Grower Summary

Developing Practical Strategies to Improve Quality and Storage Potential of UK Apples

TF 225

Final report 2021

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Project number:	TF225
Project leader:	Dr Richard Colgan - Natural Resources Institute, University of Greenwich
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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
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DISCLAIMER

GROWER SUMMARY

Increasing Fruit Dry Matter content in Gala requires a combined approach of manipulating crop load, ensuring maximum light penetration into the middle and lower canopy, and ensuring tree nutrition is well managed.

Tall spindle trees were converted into trees with a centrifugal habit to allow light to penetrate a central column surrounding the trunk allowing increased light interception in the lower and middle canopy

This was achieved by removing buds from branches located near the trunk and removing buds from the underside of the branches which encouraged more fruit to form at the terminal end of branches. Once trees had recovered from the process of conversion, centrifugally pruned trees allowed greater light penetration in the lower canopy. Combining centrifugal pruning with the positioning of reflective covers lead to a higher rate of fruit growth in August and raised %FDM by 1% in fruit in the bottom of the canopy when compared with Gala harvested from the lower canopy in tall spindle trees where no reflective covers were positioned. The combination of the two techniques evened out %FDM of apples across the tree.

Fruit thinning techniques that reduced crop load generally improved accumulation of FDM- the impact was partly dependent on the weather in terms that in years of high sunshine hours (2020) then difference between thinning treatments was less obvious. Implementation of hand thinning early in fruitlet development (10-20 mm) increased fruit size at harvest. No single thinning treatment was consistent in increasing %FDM as weather played a part in determining final FDM. Hand thinning practices where fruitlets were removed early (10-20 mm) to single fruits per cluster across the tree, singles above 1.5M and doubles below 1.5 M, or doubles across the tree along with thinning to size were effective in raising %FDM in 2019. However, in 2020 where higher levels of irradiance were encountered then FDM content in hand thinned trees (15.5-16.1 %FDM) were similar to unthinned trees (16.1%). The use of Exilis and Brevis to chemically thin crop load was variable between years. Efficacy of spray treatments is very much dependent on the timing of application and the temperatures around the time of application. In terms of increasing %FDM at harvest Brevis raised %FDM in 2 years out of 4 and Exilis 1 year in 4. Brevis application resulted in a slight reduction in class 1 fruit in 2 years out of 4 years tested, while Exilis caused a slight drop-in class 1 yield in 1 out of 4 years. The main loss of quality in Exilis and Brevis treated fruit was a slightly higher proportion of diseased, or mishappen (Exilis) fruits at harvest.

The implementation of chlorophyll fluorescence (CF) as a method to monitor changes in fruit maturity were tested over a 3-year period. The method based on repeat monitoring of CF profile starting with baseline measurements taken from developing fruits at the end of July followed by 2-3 assessments in August to track the decline in CF outputs. The rate of change in CF declined formed the basis for predicting a harvest window for Gala providing a 7–10-day advanced warning that fruits were ready to be harvested.

Headline

- Centrifugal pruning combined with positioning of reflective covers in alleyways may increase FDM content in lower canopy fruit.
- Thinning strategies are more likely to increase FMD in fruit from the upper canopy.
- Early thinning events increased fruit size at harvest.

Background

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 (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. FDM is a reflection of fruit carbohydrate content, where soluble solids content, measured as % Brix and starch are the major constituents.

The underlying basis of this relationship needs to be better understood so that it can be manipulated to deliver premium fruit quality. This will be 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, and the development of practical strategies in terms of novel pruning strategies, reflective mulches and manipulation of crop load through bud and fruit thinning to help growers to improve the quality of stored apples.

The breakdown of starch into soluble solids content during fruit ripening makes FDM a valuable and accurate indicator of potential post-harvest soluble solids content. 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

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.

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 work package in the later stages of the project to form a single trial plot.

Work package 1 summarised existing data sets of FDM content acquired from orchard sample analysis over 2 years linked to mineral analysis of fruits, leaves and soil analysis. Additional work packages centred on increasing light penetration through the canopy and reflecting available light back up into the lower canopy (WP 2). While in WP3 the impact of crop load and thinning practices on buds, flowers and the timing of fruitlet removal was investigated. In WP 4 the use of chlorophyl fluorescence was investigated to quantify changes in advancing fruit maturity in a selected range of Gala orchards with the aim to increase the prediction window to schedule harvesting.

