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Project number:	TF225
Project leader:	Dr Richard Colgan - Natural Resources Institute, University of Greenwich
Report:	Annual Report November 2020 (for 2019)
Previous reports:	Annual Report October 2019 (for 2018) Annual Report October 2018 (for 2017) Annual Report October 2017 (for 2016)
Key staff:	Debbie Rees, Chris Atkinson, Clare Hopson, Karen Thurston NRI - University of Greenwich Julien LeCourt - NIAB-EMR Abi Dalton - FAST LLP Mehrdad Mirzaee, Mark Tully, Colin Carter - Landseer
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

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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.

Dr Richard Colgan

Reader in Post-harvest Physiology

Natural Resources Institute, University of Greenwich

Signature ....  ....Date ..23/11/2020.

Dr Julian LeCourt

Post Doctoral Research Scientist

NIAB-EMR

Signature ....Date ....

Katie Hunt

Trials Manager

FAST LLP

Signature.....................................Date ....

Report authorised by:

Name

Position

Organisation

Signature .... Date ....

Name

Position

Organisation

Signature .... Date ....

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GROWER SUMMARY

Headline

- Centrifugal pruning combined with positioning of reflective mulches in alleyways may increase Fruit Dry Matter content in lower canopy fruit.

Background and expected deliverables

Fruit dry matter (FDM) content is considered a good indicator of high sugar and acid content (% Brix°) 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 the quality of fruit coming out of store 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 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. At the outset of this project, we aimed to achieve this through a combination of the following activities in orchards using Gala apples as a test cultivar:

- A meta-analysis of existing data sets to obtain a greater understanding of the factors controlling both FDM and quality.
- A comparison of different pruning strategies and their effect on FDM.
- A study of the use of reflective mulches and their impact on FDM.
- Manipulation of crop load using bud and fruit thinning to assess their impact on FDM.

The meta-analysis work was undertaken in the early years of this project and is reported on in previous project reports.

Summary of the project and main conclusions

Pruning systems and reflective mulch

At the outset of the project 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 NIAB EMR. Within the orchard, reflective mulches were laid on either side of the tree rows between the period of cell division stage (April/May) and two weeks before harvest, to determine the effects of improved light penetration and effects on Class 1 yields, FDM and components of fruit quality (TSS, colour).

In 2019, the Gala orchard used at NIAB EMR was severely affected by apple scab which would have influenced fruit quality and yield at harvest. Therefore, results in 2019 from this section need to be interpreted with caution.

In 2019, the centrifugal training system combined with reflective covers in the alleyways increased % FDM in fruit (Table 1.1) harvested from the lower parts of the canopy (15.6% FDM) and in addition produced fruit with higher firmness (86.6 N= 8.8 kg). The combined treatment delayed fruit maturity, which may be the result of fewer fruits per tree as the trees return to full crop load following their conversion to a centrifugal training system in 2016. Despite manipulation of dry matter content in the lower canopy fruit there was no corresponding increase in % Brix in fruit at harvest.

Table 1.1 Fruit maturity and Fruit Dry Matter (FDM) Content of Gala Apples Subject to Centrifugal Training and the Presence of Reflective Covers

		Int. Eth. Conc. ppb		*Starch CTIFL*		% FDM		*% Brix*		*Firmness (N)*	
	Reflective Covers	Top	Bottom	*Top*	*Bottom*	Top	Bottom	*Top*	*Bottom*	*Top*	*Bottom*
Tall Spindle	*Yes*	385	366	6.8	**8.1**	14.8	14.6	11.9	11.8	79.6	77
	No	348	377	6.2	6.5	14.4	14.6	12.1	11.8	83	81.3
Centrifugal	*Yes*	**153**	**204**	**5.8**	6.1	14.8	**15.6**	11.7	12	83.6	**86.6**
	No	**179**	330	6.7	6.8	14.6	14.9	12	12.1	82.5	82.7
F.prob		0.545		0.349		6.42		0.419		0.327	
$LSD_{0.05}$		80.5		0.35		0.3867		0.54		3.97	

N.B. numbers in bold are significantly different ($p<0.05$) from the control treatment (Tall Spindle No Covers). To convert fruit firmness from Newtons (N) to kg divide values by 9.8

Fruit thinning

The work on the effects of fruit thinning in 2019 were carried out by FAST in a Gala orchard at their Brogdale Farm, near Faversham in Kent.

Treatments 2019

NO	DESCRIPTION	RATE & WATER VOLUME	EVENTS / APPLICATIONS	BBCH STAGE	DETAILS
1.	Control	Na	Na	Na	Na
2.	Singles	Na	1	71-72	Fruit size 10-20mm before fruit fall
3.	Single (>.1.5 M) Doubles (< 1.5 M)	Na	1	71-72	Fruit size 10-20mm before fruit fall
4.	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
5.	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 water volumes (min 350L/ha no tank mix
6.	Hand Thinning Standard	Na	1	71-73	15mm to 25mm Pre/up to 2nd fruit fall (50 days post full bloom)
7.	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)
8.	Doubles		1	71-72	Fruit size 10-20mm before fruit all

* Chemical thinners were applied using manufacturers' recommendations and adapted according to conditions before, during and after applications (see product label, SDS and guidelines (Appendix 1)).

Fruit thinning practices reduced overall yield per tree but increased the percentage of Class I fruit (Table 1.2). While no single thinning treatment stood out as a preferred treatment in terms of overall yield of class I improvement, there were differences associated with size distribution of fruit and the sources of rejection (Table 1.3, Figure 1.1, Table 1.4).

Table 1.2 Grade out of Gala apples at harvest subject to thinning regimes during fruitlet development

	Control	*Singles*	*Singles/ Doubles*	*Exilis*	*Brevis*	*Standard*	*Size*	*Doubles*	*F.prob*	*LSD$_{0.05}$*
%Class1	50.6	**63.1**	**59.5**	**61.8**	48.1	**61.9**	**61.6**	**58**	0.525	17.38
Yield/Tree (kg)	**37.1**	25.0	30.8	30.3	23.0	28.3	29.1	25.4	0.002	5.93

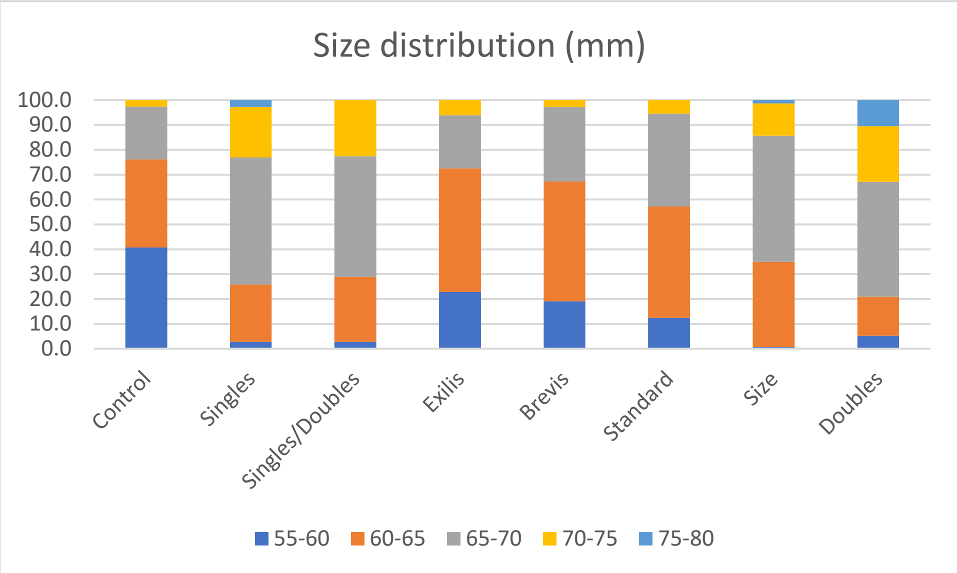


Figure 1.1 Size distribution of Gala apples subject to different thinning regimes during fruitlet development

Table 1.3 Size distribution of Gala apples subject to different thinning regimes during fruitlet development

Size Class (mm)	*Control*	*Singles*	*Singles/Doubles*	*Exilis*	*Brevis*	*Standard*	*Size*	*Doubles*
55-60	40.7	2.7	2.8	22.9	19.1	12.4	0.7	5.2
60-65	35.4	23.1	26.1	49.6	48.2	44.8	34.2	15.7
65-70	21.2	51.0	48.6	21.4	30.0	37.2	50.7	46.3
70-75	2.7	20.4	22.5	6.1	2.7	5.5	13.0	22.4
75-80	0.0	2.7	0.0	0.0	0.0	0.0	1.4	10.4

However, both spray treatments (Exilis and Brevis) shifted the majority of fruit to the 60-65 mm category. This was observed in trees subject to standard thinning practices, while as expected, un-thinned trees produced the largest proportion of 55-60 mm sized fruit.

