sugar content of Gala apples at harvest

	Covers			
	Reflective	None	fprob	$LSD_{0.05}$
% Starch	41.4	52.0	0.056	11.03
% Brix	13.6	13.7	0.336	0.444
Firmness (N)	70.5	76.2	0.013	3.65
% FDM (Oven)	17.1	17.4	0.286	0.564
% FDM (F.D.)	17.5	17.8	0.604	1.234
Fructose (µL/µL)	32.52	31.8	0.561	3.181
Sucrose (µL/µL)	22.3	22.2	0.827	1.19

Overall, the use of reflective covers increased fruit maturity at harvest (Table 2.5) and fruit were generally lower in starch coverage (41.4 %) although this just failed to reach significance ($p<0.05$). Moreover, increased fruit maturity led to lower fruit firmness (70.5 N). In the absence of reflective covers average fruit starches at harvest were 52.5% and firmness values of 75.2 N. There was no effect of reflective covers on the % Brix°, % FDM or fructose or sucrose content.

Analysis of the interaction between reflective covers and pruning regimes showed that reflective covers had the biggest impact on advancing maturity in tall spindle trees where starch content averaged 33.5% compared to 48.2% in tall spindle trees in the absence of covers (Table 2.6). The contrast is even greater when centrifugally pruned trees grown in the absence of covers (55.8%) are compared with fruit grown on tall spindle trees with reflective covers (33.5%). The effect of centrifugal pruning retarding fruit maturity and delaying softening may in part be due to lower fruit numbers per tree affecting fruit maturity at this stage in the conversion process.

Similarly, fruit firmness followed the same pattern with fruit grown on centrifugally pruned trees under reflective covers were softer than fruit cultivated without covers. However, there was no sign that the interaction of pruning with the addition of reflective covers has increased fruit dry matter or % Brix° or fructose and sucrose content at harvest.

Table 2.6 The interaction of pruning systems on 6-year-old Gala (M9) and reflective covers in alleyways on fruit maturity, fruit dry matter and sugar content at harvest

	Pruning	Covers Reflective	None	fprob	$LSD_{0.05}$
% Starch	Tall Spindle	33.5	48.2	0.363	15.6
	Centrifugal	49.2	55.8		
% Brix°	Tall Spindle	13.5	13.5	0.336	0.63
	Centrifugal	13.6	14.0		
Firmness (N)	Tall Spindle	67.6	75.4	0.174	5.17
	Centrifugal	73.5	77.0		
% FDM (Oven)	Tall Spindle	17.0	17.1	0.501	0.797
	Centrifugal	17.3	17.7		
% FDM (FD)	Tall Spindle	17.4	17.4	0.604	1.745
	Centrifugal	17.7	18.2		
Fructose (ul/ul)	Tall Spindle	32.1	31.7	0.76	4.499
	Centrifugal	33.0	31.9		
Sucrose	Tall Spindle	22.6	22.0	0.308	1.383
	Centrifugal	22.0	22.4		

N.B % FDM= Fruit Dry Matter estimated either using standard oven drying or by Freeze Drying (FD)

- **Storage**

Interestingly, at harvest fruit from centrifugally pruned trees were of less mature and marginally firmer at harvest firmness than those trained on tall spindle trees however, during storage Gala harvested from centrifugal trees softened more quickly at the final inspection after coming out of CA storage (0.5-1.0 °C) in March and this was irrespective of whether fruit had been grown under reflective covers. There was no effect of pruning or covers on the Ex-store % Brix or the incidence of rots. Internal quality of fruits deteriorated by the final inspection mostly due to the over maturity of fruit entering store. Fruits from centrifugally pruned trees had an increased incidence of senescent breakdown and where this was combined with reflective covers the incidence of breakdown increased.

Table 2.7 The storage quality of Gala apple trained under tall spindle and centrifugal systems with or without addition of reflective cover placed in the alleyways post-fruit set. Fruits were stored in 3% CO_2, 1% O_2 (0.5-1.0 °C) for 6 months.

		No Cover			Reflective Cover				
	Pruning	Dec	Feb	March	Dec	Feb	March	f.prob	$LSD_{0.05}$
Firmness	Tall Spindle	66.1	70.8	70.5	65.4	62.9	63.2	0.074	4.76
	Centrifugal	68.8	65.5	63.2	72.4	67.7	60.8		
% Brix	Tall Spindle	13.9	15.1	12.9	14.2	14.2	14.3	0.571	1.755
	Centrifugal	14.9	14.1	13.6	14.9	14.3	13.1		
% Rots	Tall Spindle	0.0	5.0	10.0	0.0	0.0	10.0	0.619	10.89
	Centrifugal	0.0	0.0	5.0	0.0	0.0	10.0		
%Sen Bdn	Tall Spindle	0.0	0.0	20.0	0.0	0.0	60.0	<0.001	8.89
	Centrifugal	0.0	0.0	60.0	0.0	0.0	90.0		
Sen Bdn	Tall Spindle	0.0	0.0	5.0	0.0	0.0	14.0	<0.001	2.87
Index	Centrifugal	0.0	0.0	17.0	0.0	0.0	24.9		

N.B Senescent Breakdown Index (Sen Bdn Index) has a maximum value of 60

Work package 3: To determine the impact of thinning strategies on fruit quality and FDM

WP 3 2016 - 2020 Years 1-5 FAST LLP Abi Dalton, Debbie Rees & Richard Colgan NRI University of Greenwich

Background

UK apple growers have recently expanded their production of Gala from high intensity plantings. To accommodate additional volume, it is estimated that around 30% of this harvest must be aimed at a later market window (FAST LLP, 2016).

Improved availability of consistently high-quality fruit will enable UK growers to compete with Southern Hemisphere imports at the start of the new season window. Extending the UK Gala season by 3 to 4 weeks could generate financial returns of £2 to £3 million per year across the industry (FAST LLP, 2016).

Many studies have been undertaken on both thinning and pruning. In terms of thinning the optimum crop load for good yield of the required fruit size is known, but not the effect on FDM of achieving this optimum crop load at different times in the season. No recent work has measured any effects on FDM on Gala in the UK. Although considerable work has been undertaken to try out different pruning strategies, mainly to increase light interception and therefore yield, the effect of different tree architectures on fruit FDM and whether fruit load can be increased without reducing FDM is not yet understood.

To increase FDM it is necessary to understand the controlling factors. There are two periods during fruit development when carbohydrate supply (from photosynthesising leaves) can be limiting; in the first weeks (typically 2 to 4 weeks from full bloom) of fruit development and just before harvest when light levels and temperature decline. Several studies have shown that reducing crop load increases FDM of the remaining fruit (Wünsche 2000, Wünsche 2005, Sharples 1968, Palmer 1997, Kelner et al 2000). However, it would also be helpful to understand how timing of thinning affects fruit cell number (which is determined by early in fruit development) and how this has impact on fruit quality. Photosynthate from leaves tends to be translocated to nearby fruits on the same branch/spur.

It is particularly important to develop knowledge of the impacts of the time of thinning on FDM by understanding the processes, not simply the outcomes and the former enables proposal of practical tree management strategies. Through utilising a commercial orchard with documented high fruit FDM, it will be possible to manipulate crop load based on tree age, precocity of flowering and size of branches, and quantify changes in FDM changes from flowering stages through to fruit development.

From previous studies, changes in % FDM from full bloom have been charted; a decrease after blossom is often seen, associated with high respiration rates of developing fruitlets, and then increases towards the end of the cell division phase before reaching a plateau which remains stable for the remainder of the season (see Figure 3.1).

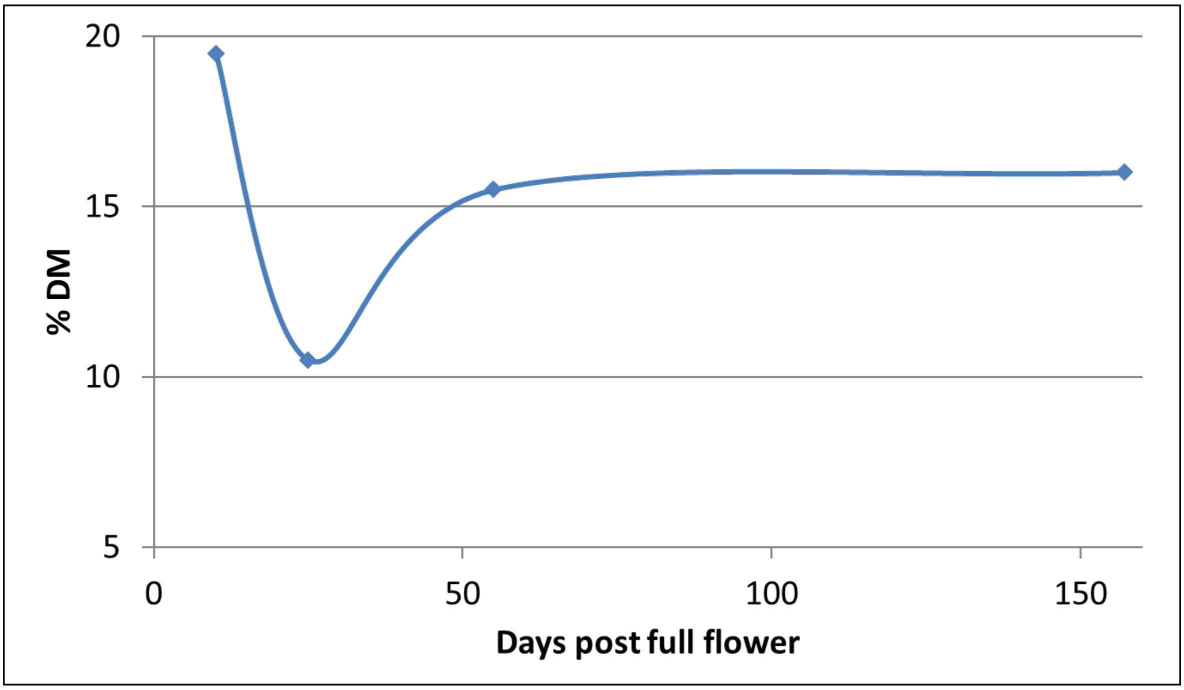


Figure 3.1. Preliminary FDM data from Gala taken during flowering and fruit development

From initial studies in two orchards the timing of thinning is thought to affect the degree to which FDM falls and rises again and potentially influence the final FDM at harvest (FAST LLP data unpublished). Many growers do not achieve the optimum crop load until late in the season - typically mid to late June through to the end of July. This trial will in subsequent years investigate the effect of achieving the optimum crop load at much earlier stages via different thinning strategies and compare with typical industry practice in terms of FDM accumulation.

The aim of the trial is to develop practical short, medium, and long-term strategies to help UK growers to optimise quality and storability of UK apples, in particular for long term storage beyond April.

This project will provide direct benefits to the growers within the project timescale as it will provide them with strategies to improve FDM.

Gala was used as a model variety to understand the relationship between quality and FDM, how to manipulate this and to follow changes in FDM and components during fruit development.

The initial phase (Year 1) was used to chart the changes in FDM content during the growing season and to quantify how early FDM was determined in the fruit development cycle - specifically at what point cell division ceases and starch accumulation becomes the main factor controlling FDM increase. This was achieved from detailed measurements of FDM and the components (structural carbohydrates, non-structural carbohydrates) through the cell division period. How this varies with fruit position within the tree canopy was investigated. Fruit from the ‘upper’ well-lit and ‘lower’ shaded portions of the canopy were collected from the selected orchard and how FDM varied with these different fruit positions in the tree was monitored to give insights into how the FDM progression may change. Further samples were collected at harvest time to determine how FDM may have progressed and the implications on storage potential and quality. This provided important information, not only on the reasons for initial difference in FDM, but also how it changed over the season and the implications for storage and consumer perception. It also provided an informed basis for the applications of tree management strategies, such as approaches to thinning which were considered in Year 2.

Outputs of a meta-analysis to improve the understanding of factors influencing FDM informed work on manipulating resource allocation and FDM by a range of thinning strategies to manipulate crop load at different timings. Treatment effects on the variability in FDM, its chemical components and related quality parameters within orchards and within the tree was also identified.

The review conducted on thinning technologies comes to some conclusions very relevant to this programme. For example, it is concluded that the resulting crop load is more important than the method used. It is likely that chemicals such as Brevis that inhibit photosynthesis could have effects that have not yet been identified. The review points out that thinning studies have tended to focus on crop yield and fruit size rather than quality. Another key observation is that there is a need to determine long-term effects on the trees.

Following the outcome of the experiment in Year 1 and Year 2, strategies to manipulate crop load at different timings in the selected Gala orchard were continued in Year 3 to allow targeting of optimum crop load at much earlier stages.

The timing and intensity of thinning treatments most likely to influence FDM were repeated using different hand, mechanical and chemical thinning methods and timings of events related to days after full bloom. The treatments will be applied to replicated blocks designed in consultation with a statistician.

It is anticipated that where particular thinning timing or crop load intensity have a major influence on FDM then the work package may be adapted to investigate variations in crop load compared to the typical orchard practice.

To achieve a more enlightened process orientated approach, a commercial orchard was utilised in order to follow changes in FDM and components of FDM during fruit development in 2016 (Year 1). During years 2 to 5 of the project different thinning treatments will be applied and it is envisaged this may increase FDM in terms of cell number and in terms of starch accumulation. This approach will enable orchard management strategies to be linked with differential changes in FDM within and between orchards.

Materials and methods

- **Location**

The second year of the trial used an established Gala orchard at FAST LLP, Brogdale Farm, Faversham - Latitude 51.294933, Longitude 0.882898, Reservoir Field, Block 1B, see Figure 3.2.

Figure 3.2. Aerial photograph of FAST trial orchard, Faversham.

The orchard section was approximately 0.07ha. There were four 50m long rows spaced at 3.5m with trees at 1.0m apart within the row.

- **Treatments 2018**

1. **Control** no thinning
2. **Bud** thinning – BBCH 52-54 (end of bud swelling to mouse ear) via bud extinction using MAFCOT Equilifruit tool ratios, completed 24 March

3. **Mechanical** thinning – 60% first open flower (BBCH 65-66) (handheld device), completed 19 May
4. **Chemical Exilis** – Fine Exilis 6-Benzyladenine + Fixor (funded by Fine) (BBCH 70-72) (PGR), completed 23 May
5. **Chemical Brevis** – Adama Brevis 150 SG metamitron 15% (funded by Adama) (BBCH 70-71 & 71-72) (PGR), completed 23 May
6. **Hand Thinning Standard** – fruit size 15mm to 25mm (BBCH 71-72), pre/up to second fruit fall, completed 3 June
7. **Hand Thinning Size** – event 1 fruit size from 25mm to 30mm (BBCH 73), event 2 fruit size 40mm (BBCH 74), completed 14 June
8. **Hand Thinning Late** – fruit size 30mm to 40mm (BBCH 73-74), after second fruit fall-completed 3 July

- **Key findings 2018 FAST**
    - Fruit set good and crop load heavy.
    - Disease pressure higher than in 2017.
    - Little effect of chemical thinners noted.
    - The dry summer affected fruit size.

- **Trial design**

The trial was made up of 1 area in 4 rows. The trail was arranged in a randomised complete block design. Each row represented a replicate block and there were 4 replicates per treatment. Each replicate treatment plot had 3 trees. There were 12 trees per treatment and 96 treatment trees in total. Guard trees were situated between replicate plots and at the ends of each row making 132 trees total. See Figure 3.3. to conditions before, during and after applications (see product label, SDS and guidelines (Appendix 1).