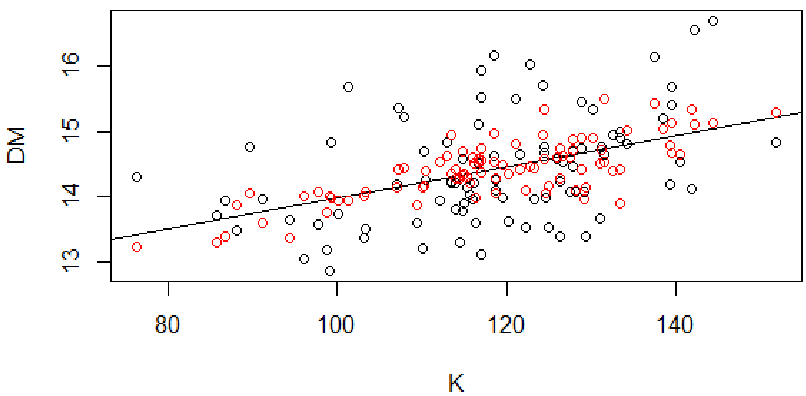
Summary

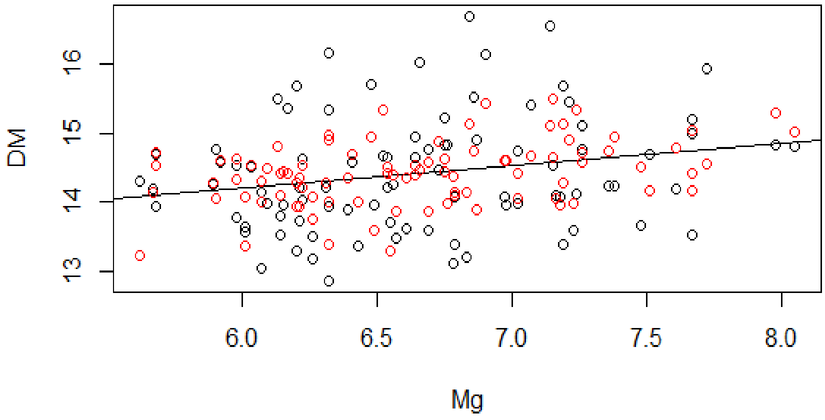
Work Package 1: Meta Analysis

Orchard surveys compiled by FAST have been collated on dry matter and mineral analysis from fruitlets, soil and leaves of 56 Gala orchards.

A preliminary multiple regression analysis was used to determine whether mineral content of soils influences fruit development and dry matter accumulation and, moreover, the extent to which mineral content of the soil influences leaflet and fruitlet analysis. From the two years of available data (2015-2016) FDM variation across all the data sets ranged from 13.6% to 18.9%, a span of 5.3% FDM. The Gala dataset consisted of 56 measurements with a range from 13.8% to16.0% FDM and a span of 2.2% FDM.

Multiple regression analysis of fruit mineral content and FDM identified that there was a weak positive relationship between higher fruit potassium and magnesium and higher FDM content while higher fruit zinc content led to lower FDM (Figure 1).





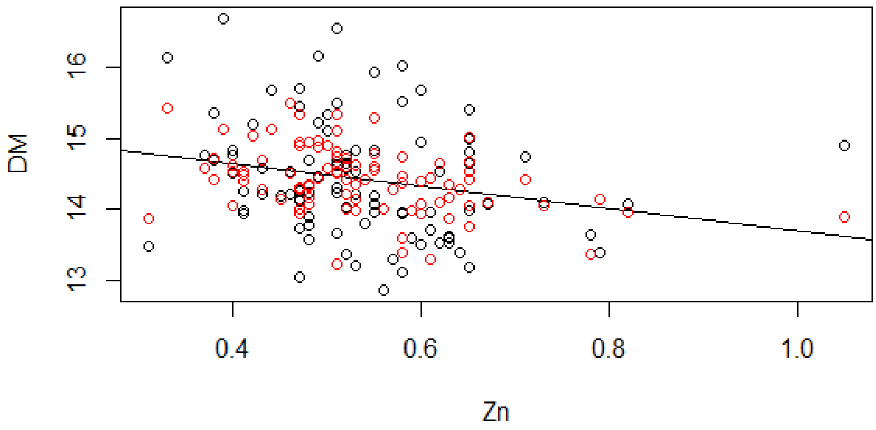


Figure 1: Multiple regression analysis depicting the positive relationship between K, Mg with FDM and a weak negative relationship with Zn. Concentration of mineral elements are in mg/100g FW.