Thinning to size, singles, singles/doubles or doubles across the tree shifted size category of the Gala with a greater proportion of 65-70 mm fruit. Thinning to singles, singles/doubles or doubles across the tree produced the smallest proportion of 60-65 mm fruit. Thinning to singles, singles/doubles, doubles or to size, minimised fruit size below 60 mm. Thinning to doubles across the tree had the unexpected result of shifting fruit size towards larger fruit with over 10% of the size classes in the 75-80 mm category (Table 1.3).The effect of thinning strategies on weight of fruit from each size class can be seen in Table 1.4; thinning to singles, singles/doubles or doubles when fruitlets were between 10-20 mm had the effect of increasing the yield of fruits in the 65-70 mm category and was equal to the thinning to size strategy. Early thinning (10-20 mm) increased the yield of class1 as did thinning to size (Table 1.4).

Table 1.4 The weight (g) of Class 1 Gala apples in each size category as a result of fruitlet thinning strategies. Figures in parenthesis represent average fruit numbers making up the yield in each size category averaged across four replicate plots.

Treatment	55-60 mm	60-65 mm	65-70 mm	70-75 mm	75-80 mm	Total wt
Unthinned	908 (11.5)	1032 (10)	751 (6)	110 (0.8)	0	560
Singles	40 (1)	933 (8.5)	2464 (18.8)	1207 (7.5)	187 (1.0)	**966**
Singles/Doubles	62 (1.0)	960 (9.3)	2264 (17.3)	1259 (8)	0	**909**
Exilis	568 (7.5)	1716 (16.3)	908 (7)	306 (2)	0	699
Brevis	402 (5.3)	1377 (13.3)	1052 (8.3)	108 (0.8)	0	588
Standard	346 (4.5)	1734 (16.3)	1747 (13.5)	297 (2.0)	0	825
Size	12 (0.3)	1344 (12.5)	2402 (18.5)	746 (4.8)	86 (0.5)	**918**
Doubles	94 (1.8)	559 (5.3)	2000 (15.5)	1190 (7.5)	654 (3.5)	**899**
$LSD_{0.05}$ 663.2 Treatment x Size class			F.prob <0.001			
$LSD_{0.05}$ 296.6 Treatment (Total weight)			F.prob <0.035			

A more detailed analysis of grade-out data taken from a nominal 60 fruit sample per plot found that lower grade out figures for Gala treated with Brevis were associated with a higher proportion of diseased fruits and a higher numbers of small fruits <55 mm (Table 1.5). Un-thinned trees produced a significant number of small undersized fruits.

Table 1.5. Types of Fruit Deformities Resulting in Rejection during Grading

Grade out-Numbers of fruit	*Control*	*Singles*	*Singles/Doubles*	*Exilis*	*Brevis*	*Standard*	*Size*	*Doubles*
Scarring/Russet	1.5	2.8	2.0	1.5	0.8	0.8	1.0	2.0
Damage - pest/physical	7.5	5.5	8.5	6.5	9.3	8.0	9.0	9.3
Misshapen	1.5	2.0	2.3	2.8	1.8	0.8	1.0	2.3
Small	12.5	1.3	2.3	4.3	7.3	1.0	0.8	1.5
Diseased	9.8	10.5	7.3	7.8	12.3	11.8	11.5	9.5
Lack % Red	0.5	1.0	3.0	0.8	1.5	1.5	0.5	2.0
Unmarketable	33.3	23.0	25.3	23.5	32.8	23.8	23.8	26.5
Marketable	28.3	36.8	35.5	32.8	27.5	36.3	37.0	33.5

Total (n=60)	61.5	59.8	60.8	56.3	60.3	60.0	60.8	60.0

Thinning practices that raised FDM were restricted to trees where fruitlets were thinned to singles across the tree, or subject to standard thinning or thinning to size. This only translated to increase % Brix in fruit where thinning to size had been practiced (Fig 1.6). In general, %FDM in the 2019 season was low, partly due to the cooler summer compared to 2018 and previous years. Brevis and Exilis applied at BBCH 70-71 & 71-72 failed to significantly increase %FDM.

Thinning generally improved fruit firmness across the treatments raising firmness by 4-5 N (0.4-0.5 kg). Thinning to single fruitlets per cluster across the tree produced the firmest fruit at 92.6 N (9.2 kg) at harvest. Individual sugar concentrations more clearly reflect changes in maturation.

Table 1.6 Overall fruit maturity, %FDM and sugar content of Gala apples at harvest grown under different fruitlet thinning regimes (average of apples from the top and bottom canopy)

Thinning	***Control***	***Singles***	***Singles/ Doubles***	***Exilis***	***Brevis***	***Standard***	***Size***	***Doubles***	***F.prob***	***LSD$_{0.05}$***
I.E.C ppb	193.2	**289.8**	**341.3**	**282.3**	**328.3**	**384.1**	**401.1**	**342.7**	<.001	52.57
Starch	5.3	**4.08**	**4.08**	**3.95**	**4.2**	4.58	4.47	4.88	0.051	0.98
% Brix	12.0	12.4	11.4	11.8	12.1	12.2	**12.8**	**12.6**	<.001	0.61
% DM	15.4	**16.4**	15.7	15.7	16.1	**16.5**	**16.5**	16.1	0.127	0.87
Fructose	123.7	**103.0**	**105.8**	114.8	119.0	**110.5**	123.9	**111.1**	<.001	9.23
Glucose	14.0	**9.8**	**9.7**	12.0	12.2	12.0	12.3	**11.3**	0.004	2.11
Sucrose	75.8	81.2	81.3	74.7	**83.1**	**82.7**	**85.0**	82.3	0.041	6.77
Firm (N)	84.5	**92.6**	**88.4**	**88.3**	87.2	**89.6**	**88.9**	**89.3**	0.003	3.40

Values in bold are significantly different (p<0.05) from fruit harvested from the control (un-thinned trees) in the same row. To convert fruit firmness from Newtons (N) to kg divide values by 9.8

Main conclusions drawn from the work in 2019

In the fourth year of this study, Fruit Dry Matter (FDM) content in Gala apples was increased by manipulating crop load through fruitlet thinning practices. However, neither the timing of thinning events, the final crop load achieved, nor the use of alternative chemical thinning agents, provided specific advantage in raising FDM in Gala.

Increasing light interception by the adoption of centrifugal training systems in conjunction with positioning of reflective mulches in alleyways raised FDM in apples harvested from the lower canopy.

The benefits of fruit thinning and centrifugal pruning combined with reflective mulches were seen in different parts of the canopy. Thinning treatments were most effective in raising FDM in the upper canopy, while centrifugal pruning/reflective covers raised FDM in the lower canopy by 0.7% to 15.6% FDM.

Hand thinning practices, where fruitlets were removed to single fruits per cluster across the tree, standard thinning or thinning to size were more effective in raising the FDM across the whole of the canopy.

Applying thinning treatments earlier at fruitlet size 10-20 mm (singles, single/doubles or doubles) led to increased fruit size at harvest, compared to implementing standard thinning practices single fruits per cluster > 1.5M and double fruitlets per cluster <1.5 M when fruits were at 15-25 mm in size.

As expected, fruit thinning raised firmness of fruit, improved the size grade out for class I and delayed fruit maturity.

Financial benefits

- No financial benefits from this work have been identified to date.

Action points for growers

- Harvesting fruits higher in the canopy separately will provide consignments with higher FDM.
- Centrifugal Pruning combined with reflective mulches can increase FDM in fruit from the lower canopy.
- Manipulating crop load through thinning, can increase %FDM. The timing of hand thinning or application of thinning agents has more influence on fruit size at harvest rather than specifically manipulating %FDM.
- Early thinning events (10-20 mm) may increase the number of fruits reaching the target 65-70 mm size and may be as effective as thinning to size strategy.
- In this study, application of Brevis or Exilis concentrated fruit size in the 60-65 mm category. Brevis treated trees had a poorer grade-out due to a higher number of smaller (< 55 mm) fruit, possibly due to poor uptake in the lower canopy.

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 is the result of the interaction of diverse cultural practices (e.g., pruning, thinning, pest and disease management), environmental inputs (e.g., water, nutrition, light, [CO_2]) 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 in 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, taking into account 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.

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 % Brix° at harvest and to a better % Brix° coming out of store. Fruit with % Brix° exceeding 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 % Brix° 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 (SF)) 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, are investigating 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

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.