SOUTH

R1	R2	R3	R4
G	G	G	G
2	4	6	3
G	G	G	G
3	1	4	2
G	G	G	G
8	3	5	8
G	G	G	G
1	2	7	4
G	G	G	G
4	5	3	7
G	G	G	G
6	6	2	6
G	G	G	G
5	7	1	1
G	G	G	G
7	8	8	5
G	G	G	G
R1	R2	R3	R4

NORTH

Number	Treatment
1	Control
2	Bud
3	Mechanical
4	Exilis
5	Brevis
6	Standard
7	Size
8	Late
G	Guard tree

Figure 3.3 Trial Plan

Table 3.1 Applications, timing, and descriptions

No.	Treatment	Rate water volume	Events	BBCH stage	Description, fruitlet size and conditions
1.	Control	Na	Na	Na	Na
2.	Bud	Na	1	52-54	MAFCOT Equilifruit tool used to extinguish excess buds and gain optimum per branch diameter of 5 fruits/cm^2 of trunk 160 fruits per tree
3.	Mechanical	6-7 km/ha at around 270 rpm (depending on orchard flower density)	1	65-66	60% first open flower
4.	Chemical Exilis & Fixor*	Exilis 3.5 to **7.5 L/ha** Fixor **100ml/ha** 100 L water	1**	70 -72	8 to 10mm Exilis + Fixor (no treatment above 10mm) (7 to 15mm Exilis alone) Above 15ºC with increasing temperatures for 3 to 4 days after
5.	Chemical Brevis*	1.1kg/ha to **1.65g/ha** (2.2kg/ha max) 1000 L water	2***	70-71 71-72	Application 1 8-10mm Application 2 12-14mm (not made in 2017) 9-11mm optimum (8-14mm max window) lower water volumes (min 350L/ha) & no tank mixing
6.	Standard Hand Thinning	Na	1	72-73	15mm to 25mm pre/up to 2nd fruit fall (50 days post full bloom)
7.	Size Hand Thinning	Na	2	71-72 & 74	Event 1 from 25mm-30mm (BBCH 73), event 2 at 40mm (BBCH 74)
8.	Late Hand Thinning	Na	1	74	30mm to 40mm after 2nd fruit fall

* Chemical thinners were applied using manufacturers' recommendations and adapted according

** 1 per year maximum application

*** NB minimum 5 days between applications

- **Bud thinning**

Treatment 2 Bud Thinning was achieved after pruning using a MAFCOT Equilifruit tool to gain optimum buds per branch diameter. The diameter was measured at the base of each branch nearest to the trunk and the values associated with the branch size used to reduce bud numbers. See Figure 3.4.

Figure 3.4. Mafcot Equilifruit Tool.

- **Mechanical thinning**

An Electroflor machine was used (Ins 9534 BT telescopic pole 1.3-1.8m with battery & mains charger, control & box (Agricare)). Practice was undertaken on similar Gala trees prior to thinning treatment trees to ensure consistent results. See Figure 3.5.

Figure 3.5. Electroflor machine.

- **Hand thinning**

Treatment 7 Hand Thinning Size involved removal of all fruit below the size required and predicted to reach optimum at harvest (63mm). This was predicted using weekly size curves from the FAST members' Top Fruit Advisory. Each of the two events involved removing fruits of different sizes from clusters which resulted in varying numbers of fruit per cluster remaining in all portions of the tree.

Treatments 6 and 8 Hand Thinning Standard and Late were carried out by removal of fruit from clusters leaving doubles below 1.5m and singles above 1.5m.

Thinning per treatment was carried out by the same FAST Trials Team member.

No quality thinning for any treatment was carried out since it was deemed to be too subjective and there was a variable and light crop load; based on the Gala Standard of 5 fruits/cm2 of trunk there were fewer than the optimum of approximately 160 fruits per tree (at 1m apart for 60 t/ha).

Crop load thinning for other treatments was also not considered in the event of over successful chemical or mechanical thinning, partially due to frost events reducing crop load.

- **Crop Care**

The trees/plants were grown according to Good Agricultural Practice following IPM protocols. Regular crop monitoring was carried out by a BASIS qualified FAST advisor for pest and disease. Standard commercial spray programmes were applied as necessary or if thresholds were exceeded and according to IPM Best Practice. Biological control was introduced as appropriate. A standard commercial nutrition programme was followed as recommended by FAST advisors and based on previous soil samples. Standard hand pruning was carried out in spring and summer pruning of the tops as required in July. See Appendix 2 Chronology.

- **Assessments**
    - **Physiological and monitoring**
        - Weekly observations of the trial area were made throughout season.
        - Weekly monitoring of BBCH CGS (Crop Growth Stage) on Control plots was commenced approximately 1 month prior to BBCH 53 (bud burst) and recorded continuing up to BBCH 74 (fruit up to 40mm T stage).
        - Temperature, RH and PAR was monitored via SMS remote sensing equipment.

    - **Visual**
        - Photographs were taken of the middle tree in each treatment plot after each fruit drop event, of fruit dropped under trees, plus prior to and after each thinning event and at harvest
        - Fruit counts
        - A membrane was installed under the middle tree in each treatment plot (from wheeling to wheeling and adjacent trunks) before BBCH stage 55 (bud thinning) and removed after BBCH stage 74 (hand thinning late).

    - Numbers of fruit naturally shed and fallen onto the membrane at each fruit drop event were counted from the middle tree in each treatment plot.
    - Counts of fruit removed from the middle tree in each treatment plot at each thinning event (treatments 6, 7 and 8 only) were recorded. Comparisons of fruit dropped naturally and deliberately thinned were made.

- **Dry matter – pre harvest**

Samples were collected at 2 events prior to harvest:

- 1 week post full bloom – BBCH 70
- 11 weeks post full bloom – BBCH 74, fruits 40mm after second fruit fall (T stage) and after all thinning events

12 fruits per plot were removed and FDM assessed. 4 fruit from each treatment tree were taken, 2 from each side, high and low in the canopy and from 2-year-old wood.

- **Harvest**

Starch progression was monitored weekly at 3 events commencing 3 weeks prior to the predicted harvest date (as per the FAST advisory) to accurately estimate the optimum harvest date. Ten fruit from guard trees in the trial area were selected at random at each event and processed.

Samples from each side of each treatment tree from 2-year-old wood within the top, middle and bottom of canopy were collected prior to harvest for:

- Maturity - 30 fruits per treatment plot total (10 per tree, 5 from each side):
    - Starch
    - Brix %
    - Fruit pressures
- Dry Matter & Fruit Mineral Analysis - 12 fruit total (4 per tree, 2 from each side)
- Quality - 60 fruit per treatment plot were assessed (20 per tree, 10 from each side):
    - Fruit was sorted into C1 and waste
    - The waste was categorised, counted & weighed (under/oversize <55mm / >80mm, disease, russet, pest, misshape, physical damage)
    - The C1 fruit was graded according to 5 size classes (55- 60mm, 60-65mm, 65-70mm, 70-75mm, 75-80mm), counted & weighed

- The percentage was calculated for waste & C1 fruit plus numbers in each size class

- Storage and quality (NRI) - 12 fruit total per plot were sampled (4 fruit per tree, 2 from each side)

Fruit was picked per 3 tree plot and weighed in the field. The average total yield kg and T/H per treatment was calculated plus Class 1 T/Ha, % Class 1 and Waste, average Waste categories, Fruit Weight, Size Distribution and Starch %, % BRIXº and Pressure (kg/mm).

- **Sampling and laboratory analysis NRI University of Greenwich**

Samples for sugar analysis were collected by NRI at three time-points, after petal fall on 9 May, at fruitlet stage 13t July, after the final thinning treatment had been applied and at harvest. Initial samples were first weighed (Fresh weight, FW) before freezing whole in liquid nitrogen while fruitlets greater than 35 mm were sectioned and opposite eighths of cortex were frozen and stored at -80°C. Samples were then subject to freeze drying (-80°C) for 5 days, after which samples were reweighed and a % FDM was calculated. Thereafter freeze-dried material was ground in either with a pestle and mortar or larger samples were powdered in a spice grinder. Samples were then subject to an analysis of sugars by extraction of 0.2g of powdered tissue in 80% ethanol for 120 mins with periodic vortexing; following incubation, the supernatant was collected following centrifugation (12,000 rpm) and filtered through 0.45 µM syringe filters and followed by analysis of sugars by HPLC.

- **Statistical Analysis**

Statistical analysis was carried out using Analysis of Variance (ANOVA) and multiple range tests (MRTs) used to determine whether the differences between individual treatments were statistically significant. Charts/tables are shown with standard error bars (where applicable). The results of the MRTs where statistically significant effects (P value < 0.05) were evident are detailed in charts/tables with P vales and LSDs indicated.

Results

Bud thinning was completed on the 24th March using the MAFCOT Equilifruit tool to estimate the number of buds to be retained. Fruit size assessments for chemical and hand thinning treatment events were commenced in May 2018. Treatments 4 and 5 (chemicals Exilis and Brevis) were applied on 23 May (BBCH 71, fruit size 12mm). Maximum and minimum temperatures along with the sum of daily light radiation 5 days before and after the application date on the 23/5/2018 (Table 3.2).

Table 3.2. Maximum and minimum temperatures and light before, 5 days before and after chemical application events (23 May 2018).

	Max Temp ºC	Min Temp ºC	Light W/M^2 (Sum)
18/05/2018	18.2	3.1	47797.2
19/05/2018	20.2	3.7	49819.3
20/05/2018	20.1	6.1	40623.6
21/05/2018	22	7.6	27540.2
22/05/2018	24	10.3	38479.5
23/05/2018	19	10	35412.4
24/05/2018	18.8	11.3	14770.3
25/05/2018	22.1	13.1	18887.7
26/05/2018	23.7	13.3	41778
27/05/2018	27.4	13.9	38872.6
28/05/2018	25.4	12.6	43706.2

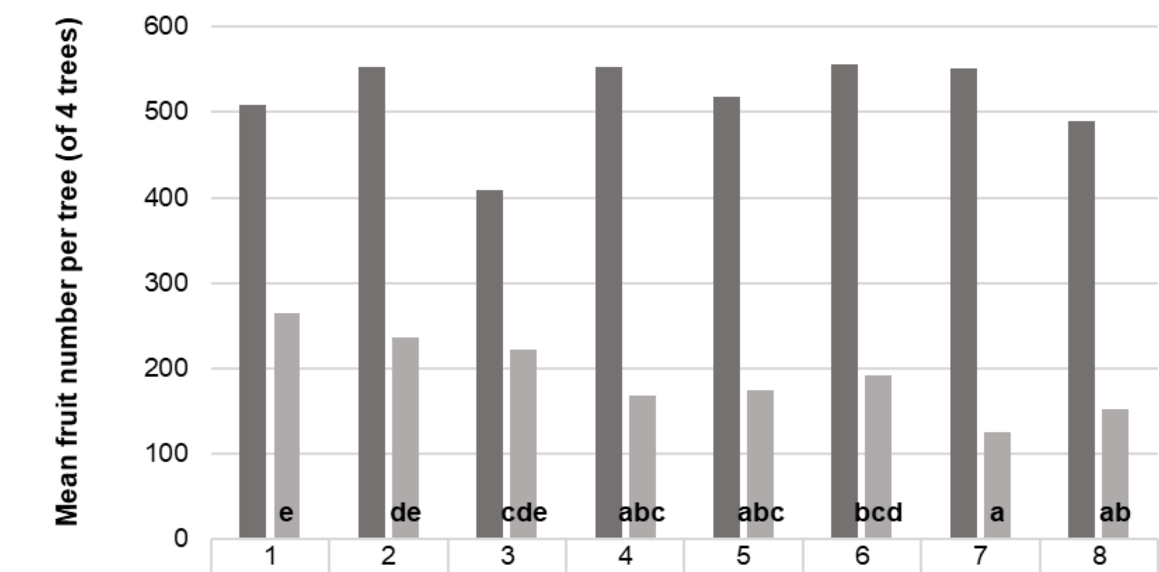
Treatment 6 Hand Thinning Standard was carried out on 3 June (BBCH 72, fruit size 21mm). Treatment 7 Hand Thinning Size was carried out on 14 June (BBCH 73, fruit size 30mm) and 3 July (BBCH 74, fruit size 40mm). Treatment 8 was carried out on 3rd July (BBCH 74, fruit size 40mm).

The proportion of fruit remaining on the tree at harvest after different thinning practices implemented during the growing season (Table 3.3 and Figure. 3.6) Over half (52.1%) the initial fruitlets/fruits aborted in non-thinned trees by September and this was a similar proportion to trees subject to mechanical flower thinning (54.3%). Bud thinning did not reduce the number of fruitlets on the tree, but more fruits were lost in June drop with 42.7% of total fruitlets developing into fully mature fruits, representing a 10% reduction in fruit number over non-thinned trees. Treatment with Exilis or Brevis led to a similar reduction in final fruit number with 30.4 and 33.8% remaining at harvest, respectively. Similar numbers were achieved through standard hand thinning practices (34.3%) or where thinning was delayed (late thinning treatment) yielded 31.3% of fruitlets remaining on the tree till harvest. The techniques that reduced fruit numbers the most was thinning to size where only 22.6 % of fruit remained at harvest.

Yield analysis from the trees revealed no significant effect of thinning practices on harvest weight per tree.

Table 3.3. Fruit numbers per plot prior to June drop and at Harvest.

Treatment	Total fruits before fruit fall	Total fruit at harvest	% Remaining
1	509	265	52.1
2	553	236	42.7
3	409	222	54.3
4	553	168	30.4
5	518	175	33.8
6	557	191	34.3
7	552	125	22.6
8	489	153	31.3



	1	2	3	4	5	6	7	8
Before fruit fall	509	553	409	553	518	557	552	489
Harvest	265	236	222	168	175	191	125	153

Figure 3.6. The effect of thinning practices on the Average Number of Fruits Counted on the Tree before fruit fall and at harvest. Treatment 1: unthinned control, 2: bud removal, 3: mechanical flower removal, 4: Exilis, 5: Brevis, 6: standard thinning,7: thinning to size, 8: late thinning.

Less hand thinning was required when fruitlets were thinned to size (26.2%) or late season thinning (15.2%) compared to 49.8% of fruit requiring thinning using the standard method prior to June drop (Figure. 3.7). However, there was a 10% reduction in fruit at harvest where thinning to size was implemented compared to standard thinning.

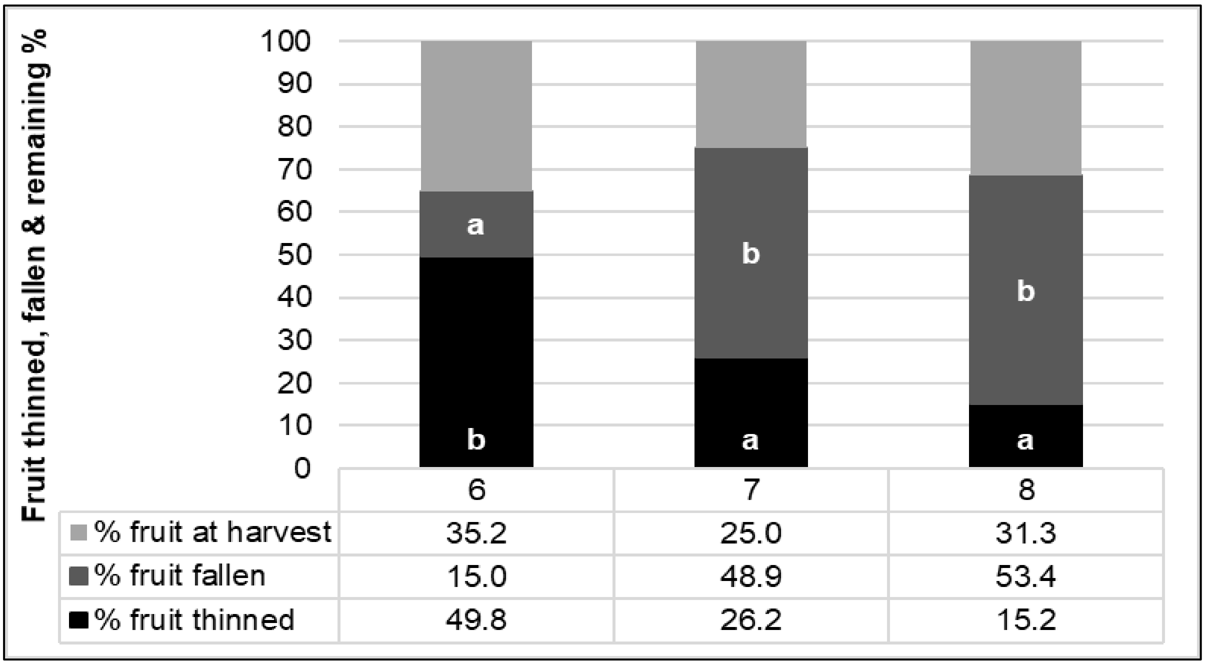


Figure 3.7. The effect of standard thinning (6): thinning to size (7) and late thinning (8) practices on the Percentage Natural v Thinned Fruit

Fruit Maturity at harvest

Starch tests for harvest prediction were carried out on 4, 11 and 14 September when values were 89.7%, 88.6% and 86% respectively. Pressure was also carried out on 11 and 14 September when results were 8.8kg and 8.6kg. % BRIXº on 14 September was 12%.