Work Package 2: Manipulation of Light Interception into the Canopy (NIAB-EMR/NRI)

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). The results as shown below represent the mean of twenty measurements per treatment showing statistically significant differences between the treatments,

The Centrifugate System (CS) shows a greater amount of light penetrating the canopy recording 19.8 % light interception compared against 12.5 % in Tall Spindle (TS) (Figure 2). However, this difference was not statistically significant due to the large inter-tree variability.

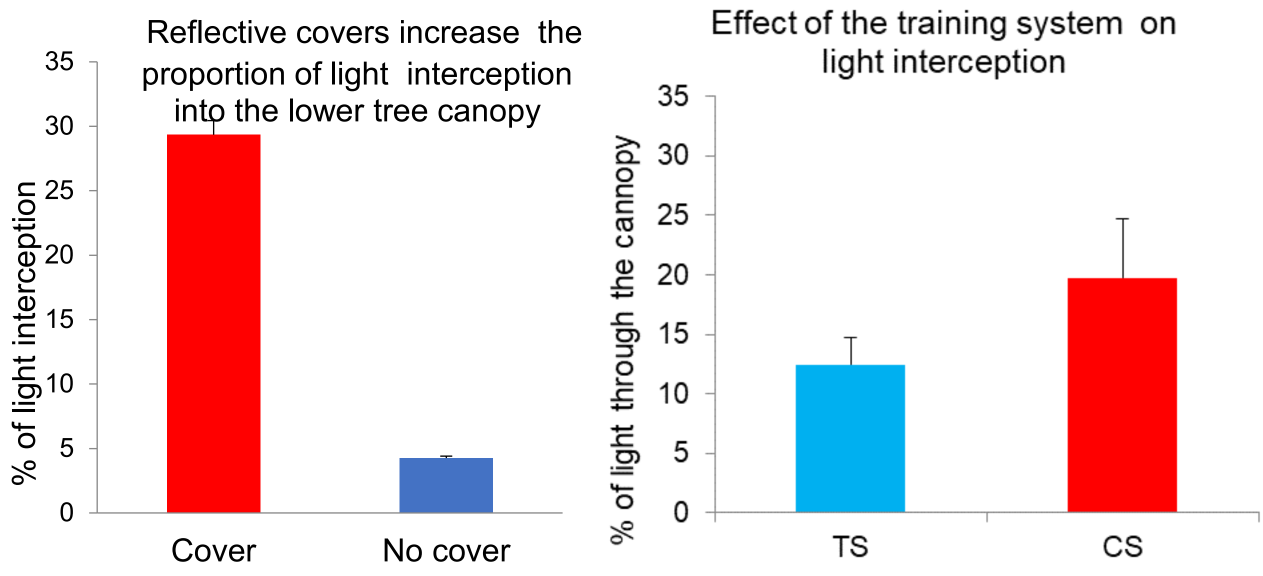


Figure 2: Light interception levels measured in the lower canopy (>1.5 M) where trees had been pruned using centrifugal pruning and/or where reflective covers had been added.

More specially the regions of the canopy that light from centrifugal pruning techniques penetrates when either applied alone or in combination with reflective covers with was investigated. Light interception in the centre of the tree and the lower canopy most benefited from combining centrifugal pruning and reflective covers.

Centrifugal pruning alone increased light interception into the lower and mid-canopy and when combined with reflective covers there was an additive effect of raising light penetration into the lower and mid canopy of the Gala apple trees (Figure 3). The impact of greater light penetration was on increased rate of fruit growth. Improving light interception combining centrifugal pruning with reflective covers led to increased fruit growth in Gala measured in August though to Harvest in September (Figure 4.0).