Background

Work package 2: To determine the impact of increasing light interception in vertically trained high-density orchards by pruning and/or using reflective mulches at different stages of Gala fruit development on fruit quality and FDM.

2016 - 2020 Years 1-5 NIAB EMR Julien Lecourt

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 (eg Lakso, 1996, Figure 1A) and increased light interception promotes dry matter accumulation (eg Palmer et al. 1992, Figure 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.

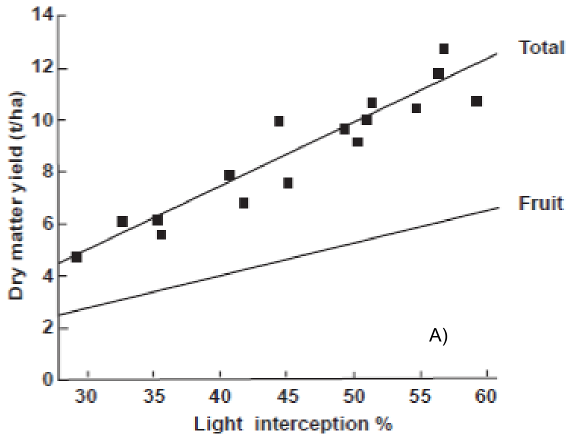


Figure 2.1 A.

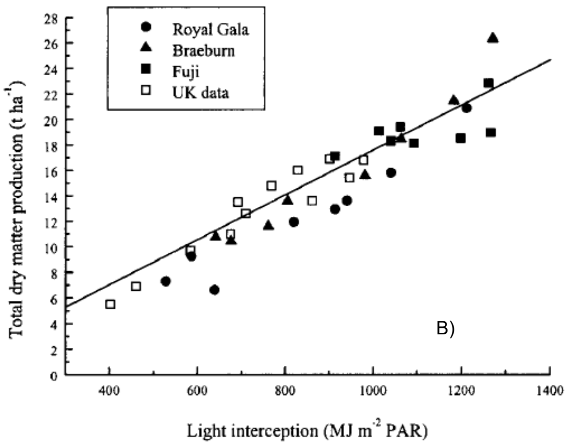


Figure 2.1B.

Figure 2.1 A. 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 2.1 B 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 with regard to 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).

Work package 3: To determine the impact of thinning strategies on fruit quality and FDM and to develop recommendations to optimise yield of high-quality fruit.

2016 - 2020 Years 1-5 FAST LLP Abi Dalton, Debbie Rees & Richard Colgan NRI UoG

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 required to achieve a good yield of fruit with the required fruit size is well established. However, the effect of thinning practices on the accumulation of FDM during the growth and development period is less well understood. No recent work has measured any effects on FDM on Gala in the UK. Manipulating tree architecture through different use of different pruning strategies have been trialled to improve uniformity of fruit size and colour and increase yield by way of increasing light interception throughout the canopy. Currently, the potential to increase yield 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 impacts 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 percentage 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 fairly stable for the remainder of the season (see Figure 3.1).

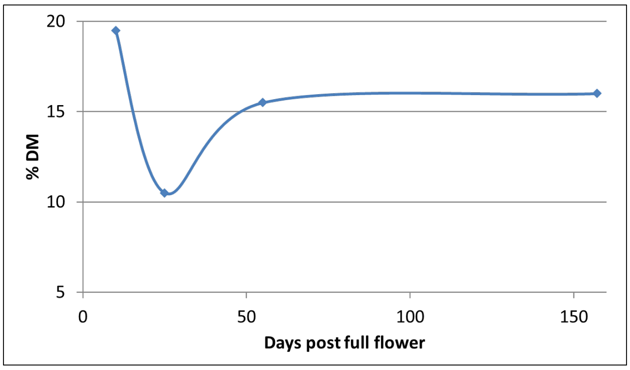


Figure 3.1. Preliminary FDM data from Gala taken during flowering and fruit development.

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 has investigated the timing of thinning events and different thinning strategies the optimum crop load at earlier stages in the fruit development cycle 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.

Materials and Methods

Work package 2: Centrifugal pruning and reflective mulches

2016 - 2020 Years 1-5 NIAB EMR Julien Lecourt

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 NIAB EMR (Figures 2.1, 2.2). This resulted in the removal of most of the main fruiting branches, resulting in a decrease in the yield potential for the next two to three years. Consequently, the results presented in this report need to be taken with caution as this is the 3rd year after the treatments have been applied to the trees.

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). Size measurements of fruit were taken from the end of July at weekly intervals to monitor fruit expansion rates.

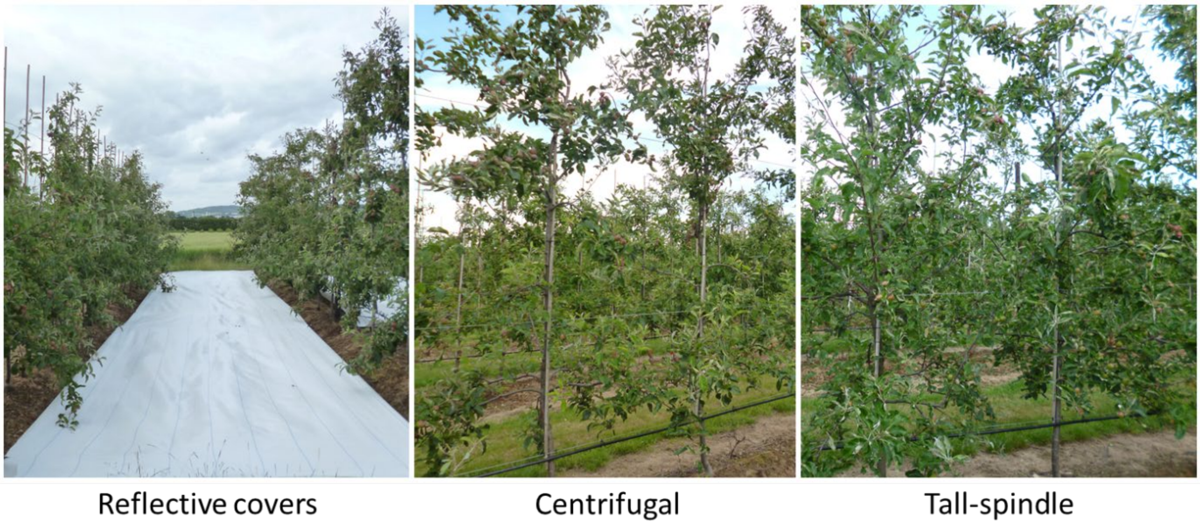
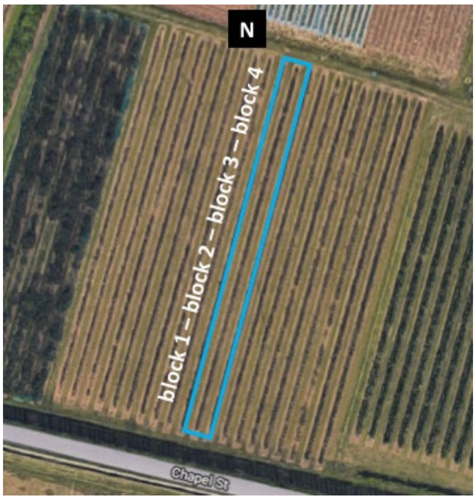


Figure 2.2. Pictures of the treatments applied during the experiment. The training and reflective mulches have been applied to a 4-year-old M9 Gala orchard located at NIAB EMR.



In year 4 of this trial, fruits were harvested on 19th September 2019. Fruit was sampled from each experimental tree and categorised top (>1.5M) and bottom (<1.5M) 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.

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 2019 and transferred to the Produce Quality Centre (PQC) where fruits were sampled for dry matter content and assessed 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 dcp, dried in an oven for 48 hours and reweighed. Tissue was then placed back into the oven for a further 24 hours and 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.

Work package 3: Bud, flower and fruitlet thinning strategies.

2016-2020 Years 1-5 Abi Dalton FAST LLP, Debbie Rees & Richard Colgan NRI-UoG

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 2019

NO	DESCRIPTION	RATE & WATER VOLUME	EVENTS / APPLICATIONS	BBCH STAGE	DETAILS
9.	Control	Na	Na	Na	Na
10.	Singles	Na	1	71-72	Fruit size 10-20mm before fruit fall
11.	Single (>.1.5 M) Doubles (< 1.5 M)	Na	1	71-72	Fruit size 10-20mm before fruit fall
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 water volumes (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.	Doubles		1	71-72	Fruit size 10-20mm before fruit all

* Chemical thinners were applied using manufacturers' recommendations and adapted according to conditions before, during and after applications (see product label, SDS and guidelines (Appendix 1)).