Fruit mineral analysis was carried out on 12 September and a pick date of 18 September recommended based on laboratory storage predictions. Fruit was harvested on 20 September. Total yields per treatment and average per tree in kg were calculated plus average total yield T/ha and Class 1 yields T/ha. See Table 3.4.

There were no significant effects of treatment upon yield. Treatments 1, 7 and 5 had the highest average total yield T/ha and treatments 8, 6 and 2 the lowest. However, treatments 7 4 and 3 had the highest average Class 1 yield T/ha and Treatments 6, 5 and 8 the lowest (Figures 3.8, 3.9 and 3.10)

Yields of fruit per tree (Fig 3.9) were not significantly different ($p<0.05$) across treatments, with unthinned trees averaging 24 kg per tree while those subject to bud thinning and mechanical flower thinning producing 25.3 and 25.0 kg per tree, respectively. Yields from Exilis (20.1 kg/tree) and Brevis (20.8 kg) were slightly lower but comparable to standard thinning (23.9 kg), thinning to size (21.6 kg) and late thinning (21.6)

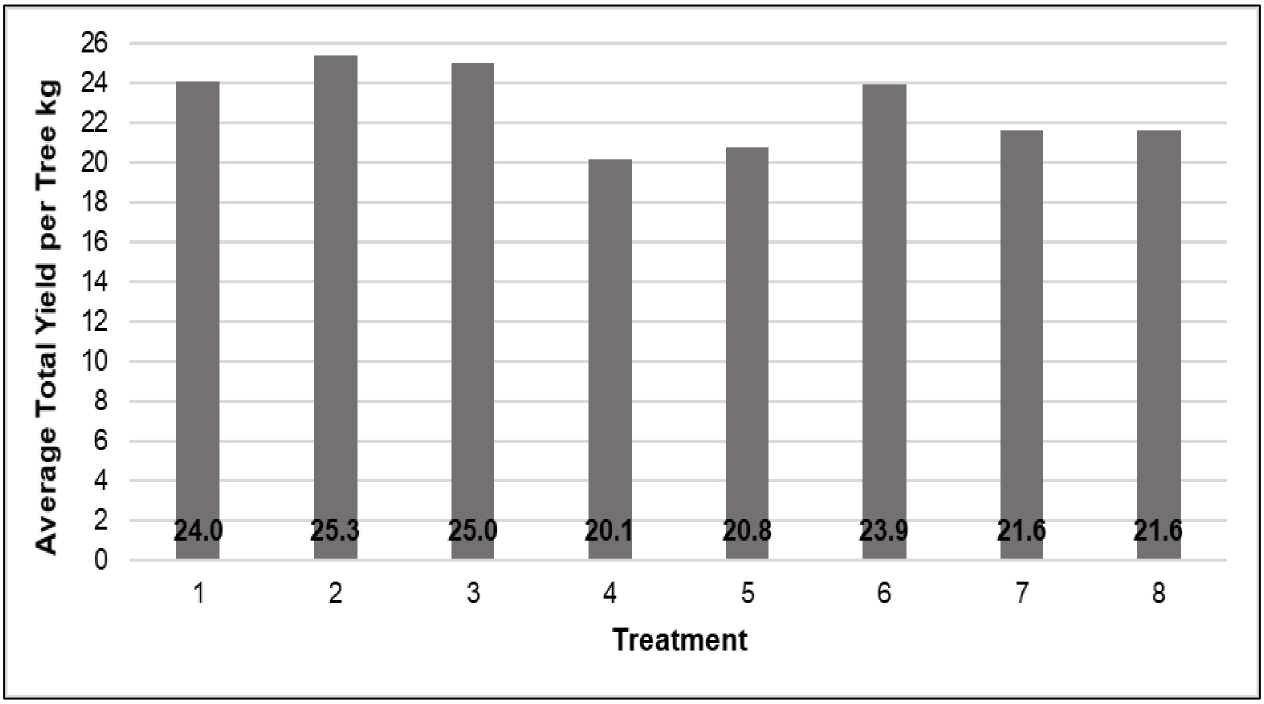
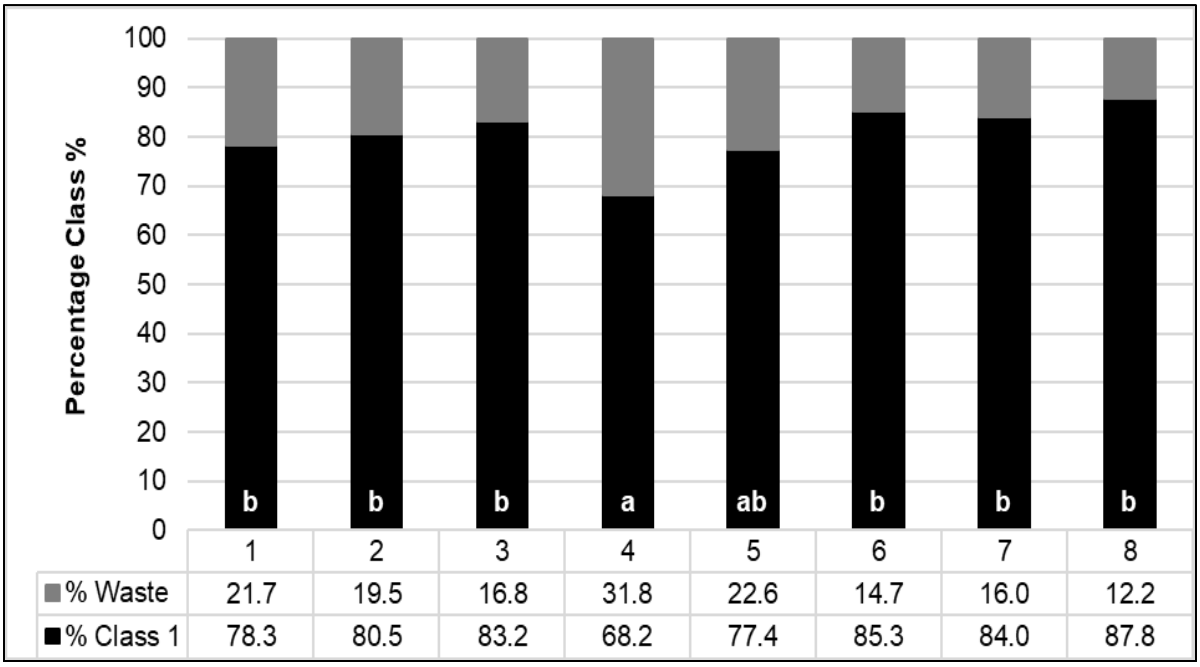


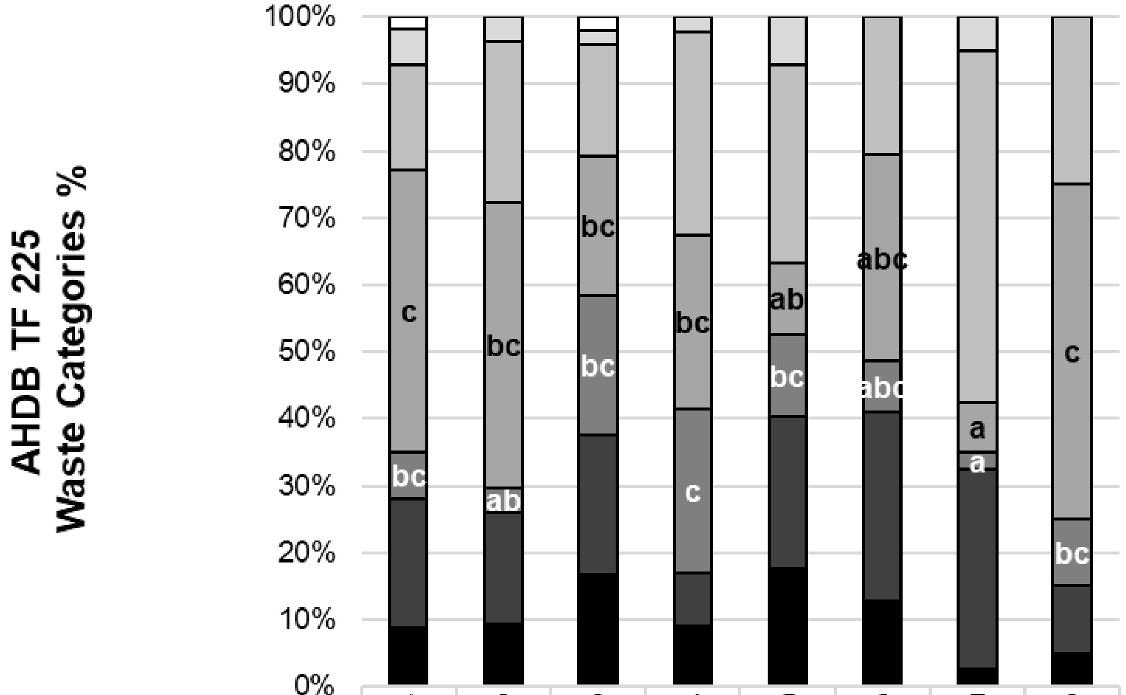
Figure 3.9. The effect of thinning practices on the Total Yield per Treatment (kg) of apples at harvest. Treatment 1: unthinned control, 2: bud removal, 3: mechanical flower removal, 4: Exilis, 5: Brevis, 6: standard thinning,7: thinning to size, 8: late thinning.

After grading the proportion of class 1 fruit in unthinned plots averaged 78.3% of the total yield compared to 85.3 % where standard thinning practices were implemented (Fig. 3.10), similar levels of class 1 fruit were achieved using thinning to size and late thinning with 84 and 87.8% of fruit reaching class 1, respectively. Exilis significantly lowered ($p<0.05$) the proportion of class1 fruit with 10% lower class 1 fruit compared to the unthinned control and this was associated with a higher proportion of misshapped and diseased fuit (Fig 3.11). The biggest proportion of undersized (<55 mm) fruit was found in unthinned and trees subject to bud thinning suggesting the timming of early thinning practices has an important bearing on fruit size. Thinning to size produce the least undersized and misshappen fruit. Recalculating the amount of class 1 fruit as tonnes per hectare (Figure 3.12) shows considerable variation in yields across treatments, with untreated plots producing 53.7 t/ha compared standard thinning practices of 58.2 t/ha, lower class 1 fruit were observed in trees treated with Exilis or Brevis but differences failed to reach significance ($p<0.05$).



	1	2	3	4	5	6	7	8
% Waste	21.7	19.5	16.8	31.8	22.6	14.7	16.0	12.2
% Class 1	78.3	80.5	83.2	68.2	77.4	85.3	84.0	87.8

Figure 3.10. The effect of thinning practices on the Proportion of Class 1 apples at harvest. Treatment 1: unthinned control, 2: bud removal, 3: mechanical flower removal, 4: Exilis, 5: Brevis, 6: standard thinning,7: thinning to size, 8: late thinning.



	1	2	3	4	5	6	7	8
Other	1.8	0.0	2.1	0.0	0.0	0.0	0.0	0.0
Lack of % red	5.3	3.7	2.1	2.2	7.0	0.0	5.0	0.0
Diseased	15.8	24.1	16.7	30.3	29.8	20.5	52.5	25.0
Small	42.1	42.6	20.8	25.8	10.5	30.8	7.5	50.0
Mis-Shape	7.0	3.7	20.8	24.7	12.3	7.7	2.5	10.0
Damage - pest/physical	19.3	16.7	20.8	7.9	22.8	28.2	30.0	10.0
Scarring/Russet	8.8	9.3	16.7	9.0	17.5	12.8	2.5	5.0

Treatment

Figure 3.11. The effect of thinning practices on the Proportion of Waste categories of apples at harvest. Treatment 1: unthinned control, 2: bud removal, 3: mechanical flower removal, 4: Exilis, 5: Brevis, 6: standard thinning,7: thinning to size, 8: late thinning.

Analysis of fruit weights of class 1 fruit found Exilis (treatment 4) produced significantly larger fruit ($p<0.05$) than unthinned trees, with an average weight of 131.0 g/fruit standard thinning averaged class 1 fruits of 122.9 g, thinning to size averaged 128.9 g/fruit and late thinning 117.0g/fruit (Fig. 3.12). Bud thinning produced average fruit weight very similar to fruit from unthinned trees

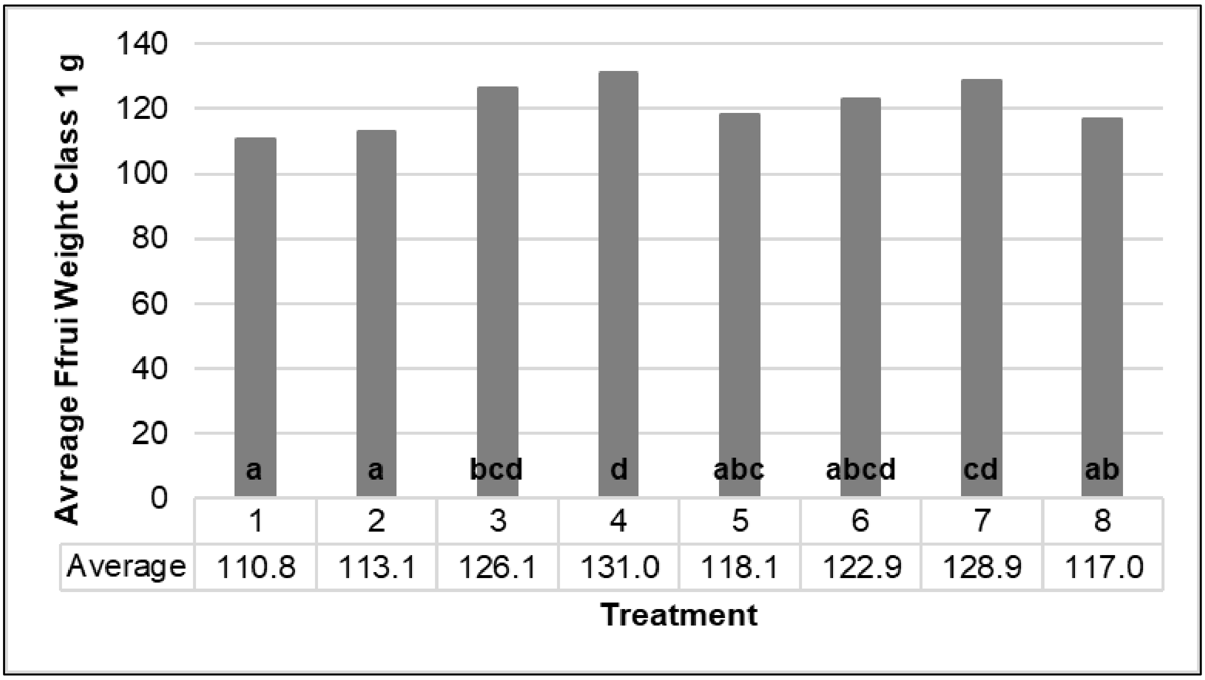


Figure 3.12. The effect of thinning practices on the Average Fruit Weight Class 1 of apples at harvest. Treatment 1: unthinned control, 2: bud removal, 3: mechanical flower removal, 4: Exilis, 5: Brevis, 6: standard thinning,7: thinning to size, 8: late thinning.