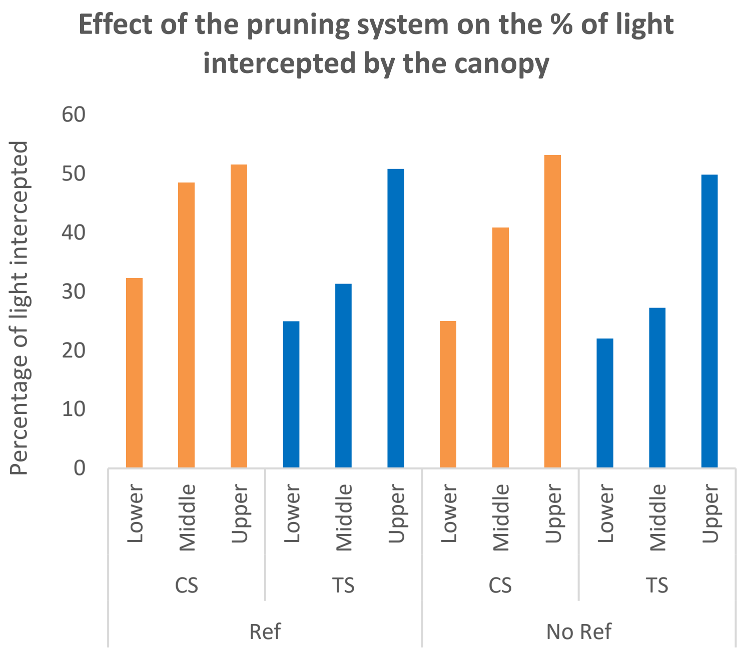


Figure 4: The % light Interception measured by Acupar at different points in the tree canopy

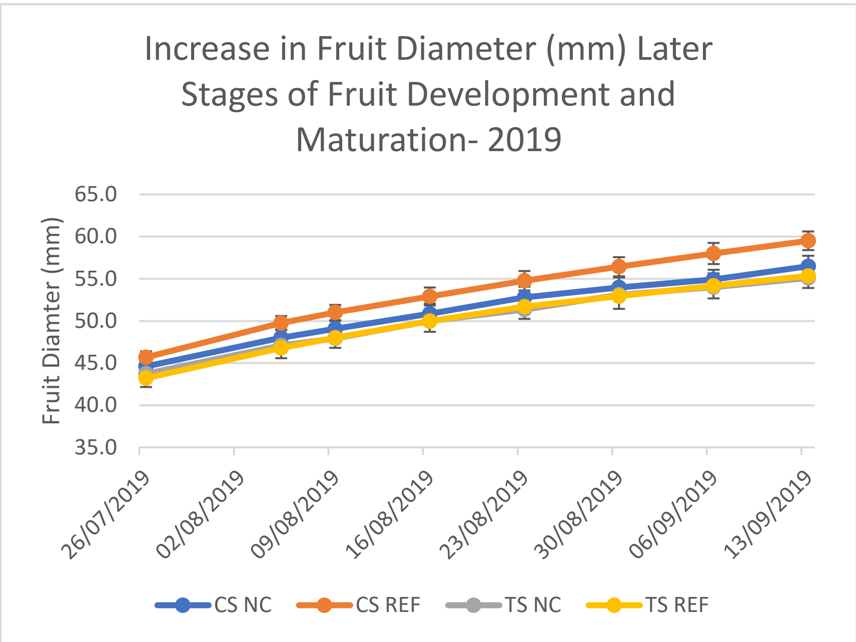


Figure 5: Fruit size increases in Gala under centrifugal training systems (CS) when light reflective covers (REF) were inserted in the alleyways during the later stages of fruit development and maturation compared to standard tall spindle training systems (TS).

For the first few years after trees were converted into centrifugally pruned trees yields and accumulation of dry matter content were lower than conventionally pruned (tall spindle) trees. In Year 4 of the project when trees have recovered sufficiently, the overall effect centrifugal pruning (+/- reflective covers) and where %FDM was averaged across fruit from the top and bottom of the canopy was o increased fruit dry matter (FDM) by 0.3% (Table 1). Overall, the impact of reflective covers (averaged across pruning system) was to raise FDM matter across the tree by 0.3%. Apples harvested from the top of the tree (>1.5M) were higher in %FDM by 0.3%.

The combination of reflective covers, centrifugal punning was most effective in raising the %FDM in fruit from the lower canopy where light is most restricted, at this point in the canopy CS+ REF led to a 1% increase in %FDM (15.6%) compared to 14.6% in fruit from the lower canopy of Tall Spindle trees where no reflective covers were installed (Table 1.0).

Fruit maturity was affected by adoption of pruning system. Apples from the upper part of CS trees were less mature based on Internal Ethylene Concentration, this may be due to crop load still having an effect or tree architecture where more fruit on CS trees was borne on younger wood. The % Brix at harvest was not impacted by pruning, light interception or fruit maturity.

Table 1: The interaction between Training Systems, Reflective Covers and Fruit Position on Fruit Maturity attributes at Harvest

		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	

The impact of pruning and increasing light interception had marginal impact on the sugar profile of fruit, with the exception that fruit subject to reflective covers had higher concentrations of sucrose which in previous trials has been an indicator of less advanced maturity with sucrose later being converted to glucose and fructose.