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.

Applications, timing, and descriptions

<u>Hand thinning</u>

Treatment 10 (Singles): Removal of fruitlets from clusters leaving single fruitlets per cluster.

Treatment 11 (Singles / Doubles): Clusters were thinned to singles in the canopy above 1.5 M and doubles below 1.5 M.

Treatments 14 (Hand Thinning Standard): Removal of fruit from clusters leaving doubles below 1.5m and singles above 1.5m was conducted over a longer period than T3 covering BBCH stage 71-73 where fruits are between 15-25 mm covering pre-June drop and a second thinning event 50 days post full bloom.

Treatment 15 (Hand Thinning Size): 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 BBCH 73 (25-30 mm) & 74 (40 mm). The thinning treatment considered removing fruits of different sizes from clusters which resulted in varying numbers of fruit per cluster remaining in all portions of the tree.

Treatment 16 (Doubles): Thinning each flower cluster to 2 fruitlets per cluster.

Treatments 2, 3 and 8 were implemented at BBCH stage 71-72 Fruit size 10-20mm before fruit fall.

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/cm^2 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.

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.

Dry matter – pre harvest

Samples were collected prior to harvest:

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

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

Harvest

Starch progression was monitored weekly at three events commencing three weeks prior to the predicted harvest date (as per the FAST advisory) to accurately estimate the optimum harvest date. Ten fruits 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 two-year-old wood within the top, middle and bottom of canopy were collected prior to harvest for:

- Maturity - 30 fruits per treatment plot total (ten per tree, five from each side):
  - Starch
  - °Brix

    - Fruit pressures
- Dry Matter - 12 fruit total (four per tree, two 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) - 40 fruit total per plot were sampled (10 from the top of the canopy >1.5 M fruit per tree, two from each side)

Fruit was picked per three tree plot and weighed in the field.

The average total yield (kg), Class 1 (%) and waste, average waste categories, fruit weight and size distribution were calculated.

Sampling and laboratory analysis (NRI University of Greenwich)

Samples for sugar analysis were collected by NRI at fruitlet stage mid-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 48 hours, after which samples were reweighed and percentage of 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. Sugars (sucrose, fructose, and glucose) were extracted from 0.2g of powdered tissue in 80% ethanol (70°C) 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 prior to analysis by HPLC.

Statistical Analysis

Statistical analysis was carried out using Analysis of Variance (ANOVA) using (Genstat v20). The results of statistically significant effects (P value < 0.05) are detailed in charts/tables with p vales and LSDs as indicated.

Results

Work Package 2: Pruning and reflective mulches 2019 results

Effect of the treatments on fruit growth

Fruit size measurements were taken at twice weekly intervals from fruit tagged either side of the row and width and height measurements were recorded (Figure 2.1). Fruit size of Gala trained in a centrifugal manner with reflective covers positioned in the alleyways led to a small (1-2 mm) increase in fruit size over the course of fruit development (Figure 2.1). Due to a high incidence of apple scab (*Venturia inaequalis*) yield and Class 1 data was not collected as the incidence of disease was sufficiently high to affect data.

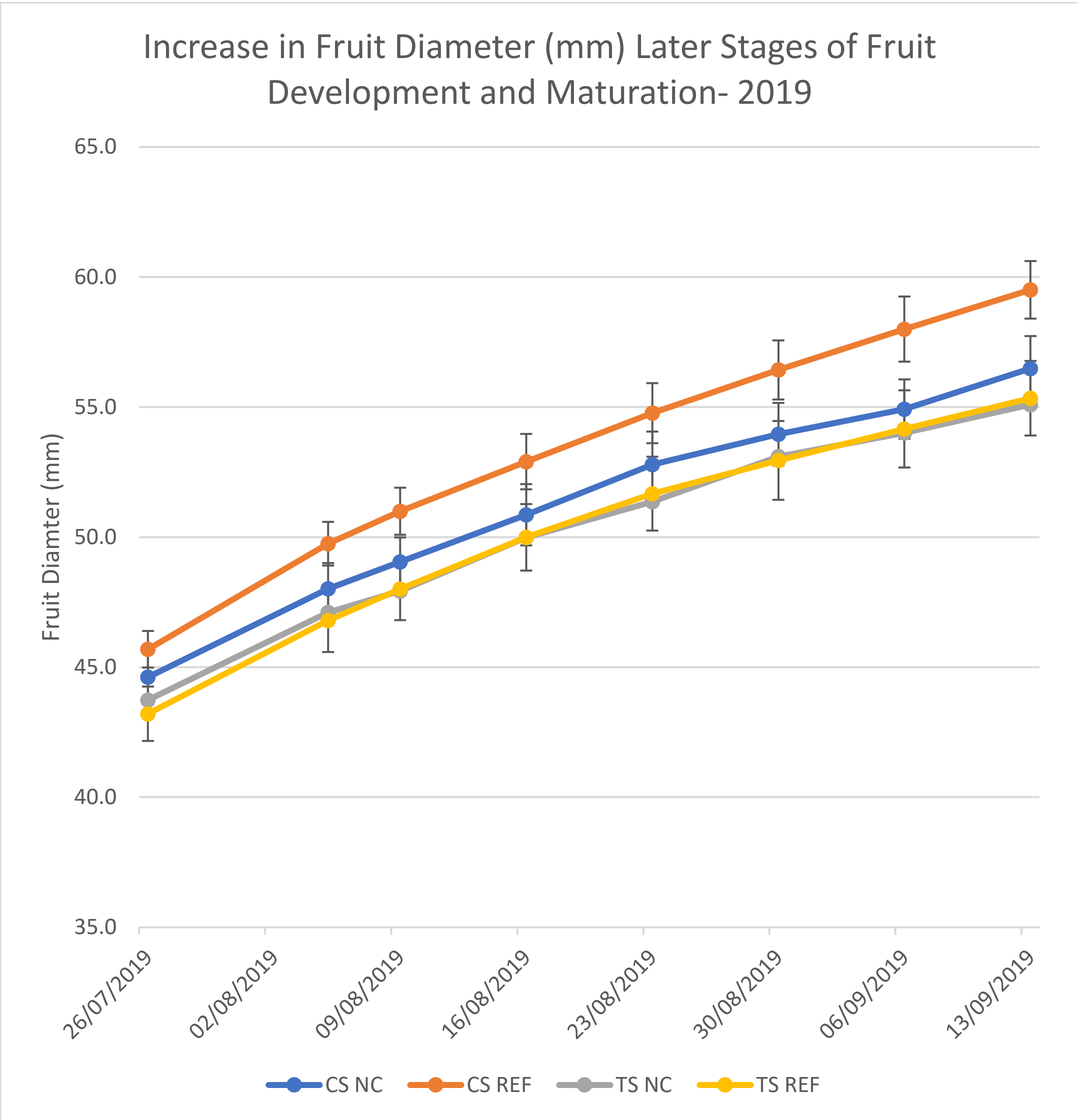


Figure 2.1 Growth rate (mm) of Gala apples subject to centrifugal training and positioning of reflective covers in alleyways. CS NC = Centrifugal system no cover, CS REF = Centrifugal system with reflective cover, TS NC = Tall spindle no cover, TS REF = Tall spindle with reflective cover

Harvest Analysis- NRI

Apples were harvested on 19th September 2019 and transferred to the Produce Quality Centre where fruits were sampled for firmness, starch and °Brix, followed by FDM assessments.

Trees under the centrifugal system produced fruit with 0.4% higher FDM with apples grown under the centrifugal system accumulating 15% FDM compared to 14.6% in apples harvested from TS trees (Table 2.1).

Moreover, fruit grown under centrifugal system were less mature based on I.E.C. and CTIFL starch patterns than fruit grown under conventional tall spindle trees (Table 2.1). The effect is most likely a result of fewer fruit numbers on the tree. Reducing crop load has been reported to inhibit fruit maturity (Johnson 1993).

The presence of reflective covers raised FDM percentage to 14.9% where covers were placed in alleyways compared to 14.6% in their absence. When averaged across the whole tree the presence of reflective covers did not alter fruit maturity characteristics (I.E.C., CTIFL Starch). However, the sucrose content of fruits was higher in apples cultivated under reflective covers. During fruit development and maturation, the concentration of sucrose declines as it is converted into fructose and glucose.

When averaged across pruning systems fruits from the upper canopy were marginally less mature based on I.E.C values but this was not backed up by starch patterns. Delayed maturity in the top of the tree is most likely the result of fewer fruits.