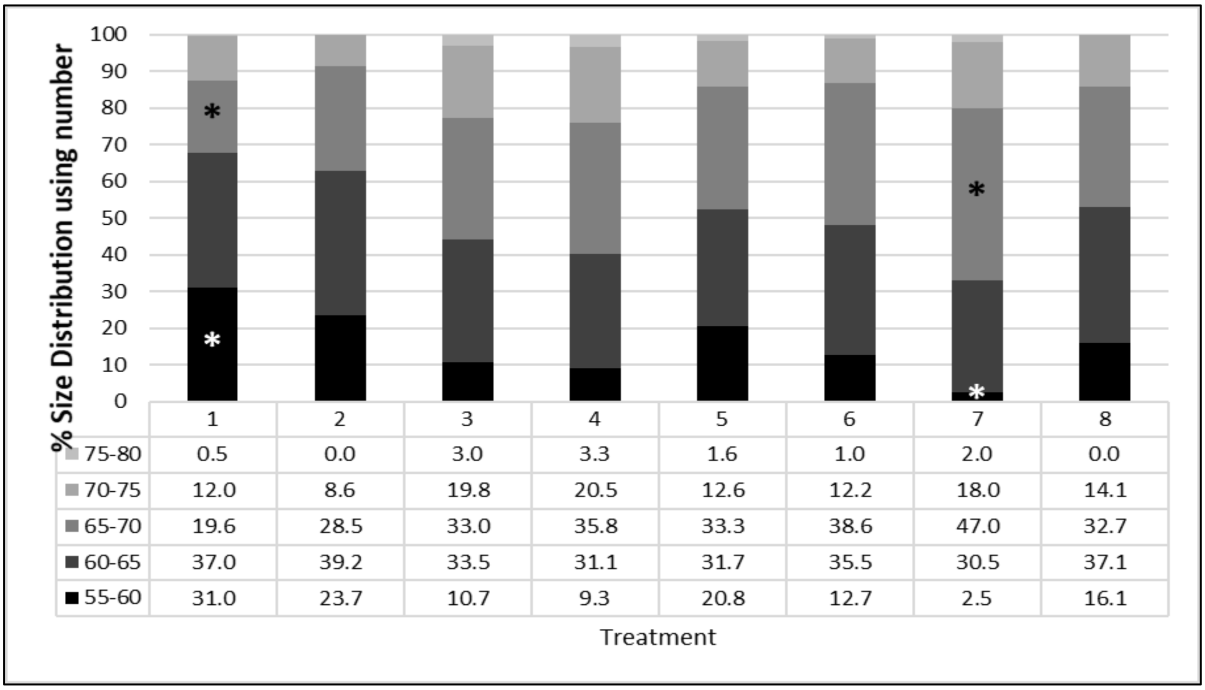


Figure 3.13. The effect of thinning practices on the Size Categories of apples at harvest. Treatment 1: unthinned control, 2: bud removal, 3: mechanical flower removal, 4: Exilis, 5: Brevis, 6: standard thinning,7: thinning to size, 8: late thinning.

The size classes of fruit were affected by thinning practices and treatments, fewer 55-60 mm sized fruit were observed in mechanically thinned trees and those that received Exilis, with the least number in trees where thinning to size was practiced, where fruit size was increased with significantly more 65-70 mm fruit recorded (Fig 3.13).

Harvest maturity measurements by the FAST team found no effect of thinning treatments on starch patterns and fruit maturity, with all trees harvested between 70-80% fruit starch (Figure 3.14) and % Brix average 12-12.5% (Figure 3.15) with fruit firmness ranging from 9.2-9.5 kg (Figure 3.16).

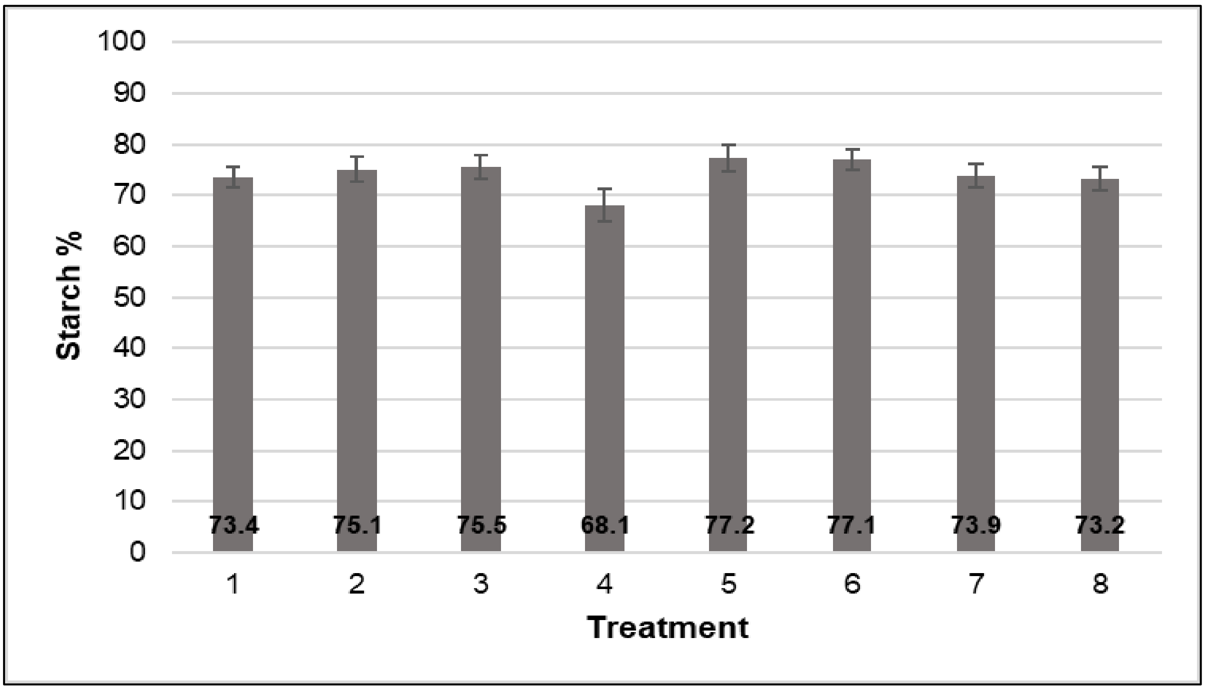


Figure 3.14. The effect of thinning practices on Percentage Starch content from fruit sampled at harvest. Treatment 1: unthinned control, 2: bud removal, 3: mechanical flower removal, 4: Exilis, 5: Brevis, 6: standard thinning,7: thinning to size, 8: late thinning.

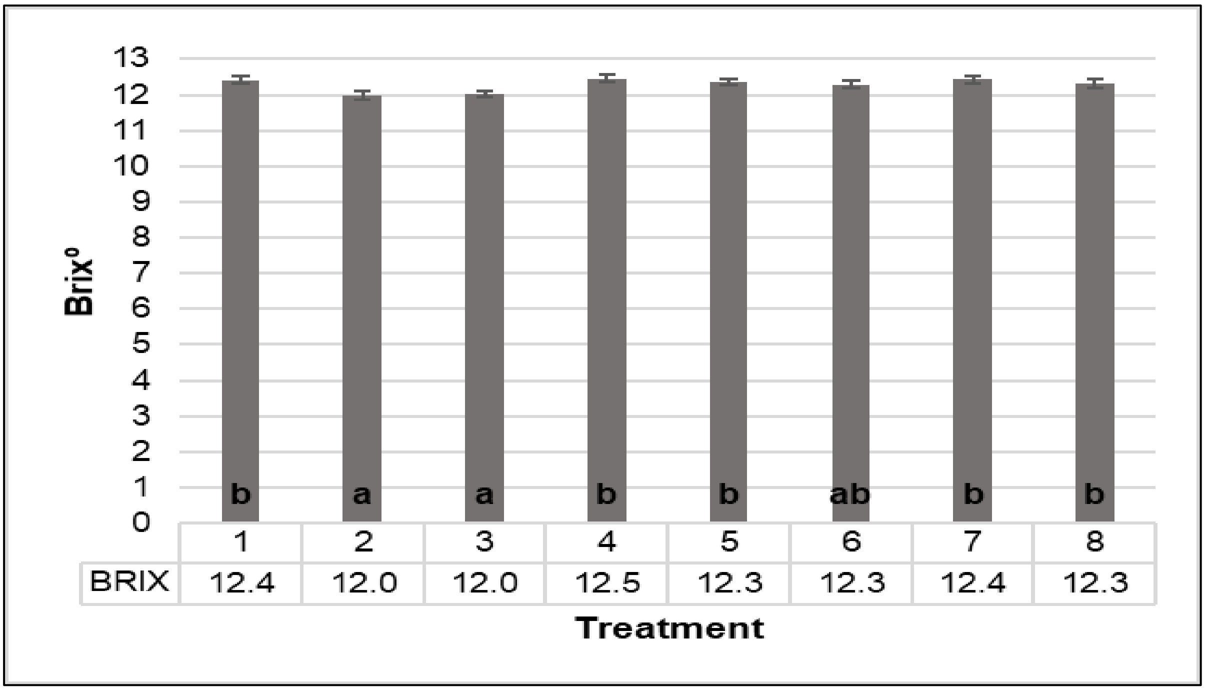


Figure 3.15. The effect of thinning practices on %BRIX of fruit at harvest. Treatment 1: unthinned control, 2: bud removal, 3: mechanical flower removal, 4: Exilis, 5: Brevis, 6: standard thinning,7: thinning to size, 8: late thinning.

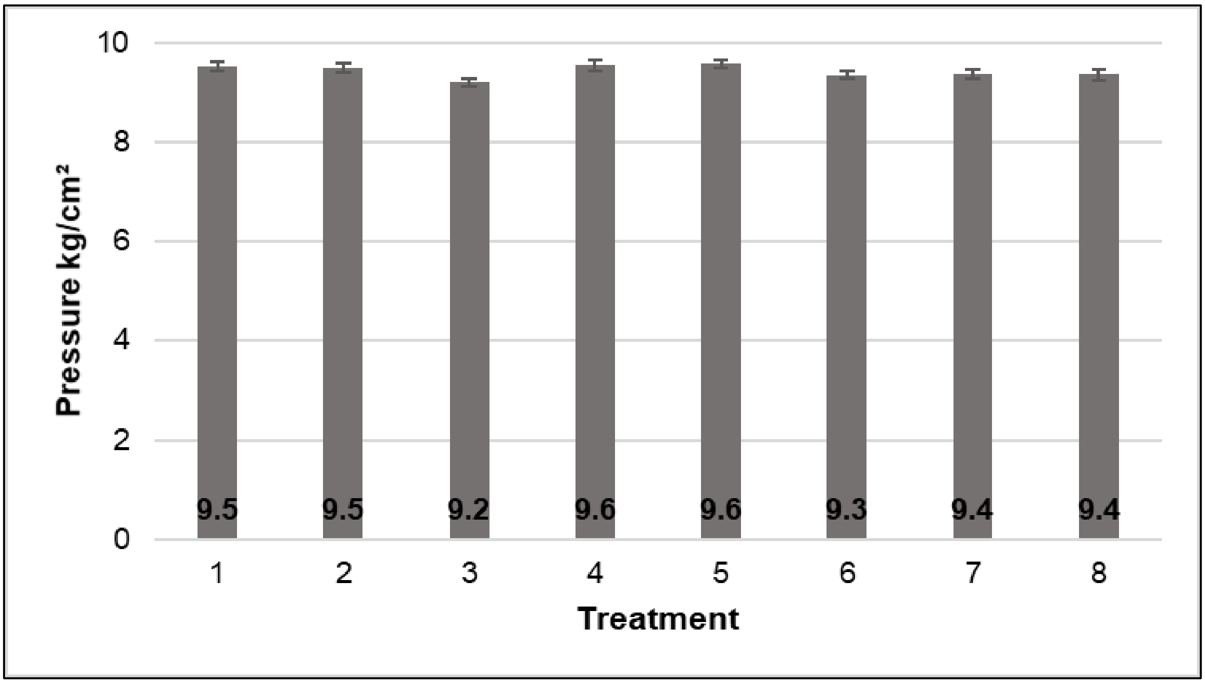


Figure 3.16. The effect of thinning practices on Fruit Firmness (kg cm^2) of fruit at harvest. Treatment 1: unthinned control, 2: bud removal, 3: mechanical flower removal, 4: Exilis, 5: Brevis, 6: standard thinning,7: thinning to size, 8: late thinning.

Fruit Dry Matter and Sugar Analysis

Apples sampled from each plot were taken to the Produce Quality Centre for harvest maturity analysis and for CA storage. Fruit firmness data measured using a Lloyd penetrometer showed firmness ranged from 83.7-86.9 N equivalent to 8.6-8.9 kg/cm in pressure across treatments. No difference in harvest firmness between treatments was observed. Harvest maturity based on starch content indicated fruit sampled from trees treated with Brevis or where trees where 'thinned to size' led to fruit with slightly more advance fruit maturity and less starch ~74.9-75.9% compared to 83% in fruit from un-thinned trees. % Brix content of fruit ranged from 11.4-12.0 % across treatments and no treatment effects of thinning were observed. Equally, no effect on Fruit Dry Matter was recorded across treatments with %FDM ranging between 15.5-16.9% when estimated using oven drying and 15.9-16.4% when freeze drying was applied. Brevis treated fruit recorded the highest %FDM under both techniques but failed to reach significance ($p<0.05$). Analysis of freeze-dried samples for sugars revealed that all thinning treatments raised fructose and sucrose content in apples compared to un-thinned fruit, however, no difference in sugar profiles between thinning treatments were observed on the content of individual sugars.

Table 3.4 Harvest maturity and %FDM and sugar content of Gala apples subject to different thinning practices during fruit development.

Treatment	Control	Bud	Mechanical	Exilis	Brevis	Standard	Size	Late	F.prob	$LSD_{0.05}$
Firmness (N)	83.7	86.5	83.8	86.9	86.5	86.6	85.5	83.9	0.55	4.8
% Brix	11.7	11.4	11.4	12	11.9	11.7	12	11.8	0.18	0.56
% Starch	83	79.8	83.7	77.8	**74.9**	80.9	**75.9**	77	0.04	5.38
% FDM (OD)	15.7	15.5	16.4	15.7	16.9	16.9	15.9	15.8	0.86	2.82
%FDM (FD)	15.9	15.9	15.9	16.1	16.4	15.9	15.9	16.1	0.68	0.68
Fructose(µl/µl)	**25.1**	32.8	33.3	32.9	32.7	34	32.8	34.7	0.18	6.96
Sucrose (µl/µl)	**14.3**	19.3	20	20.9	21.4	20.4	20.5	20	0.12	4.66

OD: Oven Drying, FD: Freeze Drying

Samples of apples from each thinning treatment were subject to CA storage (3% CO_2, 1% O_2) at 0.5-1.0 ºC and sampled after 3,5,6,7 and 8 months. Overall means, averaged over each sampling point show that application of Exilis, Brevis, standard hand thinning or where fruit were thinned to size led to fruit that were marginally firmer (1.2-1.8 N equivalent to 0.12-0.18 kg/cm), Fruit treated with Brevis and those subject to standard hand thinning had slightly higher %Brix° readings (13.0%) compared to un-thinned fruit (12.6%). No effect of thinning on rot development was observed.