Table 2: Overall effects of training system, sampling position and the presence of reflective covers on % FDM and fruit maturity

Pruning	*Tall Spindle*	*Centrifugal*	*F.prob*	*$LSD_{0.05}$*
I.E.C (ppb)	*369*	***216***	<.001	42.5
% FDM	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
% FDM	**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
% FDM	**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

Work Package 3. Manipulation of Crop Load to improve Dry Matter Accumulation (FAST LLP, NRI)

The main aim of the project was to determine how manipulation of crop load either through reducing the number of developing fruit buds, reducing flower precocity and fruitlet number can impact on accumulation of fruit dry matter and increasing % Brix at harvest and development during storage. While thinning practices have an important bearing on increasing fruit size, the impact on raising fruit dry matter is less clear. In two out of the three years tested standard thinning practices were able to raise FDM by 0.7- 1.1% over unthinned trees (Table 3). Thinning to size and late thinning also in some years increase %FMD, however a strong seasonal effect was seen. In 2018 and 2020 were years of higher total sunshine hours accumulated during fruit development and in these years the difference between thinned fruit and unthinned in terms of %FDM accumulation was lower than in years 2017 and 2019 that were duller.

In the later years of the trials thinning to single fruitlets per cluster across the tree or singles (>1.5 M) and doubles (<1.5 M) or retaining double fruitlets per cluster throughout the tree, where applied at an earlier growth stage than normal had only a small impact on raising %FDM but did increase fruit size. Chemical thinning agents offer the potential to minimise labour costs in terms of achieving optimum crop load. %Brix content of fruit at harvest was a seasonally affected with %Brix oscillating 1-2 % between seasons (Table 4). No single thinning treatment led to higher sugars at harvest, but sugars continue to rise in store post-harvest

Total yields were generally slightly lower in thinned trees, but the amount of Class I fruit harvested was consistently higher in thinned trees. Of the approaches taken

Table 3: The impact of thinning practices on accumulation of % Fruit Dry Matter content in Gala apples

%FDM	Control	Bud	Mechanical	Exilis	Brevis	Std	Size	Late	Single	Single/ Doubles	Doubles
2017	16.4	15.9	16.0	16.6	16.3	16.4	16.7	17.0	x	x	x
2018	15.7	15.5	16.4	15.7	16.9	16.9	15.9	15.8	x	x	x
2019	15.4	x	x	15.7	16.1	16.5	16.5	x	16.4	15.7	16.1
2020	16.1	x	x	16.7	15.7	x	x	x	15.8	15.5	16.1

Table 4: The impact of thinning practices on % Brix

% Brix	Control	Bud	Mechanical	Exilis	Brevis	Std	Size	Late	Singles	Singles / Doubles	Doubles
2017	11.9	11.9	11.6	11.6	12.1	11.8	12.1	13.3	x	x	x
2018	12.6	12.7	12.6	12.8	13	13	12.8	12.6	x	x	x
2019	13	x	x	13.5	13.8	13.9	13.9	x	13.7	13.4	13.5
2020	12.3	x	x	12.6	12.1	x	x	x	11.9	11.4	12.2

Table 5: The effect of thinning practices on total yield of Gala trees

Total yield kg/ha	Control	Bud Thinning	Mechanical	Exilis Fixor	Brevis	Std Hand Thinning	Size hand thinning	Late thinning	*Singles*	*Singles / Doubles*	*Doubles*
2017	62.2	55.5	55.9	58	60.9	55	62	51.3	x	x	x
2018	78.3	80.5	83.2	68.2	77.4	85.3	84	87.8	x	x	x
2019	105.8	x	x	86.4	65.6	80.7	83.0	x	71.3	87.9	72.5
2020	60.9	x	x	49.8	62.7	x	x	x	56.5	68.3	62

N.B Yield was based on a total of 12 trees sampled across 4 plots- 3 trees per plot

Table 6: The impact of thinning practices on Class 1 fruit.