Fruits at the top of the canopy were on average 0.3% higher in FDM with fruits yielding 14.9% FDM compared to 14.6% in those harvest in the lower canopy.

Table 2.1. Overall effects of training system, sampling position and the presence of reflective covers on FDM percentage and fruit Maturity

Pruning	*Tall Spindle*	*Centrifugal*	*F.prob*	*$LSD_{0.05}$*
I.E.C (ppb)	*369*	***216***	<.001	42.5
DM (%)	14.6	**15.0**	0.001	0.08
CTIFL starch	6.9	**6.3**	0.014	0.41
Fructose	130.6	122.7	0.082	12.92
Glucose	18.8	19.3	0.689	2.78
Sucrose	90.3	85.7	0.18	7.12
Covers	*Reflective Covers*	*No Covers*	*F.prob*	*$LSD_{0.05}$*
I.E.C (ppb)	*277*	*308*	*0.147*	42.5
DM (%)	**14.9**	14.6	0.006	0.08
CTIFL starch	6.7	6.5	0.419	0.41
Fructose	128.4	124.9	0.393	12.92
Glucose	17.8	20.3	0.069	2.78
Sucrose	**96.2**	79.8	<.001	7.12
Position	*Top*	*Bottom*	*F.prob*	*$LSD_{0.05}$*
I.E.C (ppb)	***266***	*319*	*0.016*	42.5
DM (%)	**14.9**	14.6	0.014	0.08
CTIFL starch	6.9	**6.4**	0.027	0.41
Fructose	130.6	122.7	0.084	12.92
Glucose	18.8	19.3	0.688	2.78
Sucrose	88.7	87.3	0.681	7.12

N.B numbers in bold represent values significantly different ($P<0.05$) in the same row.

Maturity

When the full interaction between pruning systems, reflective covers and fruit position within the tree was considered (Table 2.2) the impact of the centrifugal system was to delay maturity in fruit from the top of the canopy and this may be a direct result of fewer apples in the top canopy. Within the full interaction, the correlation between I.E.C and fruit starch staining patterns (CTIFL) was not well correlated (Table 2.2)

FDM was raised in the lower canopy of centrifugally pruned trees where the positioning of reflective covers was practiced (Table 2.2). However, in tall spindle systems no benefit of reflective covers was observed. The °Brix of fruit was not increased even in trees where the combination of centrifugal system and reflective covers raised FDM. Moreover, a higher fruit firmness (N) was recorded in fruit that were higher in FDM.

Table 2.2 The interaction between Training Systems, Reflective Covers and Fruit Position on Fruit Maturity attributes at Harvest

	Reflective Covers	*Int. Eth. Conc. ppb*		*Starch CTIFL*		FDM (%)		*°Brix (%)*		*Firmness (N)*	
		Top	Bottom	*Top*	*Bottom*	Top	Bottom	*Top*	*Bottom*	*Top*	*Bottom*
Tall Spindle	*Yes*	385	366	6.8	**8.1**	14.8	14.6	11.9	11.8	79.6	77
	No	348	377	6.2	6.5	14.4	14.6	12.1	11.8	83	81.3
Centrifugal	*Yes*	**153**	**204**	5.8	6.1	14.8	**15.6**	11.7	12	83.6	**86.6**
	No	**179**	330	6.7	6.8	14.6	14.9	12	12.1	82.5	82.7
F.prob		0.545		0.349		6.42		0.419		0.327	
$LSD_{0.05}$ P x C x Pos.		80.5		0.35		0.3867		0.54		3.97	

N.B. Values in bold are significantly different ($p<0.05$) from fruit harvested from the control (Tall Spindle, No Covers) in the same column. To convert fruit firmness from Newtons (N) to kg divide values by 9.8.

Reflective covers had a general effect of raising sucrose content, but this was only significant in some treatment combinations while the pool of fructose and glucose in fruit at harvest was unaffected by training system or reflective covers. Red colour intensity was not affected by consistently by reflective cover or pruning system.

Table 2.3. The effect of pruning system, positioning of reflective covers in alleyways and sampling position within trees of Fruit quality of Gala.

Pruning	*Reflective Covers*	Fructose		Glucose		**Sucrose**		*Yellow (b*)*		*Red (a*)*	
		Top	*Bottom*	*Top*	*Bottom*	*Top*	*Bottom*	*Top*	*Bottom*	*Top*	*Bottom*
Tall Spindle	*Yes*	**146.3**	122.1	17.7	18.1	**109.5**	92	18.6	20.8	41.2	41
	No	127.4	126.6	18.7	20.6	81.2	78.4	22.1	**24.5**	40	31.9
Centrifugal	*Yes*	121.6	123.8	17.7	17.5	84	**99.4**	20.9	**23.8**	40.1	**36.5**
	No	126.9	118.6	21	20.9	80	79.6	18.8	18.7	39.9	41.7
f.prob		0.065		0.782		0.039		0.131		0.002	
$LSD_{0.05}$ pruning x covers x position		18.27		5.552		14.24		1.58		3.42	

N.B. Values in bold are significantly different ($p<0.05$) from fruit harvested from the control (Tall Spindle, No Covers) in the same column.

Work Package 3: Fruit Thinning Practices

As expected, fruit thinning reduced the yield per tree but in most cases, this was compensated by increasing the proportion of Class 1 fruit. The overall impact of implementing thinning was to increase the proportion of Class 1 fruit. However, only ~60% of the final yield was suitable for Class 1 market in those trees subject to hand thinning (Singles, Singles/Doubles, Doubles, Standard or Thinning to Size). Exilis was the only spray treatment that produced the same proportion of Class 1 fruit, while Brevis treatments yielded only 48.1% Class 1 fruit which was in-line with un-thinned trees.

Yield and Quality data for Gala subject to different thinning treatments

Fruit Thinning

Fruit thinning practices reduced overall yield per tree but increased the percentage of Class I fruit (Table 3.1). While no single thinning treatment stood out as a preferred treatment in terms of increasing Class I yield, there were differences associated with size distribution of fruit and the sources of rejection (Fig 3.1, Table 3.2, Table 3.3). In general, the earlier thinning takes place after full bloom, the greater the chance on increasing fruit size and weight at harvest. Hand thinning to singles on the upper canopy and doubles on clusters in the lower canopy implemented while fruitlets were at 10-20 mm stage produced a larger proportion of fruit in the 65-70 mm category (48.6%) compared to standard thinning (37.2%) where the same procedure is conducted when fruitlets are between 15-25 mm in size. Implementing thinning earlier appeared to have a stronger influence on fruit size at harvest than the number of fruitlets left per cluster (singles, doubles, or singles/doubles). Thinning to size was equally effective as early thinning in increasing fruit size at harvest. The effect of thinning strategies on weight of fruit from each size class can be seen in Table 1.4; thinning to singles, singles/doubles, or doubles when fruitlets were between 10-20 mm had the effect of increasing the yield of fruits in the 65-70 mm category and was equal to the thinning to size strategy. Early thinning (10-20 mm) increased the yield of class1 as did thinning to size (Table 1.4).

Table 3.1 Yield and Class 1 grade outs for Gala subject to different fruitlet thinning treatments.

	Control	***Singles***	***Singles/ Doubles***	***Exilis***	***Brevis***	***Standard***	***Size***	***Doubles***	***F.prob***	***$LSD_{0.05}$***
Class1 (%)	50.6	**63.1**	**59.5**	**61.8**	48.1	**61.9**	**61.6**	**58**	0.525	17.38
Yield/Tree (kg)	**37.1**	25.0	30.8	30.3	23.0	28.3	29.1	25.4	0.002	5.93

N.B. Values in bold are significantly different (p<0.05) from fruit harvested from the control (Un-thinned) in the same row.

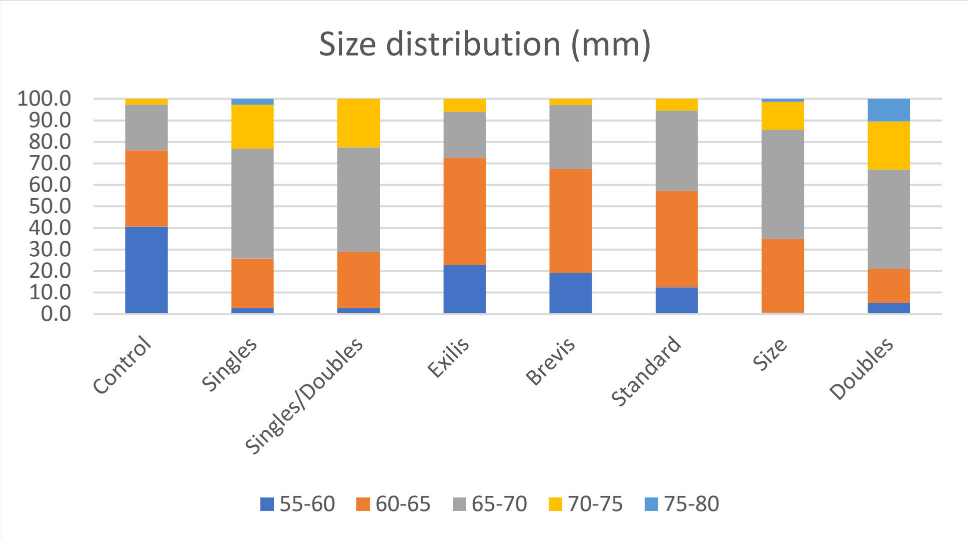


Figure 3.1 The size distribution of Gala apples at harvest subject to different thinning practices at fruitlet stage.