Table 3.5 Overall means of ex-store quality measurements of Gala apples subject to different thinning practices and stored in 3% CO_2, 1% O_2 (0.5-1.0°C)

	Control	Bud	Mechanical	Exilis	Brevis	Standard	Size	Late	$LSD_{0.05}$	F.prob
Firm. (N)	80.4	79.9	80.6	81.8	82.8	81.7	81.6	80.5	1.282	<0.001
% Brix	12.6	12.7	12.6	12.8	13.0	13.0	12.8	12.6	0.278	0.013
% Rots	1.4	0.7	2.9	0.7	0.7	2.1	2.1	0.7	8.465	0.776

N.B to convert fruit firmness (N) to kg divide by 9.61

Analysis of Firmness data for changes in quality over time found no appreciable loss of fruit firmness over 8 months of storage of Gala when assessed immediately ex-store, Final samples were also subject to 7 days at 18 ºC where no loss in firmness was observed. The benefits of retaining good fruit firmness throughout the storage season were achieved treated without SmartFresh[TM], however, CA conditions were established immediately using N2 and CO2 flushing after fruits had reached storage temperature.

Table 3.6 Firmness (N) of fruit sampled ex-store and after shelf-life (SL) during CA storage

Firmness (N)	September	December	February	March	April	April SL	May
Control	84	79	79	76	82	82	81
Bud	84	78	77	78	81	81	81
Mechanical	87	78	77	80	80	82	81
Exilis	86	78	80	81	80	86	81
Brevis	87	82	81	80	83	83	83
Standard	86	80	81	81	82	83	80
Size	87	82	80	77	81	82	82
Late	84	77	79	80	82	83	79
$LSD_{0.05}$	3.39		F.prob	0.297			

N.B to convert Firmness in newtons (N) to kg divide by 9.81.

Apple juice taken from samples at harvest and across storage showed a small rise in Brix from 11.4-12% Brix at harvest rising to 12.9-13.5% at the end of storage in May 2019. No treatment differences were observed across individual sampling points.

Table 3.7 Changes in % Brix° during storage

	Harvest	December	February	March	April	April SL	May
Control	11.4	12.7	12.7	12.7	13.1	12.9	13.0
Bud	11.7	12.3	13.2	12.9	13.1	12.5	13.3
Mechanical	11.4	12.6	13.2	12.8	12.8	12.6	12.9
Exilis	11.9	13.1	13.4	13.2	12.2	13.1	13.0
Brevis	12.0	13.5	13.2	12.3	13.7	12.7	13.5
Standard	12.0	13.5	13.7	13.0	13.7	12.4	13.2
Size	11.7	13.1	13.5	12.4	12.8	13.0	13.4
Late	11.8	13.0	13.1	12.5	12.1	13.0	13.2
$LSD_{0.05}$	0.736		F.prob	0.024			

No signs of senescent breakdown or other internal disorders were observed in fruit cut equatorially or across the stem bowl when inspected at each sample point during storage.

Summary and Key Findings WP3

- Thinning techniques did not impact on overall yield or the % of Class 1 fruit.
- Application of Exilis led to an increase in misshapen fruits and lowered the amount of Class 1 fruit at harvest.
- Average fruit weight was higher in trees receiving mechanical thinning, Exilis, thinning to size compared to fruit from unthinned trees.
- Size classes were affected by thinning. Unthinned fruit produced higher numbers fruit in the 55-60 mm size category. Thinning to size led to fruit with the highest fruit size having the most apples in the 60-70 mm category
- 2018 was exceptionally hot with prolonged periods without rain
- Chemical thinners applied to whole of canopy and were effective – too effective?
- Differences in yield between treatments and year likely due to variability of trees
- Fruit weight averages in 2018 were comparable to weights measured 2017 (between 110g and 131g)

April 2019-onwards (season 4 – Appendix 2)

Work package 4: Chlorophyll fluorescence to predict optimal harvest date Gala apples

WP 4 2016 - 2019 Years 1 -3 Mehrdad Mirzaee Landseer Ltd

Background

This work package focused on developing a non-destructive method to optimise harvest date prediction for improving the long-term storage quality of Gala.

While FDM content of fruit provides a good metric for determining the sweetness and overall eating quality of fruit, in order to maximise fruit quality at the end of storage fruits need to be picked within a narrow harvest maturity window to ensure that the benefits of CA storage are fully maximised.

The current best practice for harvesting Gala for long term storage is to pick when starch coverage declines to 90-80% of coverage (CTIFL 3-4). Often this window in starch clearance is narrow and decline in starch occurs by 2% per day once fruits get to around 90% starch coverage.

This does not allow growers enough time to organise picking before starch levels decline further. Analysis of starch coverage is difficult to determine accurately and while there is some tablet-based image analysis software available these require calibration before harvest. Non-destructive methods such as chlorophyll fluorescence may be used as a tool for fruit maturity testing and provide an early prediction of optimum harvest date. Initial studies by Landseer indicate that the system may provide up to 7 to 10 days warning for growers to pick their fruit for long-term stored fruit.

Materials and methods

Work package 4 focused on developing a non-destructive method to optimise harvest date and identifying the orchards suitable for long term storage. This can be achieved by choosing the right fruit with high dry matter and balanced minerals that are picked at the right time for extended keeping quality during long term storage. If this process is carried out correctly then UK Gala should compete effectively with Southern hemisphere fruit both on fruit firmness and, more crucially, taste.

Current harvesting of Gala for long term storage is to pick fruit between 85-80% starch coverage, where background red colour has developed sufficiently to satisfy the marketing desks. However, this narrow window does not allow growers enough time to optimise picking before starch levels decline further. The results in 2016 and 2017 confirmed that application of chlorophyll fluorescence as a non-destructive tool for fruit maturity offers the benefit of 7 to 10 days early warning to the optimum harvest date for long-term storage.

In the second year of trials, the CF profiles and mineral analysis and FDM of different orchards of Gala as fruitlet (25-30mm) were measured in 9 selected orchards in Kent in the first week of July 2017. Samples were taken from each compass point on a tree, North, East, South and West (4 fruitlets per tree, all samples picked from middle height of trees). Samples were taken in a "W" pattern across the orchard taking samples at appropriate points.

In the first week of August sample collection fruit (55-60 mm) from 9 orchards were repeated. After analysing CF, mineral profiles and FDM of fruit, according to the flow chart designed in the first year of trials for decision making about selection of the best orchards for long term storage (Figure 4.1), 5 orchards from different Gala clones: (Mondial, Galaxy and Schniga) were selected for monitoring 2-3 weeks before commercial harvest time. Since FDM and mineral analysis are reflections of orchard management and environment, these both affect fruit maturity and storability. It is essential to monitor for chlorophyll fluorescence only fruit that is intended for long term storage to obtain an accurate prediction model (Table 4.1).

Table 4.1: Comparison of dry matter and mineral analysis in 9 orchards and selecting 5 orchards for the long-term storage (season 2017-18).

FIELDREF	Test	Clone	DMC	CF (AvF)	WT	Interpretation	N	Interpretation	P	Interpretation	K	Interpretation	Mg	Interpretation	Ca	Interpretation
Orchard 1 ✓	Fruitlet (July 2017)	Schneiga	15.6	4664	36.34	Normal	87.36	Normal	13.62	Low	147.78	High	11.02	High	16.59	High
	Fruit (August 2017)		16	4703	97.71	Normal	35.2	Low	9.4	Very Low	94.28	Sli Low	7.45	Normal	10.49	High
Orchard 2 ✓	Fruitlet (July 2017)	Mondial	13.2	5665	40.22	Normal	83.16	Normal	13.21	Low	135.24	Normal	10.04	Normal	14.42	Normal
	Fruit (August 2017)		14.6	4752	103.06	Normal	39.42	Sli low	7.55	Very Low	87.9	Low	6.92	Normal	10.24	High
Orchard 3 ✗	Fruitlet (July 2017)	Galaxy	14.2	4989	48.28	Normal	55.38	Sli low	14.73	Sli Low	129.68	Normal	9.41	Normal	14.86	High
	Fruit (August 2017)		13.6	4291	111.31	Normal	36.72	Sli low	11.08	Sli Low	93.09	Sli Low	6.55	Normal	10.71	High
Orchard 4 ✗	Fruitlet (July 2017)	Galaxy	13.2	4775	43.51	Normal	80.52	Normal	13.02	Low	145.7	High	9.83	Normal	16.34	High
	Fruit (August 2017)		13.6	4553	101.74	Normal	38.08	Sli low	8.39	Very Low	86.75	Low	6.95	Normal	10.06	High
Orchard 5 ✗	Fruitlet (July 2017)	Schneiga	14	5914	47.64	Normal	81.2	High	13.45	Low	125.9	Normal	8.78	Normal	14.15	Normal
	Fruit (August 2017)		13.6	6109	85.96	Normal	48.96	Normal	9.36	Very Low	69.26	Very Low	7.11	Normal	10.69	High
Orchard 6 ✓	Fruitlet (July 2017)	Mondial	12.8	5983	46.57	Normal	67.84	Normal	13.1	Low	103.43	Sli Low	8.08	Normal	15.43	High
	ruit (August 2017)		13	5363	98.36	Normal	46.8	Normal	9.7	Low	85.76	Low	7.03	Normal	13.9	High
Orchard 7 ✗	Fruitlet (July 2017)	Mondial	14.2	4660	46.66	Normal	65.32	Normal	14.3	Sli Low	118.25	Normal	9.28	Normal	16.21	High
	Fruit (August 2017)		12.8	4726	114.86	Normal	42.24	Normal	10.45	Low	64.28	Very Low	6.04	Normal	10.17	High
Orchard 8 ✓	Fruitlet (July 2017)	Galaxy	13.6	6441	49.59	Normal	72.08	Normal	11.16	Very Low	124.99	Normal	9.3	Normal	14.59	High
	Fruit (August 2017)		13.2	5163	88.01	Normal	36.96	Low	6.48	Very Low	71.29	Very Low	6.16	Normal	10.85	High
Orchard 9 ✓	ruitlet (July 2017)	Mondial	13.4	6602	58.42	Normal	73.7	High	15.01	Normal	144.37	High	8.82	Normal	14.53	High
	ruit (August 2017)		14	5403	135.49	High	36.4	Sli low	8.7	Low	84.04	Low	6.04	Normal	8.99	High

A comparison of CF outputs based on the formula developed from Year 1 was used. The degradation formula was based on constructing a baseline CF measurement at fruitlet (25-30 mm) stage and continuing measuring fruits with the PEA fluorimeter until the reduction was less than 50% of the baseline CF:

CF degradation=$\frac{(Fn-\sigma Fn)}{(F1-\sigma F1)}$<50%

Standard starch, firmness and % Brix readings were made for each pick date.

Fruits were harvested from each orchard samples at “CF pick” and “Starch pick” then half of the samples were treated with SmartFresh™. Samples were stored in two regimes and locations for 9 months:

5%CO_2: 1%O_2 (Control & +SF) at (Howt Green) (only CF pick samples).

5%CO_2: 1%O_2 (Control & +SF) at PQC (East Malling) (CF pick and starch pick samples).

Initial monitoring of fruit coming out of commercial stores (5% CO_2: 1% O_2) was in mid-April with subsequent assessments in Mid-May 2018.

Samples stored in the PQC were stored until mid-June 2018 then all samples were tested for CF, dry matter, mineral analysis, and quality assessments. Samples in May were sent for mineral analysis and FDM assessment to YARA analytic. Fruits were subject to CF measurements, fruit firmness, %Brix° and acidity analysis at Landseer.

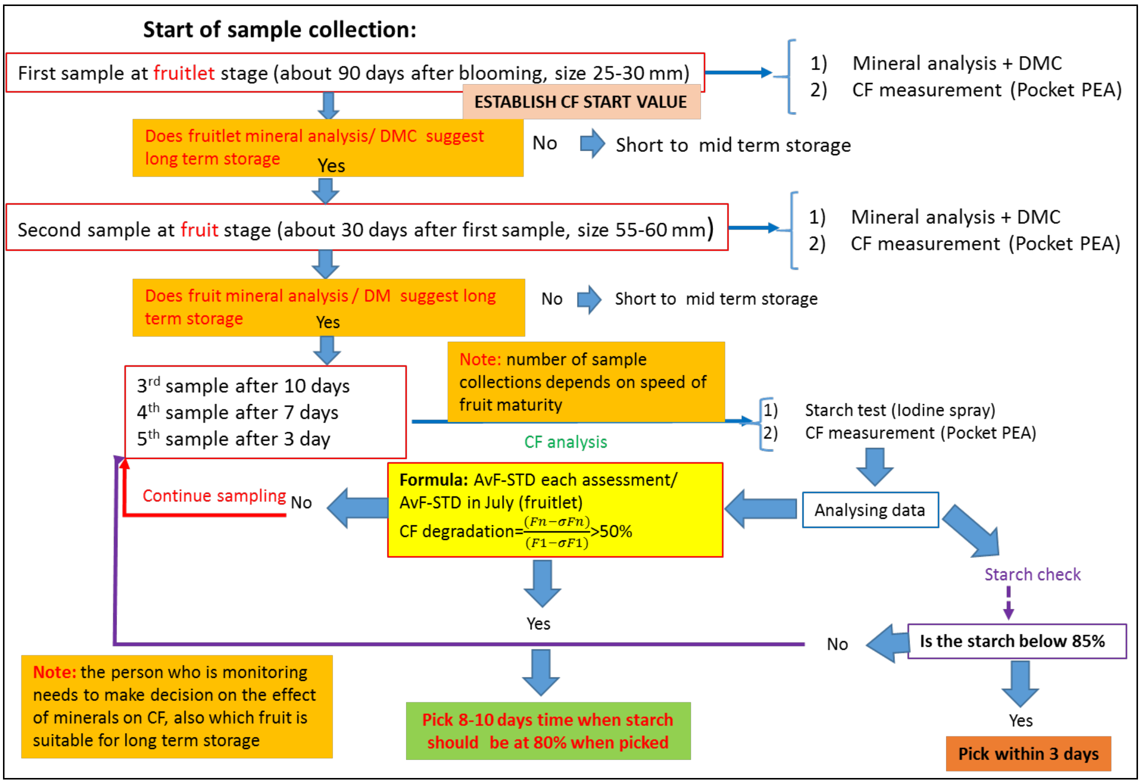


Figure 4.1. Decision tree flowchart for the process of sampling and analysing data for selecting the best orchards for long term storage and early warning for the best picking date.

Results

This work package has focused on developing a non-destructive method to optimise harvest date and identifying the orchards suitable for long term storage. Funded for 3 years as part of TF225, changes in chlorophyll fluorescent signal were investigated as a means to aid the selection of fruit at optimum harvest maturity for long-term storage. With the principle that the activity of chloroplasts in the skin surface declines as fruits mature, providing a metric to predict the optimal picking date of Gala for long-term storage. Orchards were selected to have high fruit dry matter (FDM) and that had contained the correct compliment of macro and minor minerals identifying them suitable for long-term storage. CF prediction was used to ensure fruit was harvested at the optimal picking date for long-term storage, so ensuring fruit coming out of store in Late April, May and early June are of sufficient quality to compete with new season fruits imported from the Southern Hemisphere fruits in May/June.