Class 1 kg /ha	Control	Bud Thinning	Mechanical	Exilis & Fixor	Brevis	Std Hand Thinning	Size hand thinning	Late thinning	*Singles*	*Singles / Doubles*	*Doubles*
Year 2	33.5	33.6	34.7	35.3	29.6	28.8	36.2	29.7	x	x	x
Year 3	53.6	56.5	55.8	44.9	46.5	53.4	48.3	48.3	x	x	x
Year 4	53.6	x	x	53.4	31.6	50.0	51.1	x	45.0	52.3	42.0
Year 5	24.4	x	x	22.1	29.3	x	x	x	28.8	28.7	31.9

Table 7 (a-d): The impact of thinning practices on wastage categories for each of the 4 years (2017-2021) of the thinning trial

Table 7(a)

2017	Control	Bud	Mechanical	Exilis	Brevis	Std	Size	Late
Other	0.8	1	1	0	0	6.7	3.8	2.8
Lack % Red	15.1	19.8	40.2	25.7	37.7	28.3	19	9.3
Diseased	1.7	2	4.1	1	1.4	0	0	0
Small	20.2	8.9	4.1	16.2	12.3	10	10.5	13.5
Misshapen	2.5	4	2.1	7.6	2.2	10	5.7	2.8
Damage - pest/physic.	52.1	61.4	42.3	45.7	41.3	40.8	56.2	68.2
Scarring/Russet	7.6	3	6.2	3.8	5.1	4.2	4.8	3.7

Table 7 (b)

2018	Control	Bud	Mechanical	Exilis	Brevis	Std	Size	Late
Other	1.8	0	2.1	0	0	0	0	0
Lack % Red	5.3	3.7	2.1	2.2	7	0	5	0
Diseased	15.8	24.1	16.7	30.3	29.8	20.5	52.5	25
Small	42.1	42.6	20.8	25.8	10.5	30.8	7.5	50
Misshapen	7	3.7	20.8	24.7	12.3	7.7	2.5	10
Damage - pest/physic.	19.3	16.7	20.8	7.9	22.8	28.2	30	10
Scarring/Russet	8.8	9.3	16.7	9	17.5	12.8	2.5	5

Table 7 (c)

2019	Control	Singles	Singles/Doubles	Exilis	Brevis	Standard	Size	Doubles
Lack % Red	0.5	1	3	0.8	1.5	1.5	0.5	2
Diseased	9.8	10.5	7.3	7.8	**12.3**	11.8	11.5	9.5
Small	**12.5**	1.3	2.3	4.3	**7.3**	1	0.8	1.5
Misshapen	1.5	2	2.3	2.8	1.8	0.8	1	2.3
Damage - pest/physic.	7.5	5.5	8.5	6.5	9.3	8	9	9.3
Scarring/Russet	1.5	2.8	2	1.5	0.8	0.8	1	2

Table 7 (d)

020	Control	Singles	Singles/Doubles	Exilis	Brevis	Doubles
Lack of % red	10.3	12.3	9.1	10.3	19.6	8.8
Diseased	25	47.7	46.9	37.4	29.4	30.2
Small	**43.1**	21.8	21.1	26.3	27	38
Mis-Shape	1.1	2.2	0	**5.4**	0.8	0
Damage - pest/physical	17.7	11.1	18.7	17.7	20.9	19
Scaring/damage	2.8	4.9	4.3	2.9	2.3	3.9

Table 8 (a-e): Fruit Size distribution (mm) of Gala subject to thinning treatments implemented at different stages of bud, flower, and fruitlet development

Table 8 (a)

55-60	Control	Bud	Mechanical	Exilis	Brevis	Std	Size	Late	Singles	Single/ Doubles	Doubles
2017	18.5	11.3	10.4	12.2	13.9	9.8	13.7	3	x	x	x
2018	31	23.7	10.7	9.3	20.8	12.7	2.5	16.1	x	x	x
2019	32.4	x	x	16.2	13.7	8.4	0.3	x	0.8	1.4	2.1
2020	36.7	x	x	15.8	23.8	X	x	x	18.2	24.8	35.4

Table 8 (b)

60-65	Control	Bud	Mechanical	Exilis	Brevis	Std	Size	Late	Singles	Single/ Doubles	Doubles
2017	32.2	25.5	24.3	28.8	33.3	21.1	17.3	16.4	x	x	x
2018	37	39.2	33.5	31.1	31.7	35.5	30.5	37.1	x	x	x
2019	36.8	x	x	49.1	46.9	42.0	29.3	x	19.3	21.1	12.4
2020	42.1	x	x	33	36.5	X	x	x	33.6	38.6	34.6

Table 8 (c)

65-70	Control	Bud	Mechanical	Exilis	Brevis	Std	Size	Late	Singles	Single/ Doubles	Doubles
2017	41.9	32.6	32.6	38.1	25.9	32.7	30.9	43.3	x	x	x
2018	19.6	28.5	33	35.8	33.3	38.6	47	32.7	x	x	x
2019	26.8	x	x	26.0	35.8	42.4	52.3	x	51.0	49.8	44.5
2020	16.8	x	x	35.7	26.1	X	x	x	27.3	22.6	23.9