Table 3.2. The size distribution of Gala apples at harvest subject to different thinning practices at fruitlet stage.

Size Class (mm)	***Control***	***Singles***	***Singles/Doubles***	***Exilis***	***Brevis***	***Standard***	***Size***	***Doubles***
55-60	40.7	2.7	2.8	22.9	19.1	12.4	0.7	5.2
60-65	35.4	23.1	26.1	49.6	48.2	44.8	34.2	15.7
65-70	21.2	51.0	48.6	21.4	30.0	37.2	50.7	46.3
70-75	2.7	20.4	22.5	6.1	2.7	5.5	13.0	22.4
75-80	0.0	2.7	0.0	0.0	0.0	0.0	1.4	10.4

Table 3.3 The weight (g) of Class 1 Gala apples in each size category as a result of fruitlet thinning strategies. Figures in parenthesis represent average fruit numbers making up the yield in each size category averaged across 4 replicate plots.

Treatment	**55-60 mm**	**60-65 mm**	**65-70 mm**	**70-75 mm**	**75-80 mm**	**Total wt**
Unthinned	908 (11.5)	1032 (10)	751 (6)	110 (0.8)	0	560
Singles	40 (1)	933 (8.5)	2464 (18.8)	1207 (7.5)	187 (1.0)	**966**
Singles/Doubles	62 (1.0)	960 (9.3)	2264 (17.3)	1259 (8)	0	**909**
Exilis	568 (7.5)	1716 (16.3)	908 (7)	306 (2)	0	699
Brevis	402 (5.3)	1377 (13.3)	1052 (8.3)	108 (0.8)	0	588
Standard	346 (4.5)	1734 (16.3)	1747 (13.5)	297 (2.0)	0	825
Size	12 (0.3)	1344 (12.5)	2402 (18.5)	746 (4.8)	86 (0.5)	**918**
Doubles	94 (1.8)	559 (5.3)	2000 (15.5)	1190 (7.5)	654 (3.5)	**899**
$LSD_{0.05}$ 663.2 Treatment x Size class $LSD_{0.05}$ 296.6 Treatment (Total weight)				F.prob <0.001 F.prob <0.035		

N.B. Values in bold are significantly different (p<0.05) from fruit harvested from the control (un-thinned trees) in the same column.

Treatment with Exilis and Brevis shifted most of the fruit to the 60-65 mm category (Table 3.2). This was also observed in trees subject to standard thinning practices, while as expected un-thinned trees produced the largest proportion of 55-60 mm.

Thinning to size, singles, singles/doubles, or doubles across the tree shifted size category of Gala within in these plots, with a greater proportion of 65-70 mm fruit. Thinning to Singles, Singles/Doubles, Doubles or to Size minimised fruit size below 60 mm. Thinning to doubles across the tree had the unexpected result of shifting fruit size towards larger fruit with over 10% of the size classes in the 75-80 mm category (Table 3.2).

The effect of thinning strategies on weight of fruit from each size class can be seen in Table 3.3; thinning to singles, singles/doubles, or doubles when fruitlets were between 10-20 mm had the effect of increasing the yield of fruits in the 65-70 mm category and was equal to the thinning to size strategy. Early thinning (10-20 mm) increased the yield of Class 1 as did thinning to size (Table 3.3).

A more detailed analysis of grade out data found that lower grade out figures for Gala treated with Brevis was associated with higher numbers of small fruits <55 mm (Table 3.4). Un-thinned trees produced a significant number of small undersized fruits.

Table 3.4. Grade out losses of Gala at harvest caused by thinning practices at fruitlet stage.

Grade out-Numbers of fruit	***Control***	***Singles***	***Singles/Doubles***	***Exilis***	***Brevis***	***Standard***	***Size***	***Doubles***
Scarring/Russet	1.5	2.8	2.0	1.5	0.8	0.8	1.0	2.0
Damage - pest/physical	7.5	5.5	8.5	6.5	9.3	8.0	9.0	9.3
Misshapen	1.5	2.0	2.3	2.8	1.8	0.8	1.0	2.3
Small	**12.5**	1.3	2.3	4.3	**7.3**	1.0	0.8	1.5
Diseased	9.8	10.5	7.3	7.8	**12.3**	11.8	11.5	9.5
Lack % Red	0.5	1.0	3.0	0.8	1.5	1.5	0.5	2.0
Unmarketable	**33.3**	**23.0**	**25.3**	**23.5**	**32.8**	**23.8**	**23.8**	**26.5**
Marketable	28.3	36.8	35.5	32.8	27.5	36.3	37.0	33.5
Total (n=60)	61.5	59.8	60.8	56.3	60.3	60.0	60.8	60.0

Thinning practices that raised FDM were restricted to trees where fruitlets were thinned to singles across the tree, or subject to standard thinning or thinning to size (Table 3.5). This only translated to increased °Brix in fruit where thinning to size had been practiced. In general, FDM in the 2019 season was low partly due to the cooler summer compared to 2018 and previous years. When treatment effects were averaged across the whole tree Brevis and Exilis applied at BBCH 70-71 & 71-72 just failed to significantly increase FDM (Table 3.5).

Thinning generally improved fruit firmness across the treatments raising firmness by 4-5 N (0.4-0.5 kg). Thinning to single fruitlets per cluster across the tree produced the firmest fruit at 92.6 N (9.2 kg) at harvest (Table 3.4).

Table 3.5 Overall effects (averaged across the tree) of thinning practices at fruitlet stage on Gala maturity and FDM at harvest.

Thinning	***Control***	***Singles***	***Singles/ Doubles***	***Exilis***	***Brevis***	***Standard***	***Size***	***Doubles***	***F.prob***	***LSD0.05***
I.E.C ppb	193.2	**289.8**	**341.3**	**282.3**	**328.3**	**384.1**	**401.1**	**342.7**	<.001	52.57
Starch	5.3	**4.08**	**4.08**	**3.95**	**4.2**	4.58	4.47	4.88	0.051	0.98
°Brix (%)	12.0	12.4	11.4	11.8	12.1	12.2	**12.8**	**12.6**	<.001	0.61
DM (%)	15.4	**16.4**	15.7	15.7	16.1	**16.5**	**16.5**	16.1	0.127	0.87
Fructose	123.7	**103.0**	**105.8**	114.8	119.0	**110.5**	123.9	**111.1**	<.001	9.23
Glucose	14.0	**9.8**	**9.7**	12.0	12.2	12.0	12.3	**11.3**	0.004	2.11
Sucrose	75.8	81.2	81.3	74.7	**83.1**	**82.7**	**85.0**	82.3	0.041	6.77
Firm (N)	84.5	**92.6**	**88.4**	**88.3**	87.2	**89.6**	**88.9**	**89.3**	0.003	3.40

N.B. Values in bold are significantly different ($p<0.05$) from fruit harvested from the control (unthinned trees) in the same row. To convert fruit firmness from Newtons (N) to kg divide values by 9.8

Harvest maturity

Harvest maturity of Gala assessed on I.E.C. found that thinned fruit were more mature than un-thinned fruit (Table 3.4) but significant variation was found between fruit harvested from the top and bottom of the canopy (Table 3.5). Interestingly, the lower internal ethylene concentrations found in fruit at harvest did not correlate well with starch staining patterns. It has been previously reported (Johnson 1995) that starch and soluble solids patterns are poor indicators of harvest maturity in crop load trials where fruitlet number have been manipulated through flower and fruitlet thinning. In general, sucrose concentrations were higher in fruit with higher internal ethylene. Fruitlets subject to thinning to either singles, singles/doubles or treated with Exilis-treated fruit were less ripe than fruit from many of the other thinning treatments.