Current harvesting guidelines of Gala for long-term storage requires picking fruit between 85-80% starch coverage and where background red colour has developed sufficiently to satisfy the retail specifications. However, this narrow window does not allow growers sufficient time to organise picking of orchards before starch drop rapidly below 75-80%. The results between 2016 and 2018 confirmed that application of chlorophyll fluorescence as a non-destructive tool for fruit maturity and offers the early warning that advances in fruit maturity on the tree should result in fruit being ready to pick in the following 7-10 days. In this third and final year of the trial, the same 5 orchards used previously in 2017, were monitored for changes in CF readings between July to September 2018 and continued in samples taken out of storage in July 2019.

Fruit assessments and the methodology used in collecting samples were constant between the 2017 and 2018 seasons. The first sample of fruitlets (25-30 mm) were taken in the first week of July 2018. Sampling was structured in that a single fruit was taken from each compass point on a tree, with all 4 fruitlets per tree, picked from approximately 1.2-1.5 M from the base of trees. Samples were taken as a "W" across the orchard taking samples at appropriate points.

A second period of monitoring recontinued from the second week of August with fruits averaging 55-60 mm in diameter, this process was repeated after 7 days then at further 3 days intervals up to harvest time. Changes in Chlorophyll fluorescence (CF) alongside mineral content and FDM data was used as part of a decision support system in the form of a flow chart to select the best orchards for long term storage. The data analysis provided guidance regarding the expected picking date based on the formula of reduction of CF to less than 50% of CF when first measurement started in July (CF degradation=<50%).

Starch, -iodine patterns were used to measure changes in maturity with firmness and % Brix° measurements taken for each pick date.

Results in previous years of project confirmed that changes in CF readings provided an earlier (7-10 days) warning than relying on starch clearance patterns alone to help predict harvest date. So, fruits were picked 7-10 days after the CF warning suggested fruits should be harvested. Results in Figure 4.2 and Table 4.2 show the CF-pick was on the day when starch was 85-80% (starch warning).

Details of trial plans for thinning trials agreed for 2019 (season 4) are detailed in Appendix 2

Figure 4.2: Comparison of early CF warning with starch index in one orchard (Mystole Top), clone: Schniga (2018).

Table 4.2: Comparison of fruit maturity warning by chlorophyll fluorescence Pocket PEA(CF) and starch

2018	AvF-STD (11 July)	AvF-STD (14 Aug)	AvF-STD (17 Aug)	AvF-STD (20 Aug)	AvF-STD (23 Aug)	AvF-STD (27 Aug)	AvF-STD (31 Aug)	AvF-STD (3 Sept)	AvF-STD (7 Sept)	AvF-STD (10 Sept)
							7 days			
Barnyard	4761	3685	3145	2911	3041	1838	1492	1634	797	696
Ratio to July		0.77	0.66	0.61	0.64	0.39	0.31	0.34	0.17	0.15
	DMC:15	DMC: 13.4				CF alert		CF pick	DMC: 12.6	
Starch		92%	90%	92%	90%	85%	82%	80%	75%	70%
							7 days			
Monks	4566	3180		3097	3054	2034	1198	1227	644	334
Ratio to July		0.70		0.68	0.67	0.45	0.26	0.27	0.14	0.07
	DMC:14.8	DMC: 15				CF alert		CF pick	DMC: 14.2	
Starch		94%		94%	92%	90%	86%	80%	75%	70%
								10 days		
Gibbens	4959	3773	3805	3348	3194	2639	1905	1738	1214	897
Ratio to July		0.76	0.77	0.68	0.64	0.53	0.38	0.35	0.24	0.18
	DMC:16.6	DMC: 15.4					CF alert		DMC: 14.6	CF pick
Starch		95%	94%	92%	92%	92%	92%	90%	85%	82%
							7 days			
Hill Top	4549	3038	2842	2642	2584	1585	1042	1069	416	304
Ratio to July		0.67	0.62	0.58	0.57	0.35	0.23	0.23	0.09	0.07
	DMC:15.6	DMC: 13.6				CF alert		CF pick	DMC: 13.4	
Starch		93%	91%	91%	90%	87%	86%	80%	75%	70%
									10 days	
Mystole	4665	3410		3040	3158	2412	2069	1652	1292	696
Ratio to July		0.73		0.65	0.68	0.52	0.44	0.35	0.28	0.15
	DMC:16.2	DMC: 15.6					CF alert		DMC: 14	CF pick
Starch		94%		94%	92%	92%	91%	86%	87%	82%

Internal ethylene production of samples was measured at Jim Mount by Dr Richard Colgan. Orchard consignments Mystole Top and Gibbens were predicted to be the least mature when sampled 10 days before harvest and tested by CF internal ethylene concentration, both methods showed the same priority in maturity between samples (Figure 4.3).

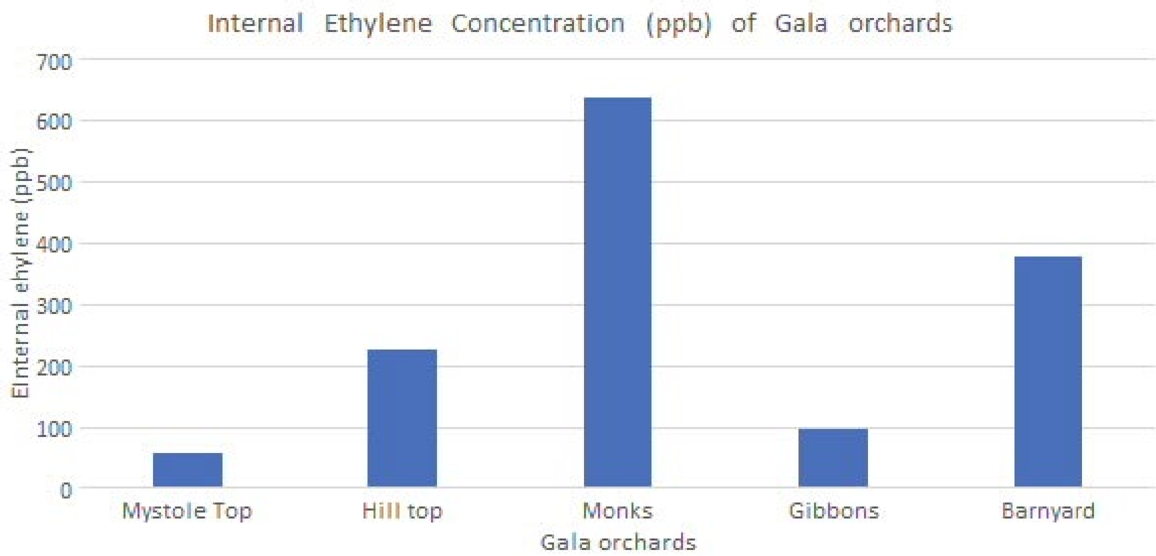


Figure 4.3: Comparison of internal ethylene production in samples from each orchard 10 days before harvest.

Samples from each orchard were picked after 7-10 days of CF warning (Table A) and half were treated with SmartFresh™ for 24 hours at store temperature before transfer to research storage cabinets in Jim Mount (East Malling) for 10 months at 0.5-1.0°C until last week of June 2019:

A. 5%CO_2: 1%O_2 (untreated and +SmartFresh™)
B. 5% CO_2 >%0.6 O_2 (untreated) -DCA storage
C. 5% CO_2 >%0.6 O_2 (+SmartFresh™) – DCA storage followed by conditioning at 3% CO_2: 2%O_2 for the last 3 months of storage

Additional samples were placed in a commercial store (Howt Green) at regime 5% CO_2: 1% O_2 (untreated and +SmartFresh™).

Initial monitoring of fruit quality from the commercial store (5%CO2: 1%O2) was undertaken in mid-April with subsequent assessments made in Mid-July 2019. Samples in Jim Mount taken out of storage cabinets in the last week of June 2019 then all samples were tested for CF, Dry matter, mineral analysis (YARA analytic) and quality assessments. Table 4.3 shows comparison of mineral analysis results between fruitlet until end of storage in different orchards. Preliminary analysis indicates samples which had deficiency of nitrogen and phosphorus had lower dry matter and ripened faster.

Table 4.3: Changes in mineral content during fruitlet of fruit development and subsequent sampling at the end of storage from selected orchards

Comparison of changes in minerals and CF in fruitlet and fruit between July 2018 to June 2019														
FIELDREF	Test	Clone	DMC	CF (AvF-STD)	N	Interpretation	P	Interpretation	K	Interpretation	Mg	Interpretation	Ca	Interpretation
MYSTOLE TOP (NEWMA FRUIT)	Fruitlet (July 2018)	Schneiga	16.2	4665	64.04	Normal	13.28	Sli Low	133.8	Normal	8.59	Normal	12.96	Normal
	Fruit (August 2018)		15.6	3410	45.28	Normal	10.34	Normal	114.3	Normal	6.45	High	9.47	High
	Fruit (September 2018)		14	1652	40.6	Normal	9.59	Sli Low	101.7	Normal	5.59	High	7.9	Normal
	Fruit (June 2019) Untreated		13.6	635	34	Sli Low	8.8	Low	90.45	Sli Low	5.05	High	7.04	Normal
	Fruit (June 2019) SmartFresh		15.2	1100	33.4	Sli Low	8.94	Low	110.6	Normal	5.47	High	6.98	Normal
MONKS FARM/ANTONY (SIMON BRAY)	Fruitlet (July 2018)	Mondial	14.8	4566	69.56	Normal	12.9	Sli Low	144	High	9.25	Normal	12.72	Normal
	Fruit (August 2018)		15	3180	46.5	Normal	11.14	Normal	127.9	High	6.51	High	9.88	High
	Fruit (September 2018)		14.2	1227	29.82	Low	10.84	Normal	118.4	Normal	5.93	High	9.72	High
	Fruit (June 2019) Untreated		14.2	173	39.76	Sli Low	11.59	Sli Low	135.2	High	5.96	High	6.53	Normal
	Fruit (June 2019) SmartFresh		12.8	1785	43.52	Normal	10.65	Sli Low	107.6	Normal	5.79	High	7.86	Normal
GIBBENS FARM/COTTAGE GALA (GOATHAM)	Fruitlet (July 2018)	Mondial	16.6	4959	66.4	Sli Low	14.26	Sli Low	144	Normal	9.07	Normal	14.5	Normal
	Fruit (August 2018)		15.4	3180	46.2	Normal	11.27	Normal	112.9	Normal	6.19	High	11.11	High
	Fruit (September 2018)		14.6	1227	35.04	Sli Low	10.39	Normal	99.82	Sli Low	5.79	High	10.59	High
	Fruit (June 2019) Untreated		13.8	2792	33.12	Sli Low	8.93	Low	97.4	Sli Low	4.84	Normal	7.33	Normal
	Fruit (June 2019) SmartFresh		13.8	1484	33.12	Sli Low	9.03	Low	86.6	Sli Low	4.5	Normal	6.94	Normal
HILL TOP GORE (GOATHAM)	Fruitlet (July 2018)	Galaxy	15.6	4549	51.48	Low	9.22	Very Low	140.2	Normal	8.3	Normal	12.56	Normal
	Fruit (August 2018)		13.6	3038	39.44	Sli Low	8.57	Low	105.9	Normal	5.68	High	7.81	Normal
	Fruit (September 2018)		13.4	1069	32.16	Sli Low	6.57	Very Low	110.3	Normal	5.12	High	8.4	High
	Fruit (June 2019) Untreated		12.6	999	25.2	Low	6.07	Very Low	102.1	Normal	4.98	Normal	6.99	Normal
	Fruit (June 2019) SmartFresh		12.4	1729	33.48	Sli Low	6.86	Very Low	106.6	Normal	5.17	High	7.03	Normal
BARNYARD (GOATHAM)	Fruitlet (July 2018)	Mondial	15	4761	57	Sli Low	12.34	Sli Low	128.5	Normal	8.23	Normal	15.68	High
	Fruit (August 2018)		13.4	3685	40.2	Normal	10.01	Normal	101.2	Normal	5.45	High	9.28	High
	Fruit (September 2018)		12.6	1634	31.5	Sli Low	8.08	Low	93.62	Sli Low	4.93	Normal	8.46	High
	Fruit (June 2019) Untreated		11.4	2498	23.94	Low	8.96	Low	89.21	Sli Low	4.47	Normal	6.75	Normal
	Fruit (June 2019) SmartFresh		12	2962	36	Sli Low	7.58	Very Low	87.89	Sli Low	4.63	Normal	7.94	Normal

Measurements of CF, firmness (kg/cm2), % Brix and acidity were undertaken at Landseer. In addition, a subset of apples was taste tested by a panel of 22 industry and trade representatives as growers, researchers (AHDB & NIAB EMR), marketeers and journalists on 1st of July 2019 at Jim Mount (East Malling).

The UK apple samples were selected as high or low dry matter in different storage regimes; (5:1 and DCA) and samples were either untreated or treated with SmartFresh^{TM}. Gala apples from the Southern hemisphere (Chili and South Africa) were obtained from 3 different supermarket chains and tested for firmness, % brix and acidity.

UK Gala samples used in taste panels they were kept for 7 days at ambient and compared to Southern hemisphere fruit stored for 6 days in chilled conditions (4°C). Fruits were segmented into quarters just prior to taste tests. The panel scored each slice as Poor (1 point) Acceptable (2 points) and Good (3 points) for overall taste. Pairs of samples providing comparisons of fruit with high or low dry matter stored in different storage were compared with a slice of apple from the Southern hemisphere.

The results showed a significant preference in favour of the UK Gala specially samples with high dry matter (Figure 4.4). All samples with high dry matter were preferred in taste tests to samples with low dry matter and the samples from the southern hemisphere.

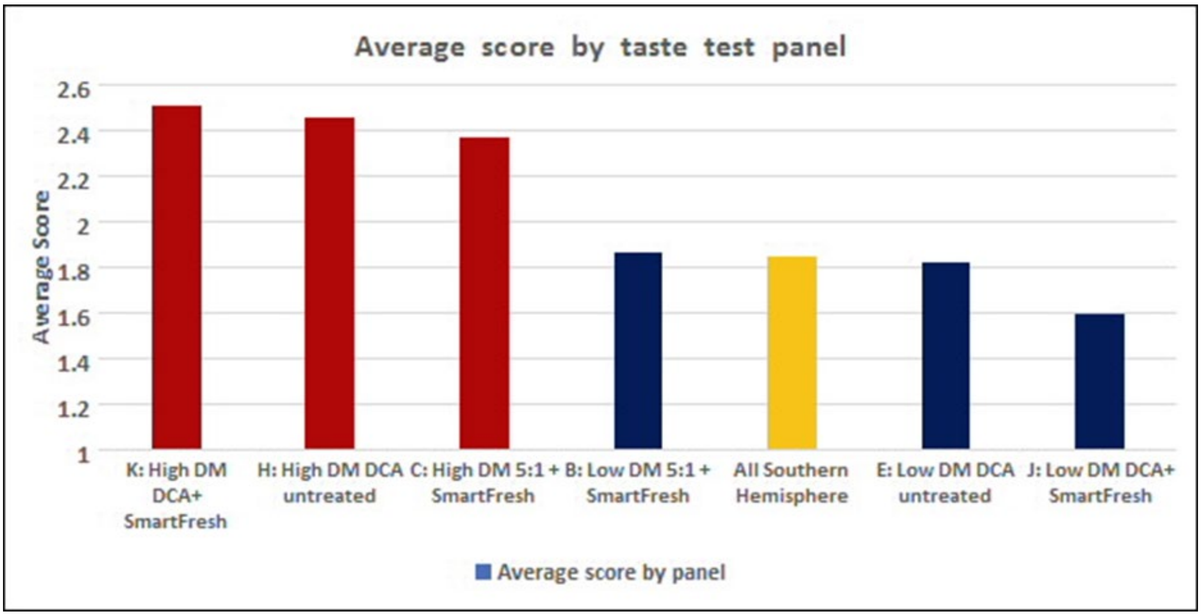


Figure 4.4: Comparison of quality and taste of long-term stored UK gala (picked September 2018) with imported gala from Southern hemisphere (picked May 2019).