Table 8 (d)

70-75	Control	Bud	Mechanical	Exilis	Brevis	Std	Size	Late	Singles	Single/ Doubles	Doubles
2017	7.3	23.4	22.9	15.8	22.2	21.2	29.5	25.4	x	x	x
2018	12	8.6	19.8	20.5	12.6	12.2	18	14.1	x	x	x
2019	3.9	x	x	8.7	3.7	7.2	16.3	x	25.0	27.7	26.5
2020	4.4	x	x	15.5	10.6	x	x	x	17.8	11.3	3.4

Table 8 (e)

75-80	Control	Bud	Mechanical	Exilis	Brevis	Std	Size	Late	Singles	Single/ Doubles	Doubles
2017	0	7.1	9.7	5	4.6	16.3	8.6	11.9	x	x	x
2018	0.5	0	3	3.3	1.6	1	2	0	x	x	x
2019	0.0	x	x	0.0	0.0	0.0	1.9	**x**	3.9	0.0	14.5
2020	0	x	x	0	0.6	X	x	x	3.2	2.8	2.7

Work Package 4. Prediction of harvest maturity of Gala using Chlorophyll fluorescence Landseer Ltd

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 practice for harvesting of Gala for long term storage is to pick fruit when starch coverage has dropped to 85-80% coverage and where background red colour has developed sufficiently to satisfy the marketing desks. However, this narrow window does not afford growers sufficient time to organise harvesting crews in time to pick orchards before maturity advances observed through declining starch content. The results gathered between 2016-2018 confirmed that monitoring fruit using a chlorophyll fluorescence meter provided a non-destructive tool for fruit maturity and that changes in CF output were observed 7 to 10 days prior to changes in starch clearance patterns providing an early warning to growers to organise their picking schedules around the optimum harvest date for long-term storage. Where CF profiles was used on orchards where fruits had ample mineral content for long-term storage and high FDM then picking fruit at optimal maturity meant fruit performed well in long-term storage.

Sampling of Gala orchards for CF analysis was standardised to reduce variability, fruitlets (25-30mm) were picked 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 (see below) five of orchards were selected based on their suitability for long-term storage and were monitored with CF for a period of 2-3 weeks prior to commercial harvest. CF prediction model was restricted to fruit intended for long term storage (Table 9).

Table 9: Comparison of dry matter and mineral analysis in 9 orchard 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 ✓	uitlet (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 below. The formula charting CF decline with advancing maturity requires construction of a baseline CF measurement at fruitlet (25-30 mm) stage and continuing measuring fruits with the PEA fluorimeter until the reduction passes 50% of the baseline CF level taken at fruitlet stage:

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 based either on the prediction form the decline in chlorophyll fluorescence termed "CF pick" and or harvested when fruits had reached 80% Starch content based on standard iodine staining of an equatorial section of fruit termed "Starch pick". 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 limited to 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.