Overall effects of fruit position on the trees averaged across thinning treatments

Averaged across treatments fruits at the top of the canopy were more mature based on the Internal ethylene concentration but this was not reflected in starch clearance patterns (Table 3.6). FDM content was higher (0.6%) in fruits harvested from the top of the canopy (> 1.5 M). Fruit maturity was more advanced based on I.E.C in fruit sampled higher in the canopy but no corresponding change in starch clearance patterns or sucrose content was observed.

There was no effect of fruit position on sucrose content when averaged across all thinning treatments however, there was a strong interaction between, fruit position and individual thinning treatments on sucrose.

Table 3.6 The overall effect of sampling position of apples (>1.5 M, <1.5M) on the tree averaged across thinning treatments.

Position	***Top***	***Bottom***	***F.Prob***	***$LSD_{0.05}$***
I.E.C ppb	**362.9**	277.7	<.001	26.29
Starch CTIFL	4.4	4.5	0.72	0.45
DM (%)	**16.4**	15.8	0.01	0.43
Fructose (µg/µl)	111.4	**116.5**	0.03	4.61
Glucose (µg/µl)	11.4	11.9	0.38	1.06
Sucrose (µg/µl)	81.2	80.3	0.58	3.38

N.B. Values in bold are significantly different ($p<0.05$) from fruit harvested from the control (un-thinned trees) in the same row.

Interaction between Thinning treatments and Fruit Position within the Canopy

Fruit Dry Matter, °Brix and Sugars

When observing the range of harvest maturity, sugar, and carbohydrate accumulation across the tree additional patterns in treatment effects become apparent. Thinning treatments applied to fruitlets >1.5 M raised FDM between 0.2-1.7% above that of un-thinned trees (Table 3.6). Brevis treated fruit from the upper canopy recorded 17% FDM, while only 15.3% FDM in the lower canopy which was no higher than apples from un-thinned controls. Exilis showed a similar pattern of effect with 16.4% FDM in fruit from the upper canopy compared to 15.1% in the lower canopy. Thinning to singles across the tree, standard thinning, thinning to size and retaining double fruit per cluster across the tree both increased and improved uniformity of FDM across the canopy (Table 3.6). No impact of thinning treatments on °Brix was observed at harvest, however, in general, fruits from the top of the canopy had marginally higher °Brix (not significant $p<0.05$).

All hand thinned treatments led to a rise in sucrose content at harvest (Table 3.7), interestingly Brevis and Exilis failed to increase sucrose in apples harvested from higher in the canopy despite having higher percentage of FDM. Fructose and glucose content remained lower in Gala from thinned trees which may correlate with fruits having an increased harvest maturity and higher respiration rates utilising amounts of reducing sugars.

Fruit Maturity

In general, fruits from the higher part (1.5 M) of the canopy were more advanced in maturity than trees from the lower canopy (Table 3.7). Certain thinning treatments advanced fruit maturity based on higher I.E.C at harvest. Trees that were thinned to singles fruitlets in the higher canopy with double fruitlets (Singles/Doubles) in the lower canopy, Brevis-treated trees, and those where fruitlets have been thinned to size all resulted higher I.E.C. Interestingly, where trees had been thinned to singles across the tree, no such increase in maturity was observed.

A disparity between I.E.C values and starch readings based on iodine staining was recorded and this difference was greatest in fruits harvested from the lower canopy of un-thinned trees where the lowest internal ethylene concentration (ppb) but recorded but fruits had the most advanced starch clearance patterns (CTIFL score of 5.4 and I.E.C of 130 ppm). Apples harvested from the top of the canopy had higher I.E.C values.

Firmness and Colour

Hand thinned treatments led to firmer fruit in the upper canopy, but these treatments did not impact on fruit firmness in the lower canopy, apart from where trees had been thinned to single fruitlets per cluster across the tree (Table 3.8). Fruit colour was not affected by thinning treatments (Table 3.8).

Table 3.7 The interaction between Thinning Treatments and sampling position of apples (>1.5 M, <1.5M) on the tree.

Thinning	Internal Eth Conc. ppb		CTIFL Starch score		% DM		Fructose		Glucose		Sucrose	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Unthinned	**255.6**	130.8	5.3	5.4	15.5	15.3	122.7	124.7	13.8	14.1	76.5	75.0
Singles	282.8	**296.9**	3.7	4.5	**16.5**	**16.3**	**99.8**	**106.3**	**9.0**	**10.5**	**80.1**	**82.3**
Sing/Dou	**434.7**	**247.9**	4.2	4.0	15.9	15.5	**100.2**	**111.4**	**8.9**	**10.4**	78.3	**84.2**
Exilis	299.4	**265.3**	4	3.9	**16.4**	15.1	**112.8**	**116.7**	**12.1**	**11.8**	74.0	75.5
Brevis	**393.7**	**262.9**	4.3	4.1	**17.0**	15.3	**112.7**	125.3	**11.8**	**12.5**	**83.4**	**82.9**
Standard	**380.8**	**387.3**	4.3	4.9	**16.7**	**16.3**	**108.5**	**112.5**	**11.3**	**12.7**	**84.8**	**80.5**
Size	**480.0**	**322.2**	4.8	4.2	**16.7**	**16.3**	122	125.7	**12.6**	**12.0**	**86.8**	**83.3**
Doubles	**376.6**	**308.8**	4.7	5.1	**16.3**	**16.0**	**112.7**	**109.4**	**11.7**	**11.0**	**86.0**	78.6
F.prob	<.001		0.813		0.127		0.739		0.883		0.62	
LSD 0.05 Treat x Pos.	74.35		1.262		0.433		4.61		1.056		3.384	

N.B Figures in bold are significantly different ($p<0.05$) from the control (un-thinned) trees in the same column of data

Table 3.8 The effect of tree position on the accumulation of FDM, °Brix, Firmness and Fruit colour

	DM (%)		Red Colour		Yellow Colour		°Brix (%)		Firmness	
	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom
Control	15.5	15.3	42.6	38.4	18.6	19.9	12.2	11.8	82.5	86.4
Singles	**16.5**	**16.3**	43.1	40.1	17.5	20.8	12.5	12.2	**93.2**	**92.0**
Singles/Doubles	15.9	15.5	42.9	38.4	18.2	21.2	11.9	10.9	**90.4**	86.4
Exilis	**16.4**	15.1	42.4	41.6	17.6	19.2	11.8	11.8	87.9	88.7
Brevis	**17.0**	15.3	40.5	35.8	19.9	20.9	12.3	11.8	87.3	87.0
Standard	**16.7**	**16.3**	42.5	39.4	19.0	20.9	12.1	12.4	**89.9**	89.3
Size	**16.7**	**16.3**	44.5	41.3	17.0	20.4	12.9	12.6	**89.1**	88.7
Doubles	**16.3**	**16.0**	43.3	38.5	20.1	22.1	12.8	12.5	**89.8**	88.8
F.prob	0.585		0.801		0.835		0.665		0.571	
$LSD_{0.05}$ Treat x Pos.	1.22		3.61		2.62		0.86		4.81	

N.B. Values in bold are significantly different ($p<0.05$) from fruit harvested from un-thinned trees in the same column. To convert Newtons (N) to kg divide values by 9.86.

Storage

Fruits were stored in 3% CO2/ 1% O2 at 0.5-1.0°C for 8-9 months. Fruits were removed and a single ex-store assessment was undertaken. Gala from the thinning trial- demonstrated that fruits that had undergone thinning retained their increased °Brix content throughout storage. Those fruit subject to thinning to singles, standard thinning, thinning to size or where trees treated with Brevis had °Brix content 0.7-0.9% over un-thinned fruit. Moreover, Brevis was as effective as hand-thinning in raising °Brix content of fruit. Overall fruit retained firmness throughout storage losing less than 10 N (~1 kg) in pressure throughout 9 months storage - these fruits received no additional post-harvest treatments prior to sealing the cabinets (Table 4.1). however, no shelf-life assessments were taken for this trial due to Covid-19.

Table 4.1. Overall fruit firmness (N) and °Brix values of Gala apples subject to fruitlet thinning treatments, stored for 9 months in (3% CO_2/ 1% O_2 at 0.5-1.0°C)

Thinning	*Control*	*Singles*	*Singles/ Doubles*	*Exilis*	*Brevis*	*Standard*	*Size*	*Doubles*	*F.prob*	*$LSD_{0.05}$*
°Brix (%)	13.0	**13.7**	13.4	13.5	**13.8**	**13.9**	**13.9**	13.5	0.033	0.572
Firmness (N)	80.7	81.0	80.9	81.5	82.0	82.0	80.8	82.0	0.904	2.690

The quality of fruit coming out of store after 9 months was excellent- with a minimal decline in firmness. There was no difference in fruit firmness readings between fruit selected from the top and bottom fruit of the canopy. Due to the Covid-19 situation there was a delay in completing assessments which will have impacted on the results to a degree. °Brix values were generally higher for upper canopy fruit with fruit hand-thinned to singles, singles/doubles, doubles, standard thinning and thinning to size, Brevis-treated (Table 4.2), but differences failed to reach significance (p<0.05).