Fruit firmness of UK apples stored for 10 months under CA conditions, followed by 7 days shelf-life and irrespective of FDM content or SmartFresh^{TM} application were significantly firmer than new season apples from Southern Hemisphere (Figure 4.5). All Gala apples coming out of store at the end of June and following a weeks shelf-life were between 8-9 kg firmness, compared to imported fruit averaging 6 kg firmness.

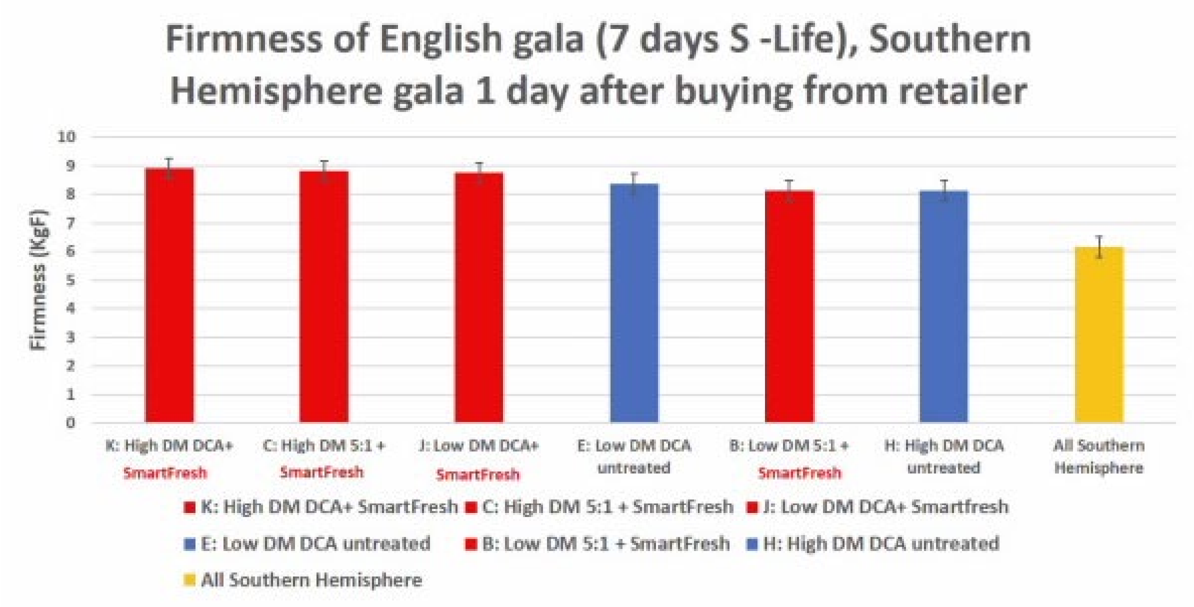


Figure 4.5: Comparison of fruit firmness in different treatments.

Although generally fruit dry matter decreases during storage , the reduction rate in untreated samples was more rapid than those treated with SmartFresh^{TM} between harvest in September 2018 to end of storage in last week of June 2019 (Figure 4.6).

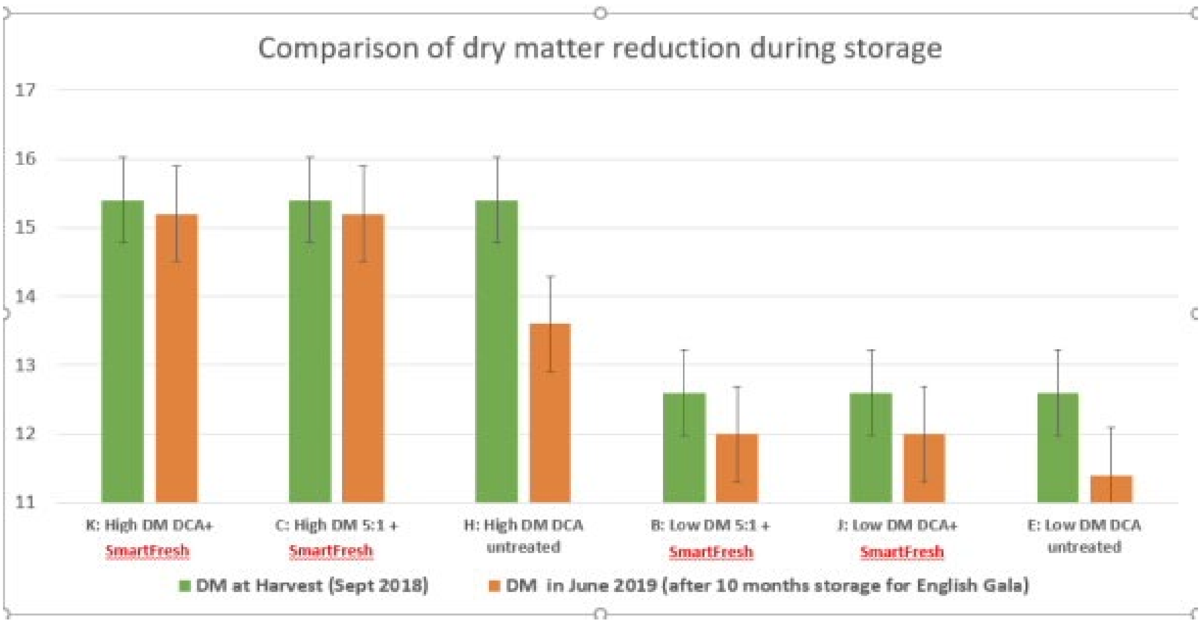


Figure 4.6: Comparison of reduction in dry matter during long term storage

There was a correlation between dry matter and Brix, samples with higher dry matter, had higher Brix (Figure 4.7).

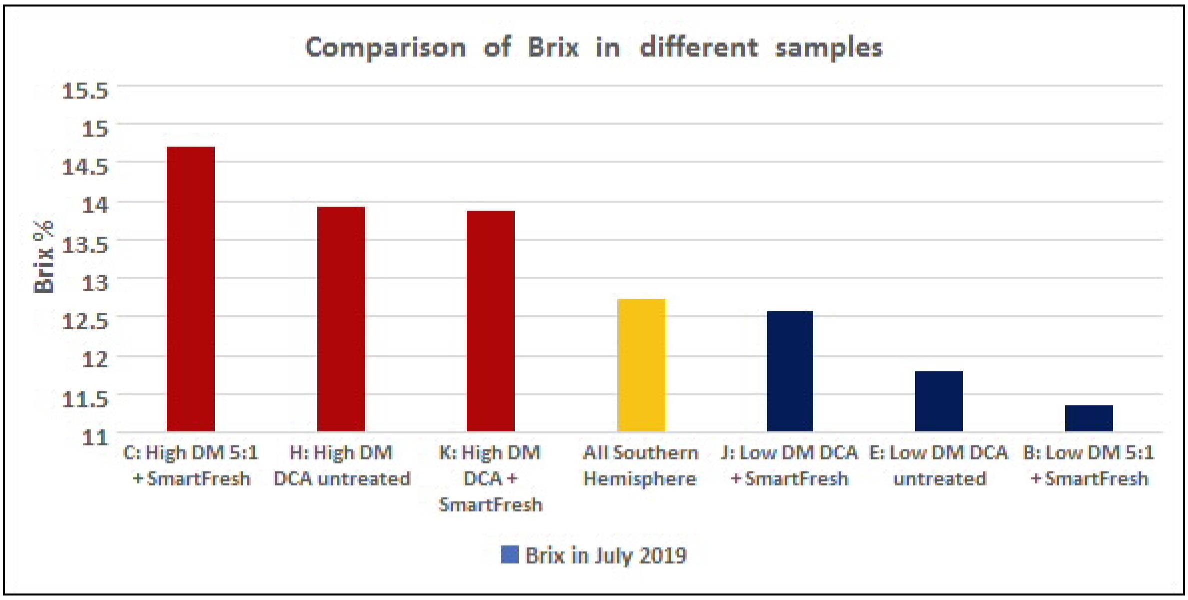


Figure 4.7: Comparison of Brix in different samples. Samples with higher dry matter had significantly higher Brix.

Samples treated with SmartFresh^{TM} showed higher acidity (Figure 4.8), and this might have been expected as there is a correlation between acidity of fruit and flavour. SmartFresh^{TM} by maintaining acidity of fruit helps to keep flavour after long term storage.

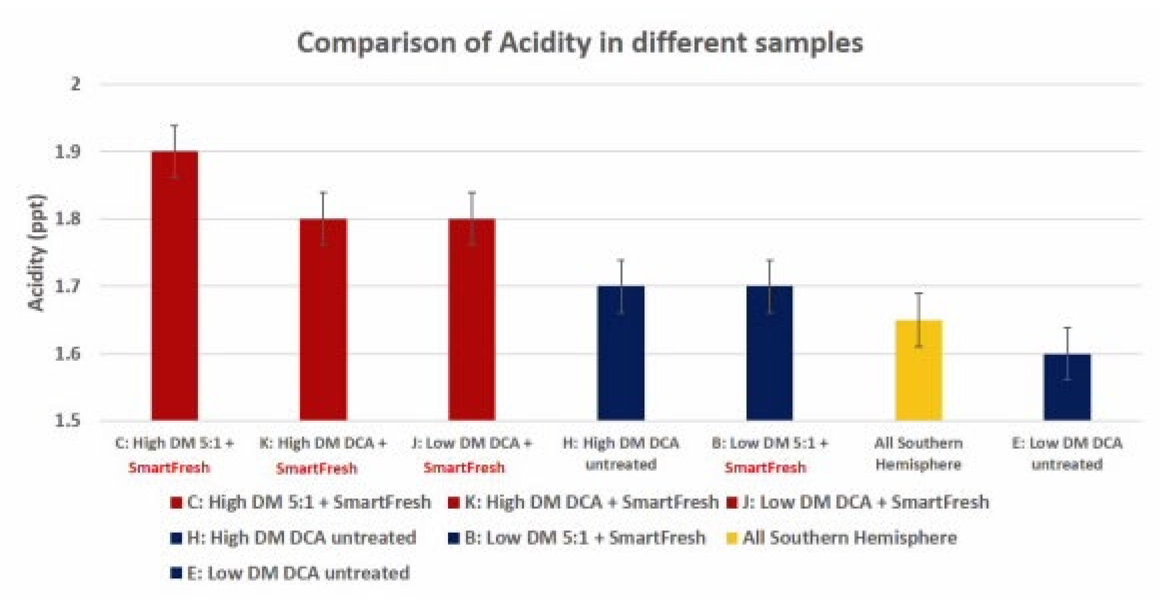


Figure 4.8: Comparison of acidity level in different treatment and imported fruit from southern hemisphere.

All UK Gala had greener background comparing with imported southern hemisphere gala (Figure 4.9). Also, most samples treated with SmartFresh™ kept a greener background. SmartFresh™ reduces the degradation of chlorophyll and hence keeps the background green.

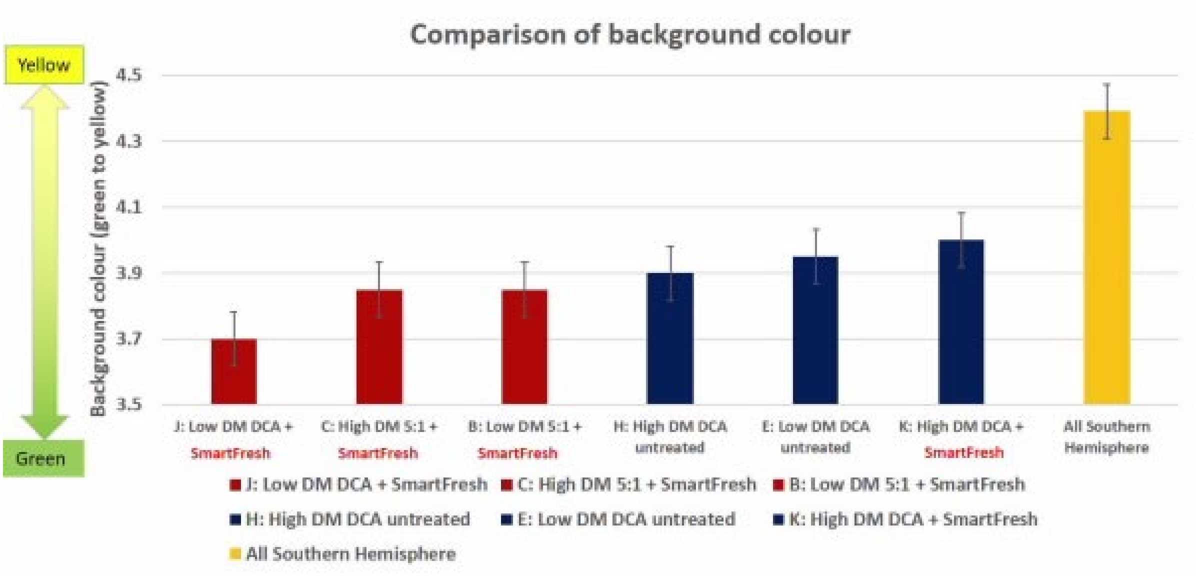


Figure 4.9: Comparison of treatments for maintaining green background colour (Measured by colour cards)

Summary results:

Fruit firmness has effect on mouth feel and consumer preference, SmartFresh™ helps to maintain firmness in different storage regimes; all UK samples treated and untreated retained good firmness above 8 kg/cm during 9 months of CA storage. Fruit Dry Matter has an important role in maintaining the organoleptic properties; fruits with high dry matter tend to be sweeter and retain flavour after a long-term storage. Acidity has an important role in fruit taste and SmartFresh™ by maintaining acidity during storage helps to maintain the taste/flavour. SmartFresh™ reduces degradation of chlorophyll and helps to keep background greener during storage.

Conclusions:

Results obtained this season confirmed data from the 2 previous years data showed in that the prediction model gave 7-10 days early warning for picking samples this could provide a tool to help with the harvest decision making process.

Storage monitoring showed that it is possible to store UK Gala for 9 months and retain good eating quality if fruit is picked within the optimum harvest window and that fruits contain the correct complement of minerals and a high FDM. Establishing CA conditions as soon as fruits have reach store temperature and application of SmartFresh™ can help to maintain quality of fruit. This shows that supermarkets can be supplied by UK Gala after April, and in some cases until late June or early July.

The fruit quality and flavour of high dry matter gala which was picked on time and stored for 10 months is similar or better than imported fruit.

The main parameters for a successful long-term storage are:

- Identifying high dry matter fruit
- Picking within the optimal harvest window for each variety
- Filling stores in a short period
- SmartFresh™ fruit in different regimes (5:1 or DCA)

Future work:
Data analysis of CF outputs is complicated and time consuming. Landseer's aim is to develop a practical and affordable handheld device for growers to use in their orchards. To make the device useful for UK growers there is a need to build up data sets over several years in our conditions and provide a tool for grower decision making. Additional funds are required to help transition the work of CF prediction to a practical tool for growers.

Discussion Work Packages 1-4

High sunlight interception throughout fruit development and possibly as early as bud development in the previous season will impact subsequent fruit quality. Increasing the amount of light interception by centrifugal pruning techniques affords the opportunity to improve tree performance above existing standard spindle tree architecture systems supported on post and wire structures. Laying down reflective mulches at key developmental stages in the life cycle of fruit buds and developing fruits demonstrates the importance of improving light interception within the orchard on fruit quality at harvest.