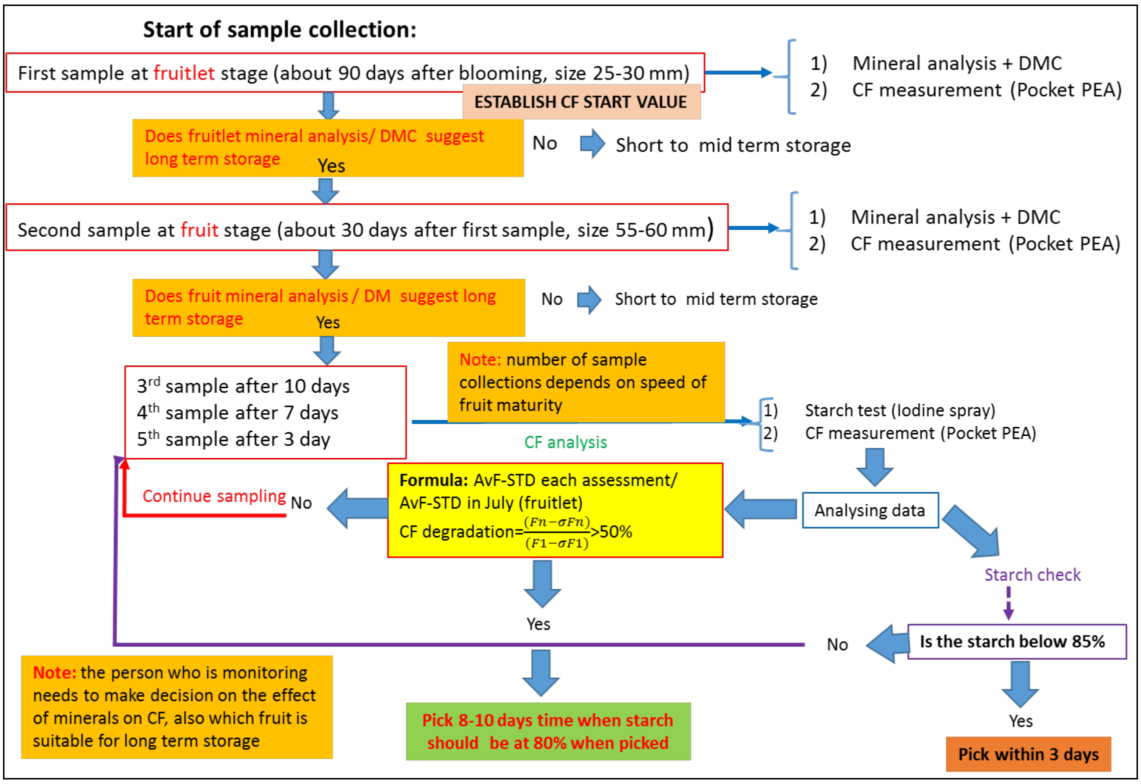


Figure 6: Decision tree flowchart for the process of sampling and analysing data for selecting the best orchards for long term storage and early warning for the best picking date.

Table 10: Comparison of fruit maturity warning by chlorophyll fluorescence Pocket PEA(CF) and starch staining patterns (2018).

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%

CF analysis predicted that Gala orchards from Barnyard, Monks and Hill Top should be picked in advance of orchards Gibbens and Mystole. Samples of apples from these orchards were analysed for Internal Ethylene Concentration (IEC) at the Produce Quality Centre. Based of IEC values the maturity of apples from selected orchards was ranked Monks>Barnyard>Hill top> Gibbons>Mystole, with Gala from Monks being the most mature and Mystole the least (Figure 7)

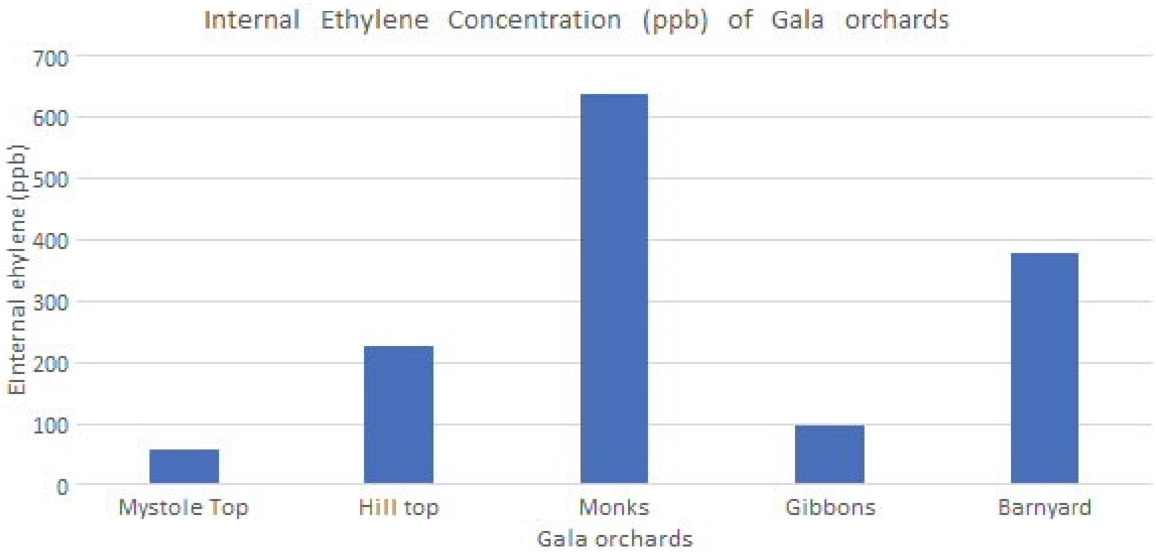


Figure 7: comparison of internal ethylene production in samples from each orchard 10 days before harvest.