Table 4.2 Fruit firmness (N) and °Brix values of Gala apples from the top (> 1.5 M) and bottom (<1.5 M) subject to fruitlet thinning treatments, stored for 9 months

	Firmness (N)		°Brix (%)	
Firmness (N)	Top	Bottom	Top	Bottom
Control	80.8	80.5	13.0	13.0
Singles	84.0	77.9	**13.8**	13.5
Singles/Doubles	82.4	79.5	13.7	13.0
Exilis	82.7	80.3	13.7	13.3
Brevis	82.6	81.4	**14.0**	13.6
Standard	83.2	80.8	**14.4**	13.3
Size	81.3	80.3	**14.1**	13.7
Doubles	82.8	81.2	**13.8**	13.2
F.prob	0.57		0.75	
$LSD_{0.05}$	3.8		0.81	

N.B. Values in bold are significantly different (p<0.05) from fruit harvested from the control (unthinned trees) in the same column. To convert fruit firmness from Newtons (N) to kg divide values by 9.86

Storage Assessment of Gala from Centrifugal Pruning System and Reflective Covers

After 9-month storage Gala lost less than 1-3 N (<0.1-0.3 kg) in firmness since harvest. Fruit stored from centrifugally pruned trees and subject to reflective covers during the growing season were marginally firmer than fruit than fruit from tall spindle trees and in the absence of covers (Tables 4.3; 4.4). °Brix were very similar between fruit from centrifugal and tall spindle trees nor did reflective covers increase °Brix in fruit coming out of store.

Table 4.3. Overall means of pruning (Tall Spindle, Centrifugal System), the presence of reflective covers and sampling occasion (September 2019/June 2020) on fruit firmness (N) and °Brix of Gala apples stored in in (3% CO_2,1% O_2 at 0.5-1.0°C)

Firmness (N)	Tall Spindle	Centrifugal	f. prob	$LSD_{0.05}$
Pruning	79.7	**82.5**	<0.01	1.125
	Reflective Covers	No Covers		
Covers	79.9	**82.3**	<0.01	1.125
	Harvest	June		
Time	**82.0**	80.2	0.003	1.125
°Brix (%)	Tall Spindle	Centrifugal	f.prob	$LSD_{0.05}$
Pruning	12.0	12.2	0.06	0.156
	Reflective Covers	No Covers		
Covers	12.1	12.2	0.406	0.156
	Harvest	June		
Time	11.9	12.3	<.001	0.156

N.B. Values in bold are significantly different (p<0.05) from values in the same row. To convert fruit firmness from Newtons (N) to kg divide values by 9.86

Table 4.4. The interaction of pruning and reflective covers on firmness and °Brix of Gala apples stored for 9 months in (3% CO_2,1% O_2 at 0.5-1.0°C)

	Pruning	Ref. Covers	September	June	f.prob	$LSD_{0.05}$
Firmness (N)	Tall Spindle	Yes	**78.3**	**77.7**		
		No	82.2	80.7		
	Centrifugal	Yes	82.6	81.2		
		No	**85.1**	81.3	0.147	2.249
°Brix (%)	Tall Spindle	Yes	11.8	12.2		
		No	11.9	12.3		
	Centrifugal	Yes	12.0	12.3		
		No	11.8	12.6	0.145	0.3119

N.B. Values in bold are significantly different (p<0.05) from fruit harvested from the control (Tall Spindle, no reflective covers) in the same column. To convert fruit firmness from Newtons (N) to kg divide values by 9.86

Discussion

Dry matter accumulation of fruit is dependent on the position of fruits within the canopy. Fruits from the high (>1.5 m) canopy were approximately 0.6% higher in FDM (16.4%) than fruits picked from the lower regions of the canopy (<0.6 m) where fruit averaged 15.8% FDM.

Increasing the amount of light interception by centrifugal pruning techniques affords the opportunity to improve tree performance above existing standard spindle tree architecture systems.

Centrifugal pruning changes the proportion vegetative shoots in favour of fruit bearing shoots (Willamue et al., 2004, Stephen et al., 2008) and improves light penetration through the canopy. Over time this system should help to improve yields, increase FDM and reduce the need for pruning. In current trials at NIAB-EMR, trees are recovering from their initial re-training and in 2019 a severe scab infection caused a decline in yields and tree health, however year on year yields are recovering to match those of tall spindle trees. Centrifugal growing systems have increased light penetration and used in conjunction with reflective covers the system is able to increase FDM in the lower canopy.

Previous reports (Palmer 2010; McGlone 2003) highlight a strong relationship between overall FDM and the amount of sugar (°Brix) in the crop at harvest and that this relationship carries on during the early stages of storage (3 months). In this current trial higher FDM have not translated into higher °Brix in fruit at harvest. The difference in FDM between treatments was relatively small (0.6%) and thus may have translated into significant increase in °Brix. The presence of reflective covers raised fruit sucrose and fructose content in fruit from the upper canopy of Tall Spindle trees, and in CS trees sucrose was elevated in the presence of reflective covers. Interpreting changes in sugar content in fruit is difficult. Fructose is the predominant sugar as a result of sorbitol loading into fruit breaking down to fructose, with only 20% of the photosynthate entering fruit as sucrose. Fructose and glucose are in continual flux through utilisation in respiration and replenishment through the breakdown of sucrose by the action of invertases. Fruit maturity and crop load also play a role in influencing sucrose content as there is a general trend of decreasing sucrose content as fruits reach maturation. In the thinning trial, fructose, glucose, and sucrose were lower in fruit where thinning had been practiced.

It is difficult to relate °Brix and starch profiles to maturity where different thinning treatments have been imposed that impact on crop load (Johnson, 1992, 1994, 1995). The I.E.C is a more accurate measure of fruit maturity and from the results all thinning treatments raised I.E.C values. It has been reported previously that thinning practices can advance fruit maturity (Johnson 1995). Fruit from the upper canopy was more advance in maturity than fruit from the lower canopy. Interestingly the most significant contrast in I.E.C's was observed where trees were thinned to singles in the higher canopy and doubles in the lower canopy when fruitlets were 10-20 mm in diameter, when this process was repeated a few weeks later as part of the standard thinning practice the resultant effects on maturity at harvest of low hanging was an equalling out of fruit maturity across the tree. A similar large difference between fruit from the top and bottom of the canopy were seen where apples had been thinned to size. While fruit maturity tended to be higher in fruit from the higher canopy based on I.E.C, a similar difference in individual sugars was not observed.

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.

Increased firmness was more closely correlated with FMD rather than fruit maturity at harvest with the least firm fruit recorded in un-thinned fruit most likely the result of less structural carbohydrate being laid down in cell walls in fruit during development.

In terms of achieving manipulation of FDM by chemical application of thinning agents, Brevis and Exilis raised FDM above un-thinned controls and achieved a similar increase to hand thinned trees. Brevis treated Gala yielded 17% FDM in fruit from the upper canopy. However, Brevis treated trees exhibited a higher grade out due to undersized fruits reducing the overall % of Class 1 fruit. The lack of effect of Exilis and Brevis in the lower canopy may be due to poorer chemical uptake by more densely packed canopy in the lower part of the tree.

Fruit quality was retained during storage in 3% CO2/ 1% O2 at 0.5-1.0°C and this was helped by rapid establishment of CA conditions at the start of storage using nitrogen flushing once fruit had reached store temperature. The higher °Brix in fruit in thinned fruit and in particular fruit harvested in the upper canopy was retained throughout storage.

Conclusions

WP 2: Centrifugal pruning and reflective mulches

Centrifugally pruned trees combined with reflective covers raised the FDM in fruit from the lower canopy. The Combination of centrifugal system and reflective covers delayed fruit maturity -however this may be influenced by crop load. In 2019, significant incidence of apple scab was recorded in certain plots, and this will have skewed the data.

WP 3: Blud, flower, and fruitlet thinning strategies

Thinning in general increased FDM but changing the timing of hand thinning did not increase FDM. Some thinning strategies had a stronger effected on manipulating size of fruit and different practices may be useful for delivering fruit profiles for particular customers. Apples from the upper canopy had higher FDM and °Brix.

Knowledge and Technology Transfer

Lecourt, J and Colgan, R.J Agronomist day Demonstration of pruning and reflective mulches. September 2019. (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 say at least 1 week