In previous year's trial higher FDM was observed in fruit samples segregated for position on the tree with higher FDM found at the top of the canopy. In the 2018 trial apples taken from across the tree canopy were used for FDM analysis. Centrifugally pruned trees had a 0.4-0.5% increase in FDM compared to fruit cultivated on standard tall spindle trees, however the sugar content predominately made up of fructose and sucrose failed to show any increase in fruits from either training system. Interestingly, in the 2018 trial reflective covers had no additional benefit in increasing FDM or sugars. Overall, reflective covers advanced the maturity of Gala in fruit harvested from tall spindle trees, leading to more rapid loss of starch in fruit at harvest across the canopy. This was most probably a result of increasing light and heat into the lower part of the canopy.

In contrast, apples from centrifugally pruned trees fruit maturity was less advanced most probably a result of lower fruit numbers per tree.

The 2018 growing season was particularly warm with higher than average sunshine hours and this is reflected in the high FDM (~17% FDM) content of fruit irrespective of training system or presence of reflective covers. In years with weather patterns more consistent with the Long-Term Averages (LTA) treatment differences may be expected to be more pronounced.

Previous reports (Palmer 2010; McGlone 2003) highlight a strong relationship between overall FDM and the amount of sugar (% BRIXº) in the crop at harvest and that this relationship carries on during the early stages of storage (3 months).

While fruit from the upper canopy intercepts more sunlight, increasing light penetration with centrifugal pruning or reflecting light back up into the canopy failed to increase FDM, however, the high % FDM observed across treatments suggests that the relationship between light interception and FDM is not linear and that in 2018 season fruits were at the higher end of FDM spectrum.

In this second year of implementing bud and flower thinning strategies no significant impact on FMD content was observed, however, Brevis and Exilis treated trees were as effective as standard hand thinning in reducing fruit numbers at harvest but Exilis increased the number of misshapen fruits. In two years of the trials application of Brevis was as effective as standard thinning in increasing FDM, increasing the plot size of treatments will help to reduce the variability of treatments. Weather events around application time are critical to the effectiveness of chemical thinning agents and caution should be taken when considering a second application, if the first failed due to poor uptake.

Bud thinning and mechanical removal of flowers were the least effective at reducing fruit numbers at harvest, and bud thinning had no effect on raising %FDM, however, all of the thinning treatments raised sucrose and fructose content in fruit at harvest to a similar concentration, suggesting there is a certain degree of plasticity in the way fruits accumulate sugars. In trees where bud/flowers were removed, a higher retention of fruits retained similar amounts of sugars to treatments where fewer fruits remained on the tree at harvest but where thinning events happened later in the fruits development cycle. Targeting thinning strategies around cell division may help to increase FDM- this is the focus of the 2019 trial.

Brevis not only lowers fruit numbers but also reduces the photosynthetic capacity of shoots and the growth rate of water shoots which act as a sink for carbohydrate. Understanding the source sink relationship between shoots and fruits under different thinning treatments may provide a greater understanding of how best to manipulate tree architecture to increase FDM.

Other factors such as soil, tree age and rootstock will clearly affect tree architecture, resource allocation and precocity of flowering and fruit set. Therefore, a complex interaction between many agronomic factors plays a part in influencing portioning of carbohydrate into fruits. Some of these factors are more amenable to manipulation than others.

Thinning strategies to remove fruit numbers based on branch thickness, using the Mafcot Equilifruit tool, goes some way in manipulating crop load.in relation to tree architecture. However, a greater understanding of the optimum crop load and fruit number in relation to the size of the tree canopy and how this impacts on raising %FDM is required; using LIDAR to generate architectural profiles of tree canopies may take this forward.

Analysis of existing FMD data sets of 56 orchards provided by FAST LLP using Pearsons Correlations and multiple regression analysis of over 3 years' data of FDM against leaf and fruit mineral analysis found weak positive correlation with Fe, K, Mg, P, K:Ca ratio. Leaves under Mg and K deficiency hold on to their photosynthates and are less likely to partition carbohydrates to roots (Cakmak et al 1994) or other sink organs such as fruits. Zhoa (2001) reported that K deficiencies in cotton plants led to lower chlorophyll content, poor chloroplast ultrastructure and reduced translocation of sugars due to reduced entry of sucrose in the transport pool or lower phloem loading. Increasing leaf Mg and K may help to encourage greater translocation of photosynthates into fruits increasing FDM. Importantly, Mg and K act as antagonists to calcium binding to pectin in the middle lamella and pectins within the cell wall; increasing fruit Mg and K excessively could have implications for the long-term storage capacity of fruit unless fruit calcium concentrations can be increased at the same time.

Being able to predict the onset of changes in starch clearance patterns before such changes in maturity happen offers some interesting options for the future management of harvest maturity prediction. Chloroplast fluorescence is an indirect measure of plant health; when tissues age the amount of energy released in the form of fluorescence increases because energy escapes through the photosynthetic II (PSII) pathway, as the efficiency of the pathway is lost.

While an increase in ethylene synthesis charts the start of the respiratory climacteric, the magnitude and duration of the rise is variety specific. Additional studies on the relationship between internal ethylene and starch clearance patterns has found a tight correlation exists when IEC's <100 ppb and starch content are high (80-95 %); once starch clearance patterns drop below 75% significant variability in the corresponding IEC's exist. With this is mind CF might provide an additional insight into changes in starch clearance. However, it is important to consider that as the relationship between ethylene and starch clearance is not tightly linked as maturity proceeds, any measure attempting to correlate maturity may encounter inherent problems.

Knowledge and Technology Transfer

Lecourt, J and Colgan, R.J Agronomist day Demonstration of pruning and reflective mulches. September 2018. (NIAB-EMR)

Dalton, A.F. Thinning Effects on Fruit Dry Matter. Fruit Science Live Event (FAST, ICL & BASF). 24 July 2018.

Colgan, R.J. Optimising Fruit Dry Matter for long-term storage of Gala. AHDB Tree Fruit Panel meeting 6 March 2018.

Dalton, A.F. Thinning Effects on Fruit Dry Matter. AHDB Tree Fruit Panel meeting 6 March 2018.

Dalton, A.F. Thinning Effects on Fruit Dry Matter. AHDB Tree Fruit Day 22 February 2018.

Lecourt, J. Centrifugal Pruning. AHDB Tree Fruit Day 22 February 2018.

Merhdad, M. Application of chlorophyll fluorescence to predict fruit maturity in Gala Apples. AHDB Tree Fruit Day 22 February 2018.

Dalton, A.F. Thinning Effects on Fruit Dry Matter. FAST LLP Members Conference 1 February 2018.

Lecourt, J and Colgan, R.J Agronomist day Demonstration of pruning and reflective mulches. 13 September 2017. (NIAB-EMR)

Colgan, R.J. & Lecourt, J. Optimising Fruit Dry Matter for long-term storage of Gala. AHDB-Tree Fruit day, 23 February 2017. (NIAB-EMR)

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APPENDIX 1 WP 3 CHEMICAL APPLICATION GUIDELINES

Chemical thinners were applied using manufacturers' recommendations (see product label and SDS) AND adapted according to weather conditions before, during and after application:

Exilis + Fixor (100 g/l NAA)

- 8-10mm fruit size (no treatment after 10mm) and
- temperatures increasing to an expected daily maximum of between 15ºC and 28ºC at application and continuing for 3 to 5 days afterwards
- If conditions not suitable at 8-10mm Fixor may be omitted from application (but check with Fine first)
- Product should not be applied in temperatures of under 15ºC, over 28ºC cool, frosty or slow drying conditions.
- Fruit size can increase in 1 week from 11 to 15 mm if hot.

Brevis

- 8-10mm fruit size application 1
- 12-14mm fruit size application 2
- 5 days minimum in between and
- 2 to 3 days optimal conditions before and after application comprising:
- medium solar radiation and
- <10ºC night time temperatures.
- At moment of application temperatures are not important
- Product should not be applied when night time temperatures are over 10ºC, night frosts are predicted.
- Thinning will be stronger when in the week before application the night temperatures are between 10 - 15C and radiation is below 1600J/cm2.
- Thinning will be weaker when in the week before application the night temperatures are between 5-10C and radiation is above 1600J/cm2.
- The fruitlet stage is less important than the climatic conditions before and after the application
- But before 6 mm and after 16 mm efficacy is less
- Any second application may be done to top of tree only.
- When trees are vigorous thinning effect will be stronger (more competition on carbohydrates)
- Older trees are more difficult to thin than young trees
- Gala, Fuij, Junami and Elstar are more difficult to thin than Golden and Braeburn
- BREVIS should not be applied with foliar feeds as this can enhance the thinning effect

Gibberelins, oily products or foliar feeds should not be applied directly before BREVIS for at least 1 week

APPENDIX 2 Trial Plans for Thinning Trials in 2019 April 2019-onwards (season 4)

VARIETY, PLANTING DATE, SPACING & DENSITY

There will be 1 variety of Apple – Gala clone Michgla, planted in approximately 2008 and supported on a post and wire system.

Trees are spaced at 1m within row and 3.5m between rows. The planting density is 2857 trees per ha.

TREATMENTS

For the 2019 season the consortium has agreed to alter thinning treatments, removing bud thinning, mechanical and late season hand thinning and instead alter through early hand thinning to manipulate crop load to 100, 150 and 200 fruits per tree, keeping fruit numbers above 1.5 M to single fruits per cluster.

NO	DESCRIPTION	RATE & WATER VOLUME	EVENTS / APPLICATIONS	BBCH STAGE	DETAILS
9.	Control	Na	Na	Na	Na
10.	Hand 100	Na	1	71-72	Fruit size 10-20mm before fruit all
11.	Hand 150	Na	1	71-72	Fruit size 10-20mm before fruit all
12.	Chemical Exilis & Fixor*	Exilis 3.5 L/ha to **7.5 L/ha** in 100 L water Fixor **100ml/ha**	1 per year maximum application	70 -72	8 to 10mm Exilis + Fixor (no treatment > 10mm) 7 to 15mm Exilis alone KING FRUIT SIZE >15ºC & increasing temperatures 3 to 4 days after
13.	Chemical Brevis*	1.1kg/ha to **1.65g/ha** (2.2kg/ha max) in 1000L water	2 NB minimum 5 days between applications	1 = 70-71 2 = 71-72	Application 1 8-10mm Application 2 12-14mm KING FRUIT SIZE

					9-11mm (8-14mm max window) lower watervolumes (min 350L/ha no tank mix
14.	Hand Thinning Standard	Na	1	71-73	15mm to 25mm Pre/up to 2nd fruit fall (50 days post full bloom)
15.	Hand Thinning Size	Na	2	1 = 73 2 = 74	Event 1 from 25mm-30mm (at fruit fall) Event 2 at 40mm (late, after fruit fall)
16.	Hand 200		1	71-72	Fruit size 10-20mm before fruit all

See further details under APPLICATIONS AND TIMINGS and GUIDELINES.

ASSESSMENTS

PHYSIOLOGICAL AND MONITORING

Weekly observations of the plots will be made through the season.

Weekly monitoring of BBCH CGS on Control plots commencing 1 month prior to and recording BBCH 53 (bud burst), continuing up to BBCH 74 (fruit up to 40mm T stage).

Temperature, RH and PAR will be monitored via SMS remote sensing equipment.

FRUIT COUNTS – MIDDLE TREE IN EACH PLOT

Fruit from the middle tree only in each plot will be counted and recorded at 2 events:

1. At thinning – fruit removed (treatments 2, 3, 6, 7 and 8 only)
2. At harvest – all fruit all treatments

DRY MATTER – PRE-HARVEST NRI

Samples (12 fruits per plot) will be collected at 2 events prior to predicted harvest date: at stage BBCH 70 (1 week post petal fall) and BBCH 75 – (fruit about 50 % final size)
were taken a=and FDM assessed.

FRUIT MINERAL ANALYSIS – PRE-HARVEST FAST

Samples (10 fruits/row were picked from guard trees (1 from each side, high and low in the canopy from 2-year-old wood) were picked 1 week prior to predicted harvest date and analysed for Fruit Minerals and FDM

HARVEST

Starch progression was monitored weekly intervals commencing 4 weeks prior to predicted harvest date (as per FAST Advisory) to accurately estimate optimum harvest date. 10 fruit from the trial area will be selected at random from guard trees at each event and processed (by the Top Fruit Maturity Service).

- Samples from each side of each treatment tree from 2-year-old wood within the top, and bottom of canopy will be collected and weighed prior to harvest for:
  - FAST
    - Maturity = 36 Class 1 fruit total (12 fruit per tree, 6 from each side) (pressure, BRIX and starch)
    - FDM & Fruit Mineral Analysis = 12 Class 1 fruit total (8 fruit per tree, 4 from each side)
    - Quality = 60 randomly selected (all classes) fruit total (20 fruit per tree, 10 from each side)
  - NRI UNIVERSITY OF GREENWICH
    - FDM = 12 Class 1 fruit total (4 fruit per tree, 2 from each side)
    - NRI Storage = 120 Class 1 fruit total (40 fruit per tree, 20 from each side)
- Fruit from the middle tree per plot will be counted.

- Fruit will be picked and weighed per plot in the field. Average kg yield per tree per treatment will be calculated. Average T/Ha per treatment will be calculated.

- Maturity per plot – 12 fruits per treatment plot (to be shared between parameters) will assessed at harvest for (and averages per treatment calculated):
  - Fruit pressures
  - Brix %
  - Starch

- Quality – 60 fruit per treatment plot will be assessed following harvest:
  - Sorted into C1 and waste fruit
  - Waste categorised, counted & weighed (under/over size <55mm/>80mm, disease, russet, pest, misshape, physical damage)
  - C1 fruit graded according to 5 size classes (55- 60mm, 60-65mm, 65-70mm, 70-75mm, 75-80mm) counted & weighed

- % waste & C1 fruit (T/Ha) plus each size class calculated

Fruit will be collected in string bags or crates and labelled with blue labels.

CROP CARE

- The trees/plants will be grown according to Good Agricultural Practice following IPM protocols.
- Regular crop monitoring will be carried out by a BASIS qualified FAST advisor for pest and disease.
- Standard commercial spray programmes will be applied as necessary or if thresholds are exceeded and according to IPM Best Practice.
- Biological control will be introduced as appropriate.
- A standard commercial nutrition programme will be followed as recommended by FAST advisors and based on previous soil samples.
- Standard hand pruning will be carried out in spring before any treatments are applied by the same operative each year. Other husbandry will be carried out to commercial standards.
- Trees are not irrigated.

GUIDELINES

HAND THINNING – carried out by same operative, trained by top fruit advisor

Hand thinning for Treatments 2, 3 and 8, crop load intensity, will be carried out by removal of fruit from clusters so that the appropriate number of fruit per tree are left in approximately similar density in the upper and lower canopy – 100 fruit per tree, all singles; 150 fruit per tree doubles below 1.5m and singles above 1.5m; 200 fruit all doubles.

Hand thinning for Treatments 6, Standard, will be carried out by removal of fruit from clusters leaving doubles below 1.5m and singles above 1.5m (not to crop load).

Treatment 7 Size hand thinning will involve removal of all fruit below the size required and predicted to reach optimum at harvest (65-68mm). This will be predicted using weekly size curves from the FAST members' Top Fruit Advisory. Each of the two events will involve removing fruits of different sizes from clusters/singles which will result in varying numbers of fruit per cluster remaining in any portion of the tree.

Thinning per treatment will be carried out by the same FAST Trials Team member.

No quality thinning for any treatment will be carried out as it is deemed to be too subjective. However, as contingency for under optimal thinning by chemical and mechanical methods, crop load / fruit number hand thinning may be required for Treatments 4 & 5 2 to 3 weeks after applications to coincide with the second event of T7. Crop load may be reduced to similar numbers as per hand thinning treatments of say 150 fruits per tree (based on Gala Standard of 5 fruits/cm^2 of trunk = approximately 160 fruits per tree (at 1m apart for 60 t/ha.

Crop load thinning for other treatments will not be considered in the event of over successful chemical or mechanical thinning.