

Open Access Apple Fruit position and temperature data

The here presented file, is an in-depth description of the data available in the datasets published at:

[10.5281/zenodo.10805064](https://doi.org/10.5281/zenodo.10805064)

Below are reported information regarding each of the data collection season.

2021 - UNIBO – Apple temperature and position datasets

Treatments

In relation to thermal information of apple fruit (*Malus domestica*), for the “**Apples_Thermocouples_data**” file dataset, temperature measurements were taken in 2 different training system*shading treatments:

- **A:** Spindle training system (3.3 m x 1 m planting distances) * Black anti-hail net coverage (15-20% shading). Considered as “Standard Sunburn Susceptibility Situation”. For spindle trees only different irrigation were applied to test water scarcity effect in sunburn development:
 - Irrigation 100% of the computed ETc .
 - Irrigation 70% of the computed ETc.
 - Irrigation 50% of the computed ETc.
- **P:** Planar Cordon training system (2 m x 3 m planting distances) *Grey anti-hail net coverage (15-20% shading). Considered as “Mid-High Sunburn Susceptibility Situation”.
 - Irrigation 100% of the compute ETc.



A



P

Treatments' conditions: **A** – “Standard Sunburn Susceptibility Situation”; **P** – “Mid-High Sunburn Susceptibility Situation”;

The purpose of comparing these treatments was to investigate different environmental conditions in relation to sunburn damage susceptibility, and to try to investigate the effect of water deficit in the appearance of sunburn symptoms. The collection of a wide range of data that can support further modelling and investigations of temperature, fruit position and sunburn damage.

Fruit localization

In this first year of data collection, no information regarding the fruit position were collected.

Sunburn symptoms evaluation

The sunburn evaluation was conducted by mean of identification of the sunburn damage presence on the fruit monitored during the season (i.e., categorical classification at harvest: damaged / not damaged fruit)

Fruit temperature and weather data

Local weather data are made available in the files:

- “**Weather_Ext_orchard**” file: including weather data collected outside of the orchard.

- “**Weather_Under_antihailnet**” file: including microclimatic data collected inside of the orchard in trial (with spindle training system).
- * No Microclimatic data for Planar cordon training system were collected.

Fruit temperature data were collected from 14/07 to fruit harvest 10/08. Gala apple fruit were continuously monitored (data resolution 15 min, data presented as hour average) for their temperature using calibrated thermocouples (Tcouple) (model: ‘Type K’ Tcouple, WiNet srl, Cesena – Italy) connected to a wireless sensor network (WSN) (WiNet srl, Cesena – Italy).

For all the training system * irrigation treatment four highly exposed fruit on each side (east and west) were selected, at medium height, for monitoring their temperature (N = 8 per treatment). Tcouple were fixed to the fruit using medical tape on the back / less exposed fruit side to keep cable in position, while the Tcouple itself was maintained in position thanks to the high cable plasticity. Tcouple was always touching the fruit, without damaging it, as shown in Fig. below. Tcouple was checked 1 – 2 per week for their correct positioning.



Detail of thermocouple mounted on apple fruit



Detail of aluminum foil placed underneath an apple fruit monitored with thermocouple

***Aluminum Foil applications** - Due to the highly reduced number of fruits developing sunburn, on 19th of July, aluminum foils were placed underneath fruit (n=4 per treatment but ‘A’*50% irrigation) monitored with thermocouples in order to stimulate the damage, assuming an increase in fruit temperature and peel stress according to an increased exposure to light. This to obtain data for the later development of prediction model in the SHEET project context.

Data collected are available in the “**Apples_Thermocouples_data**” file with the structure presented in the figure below.

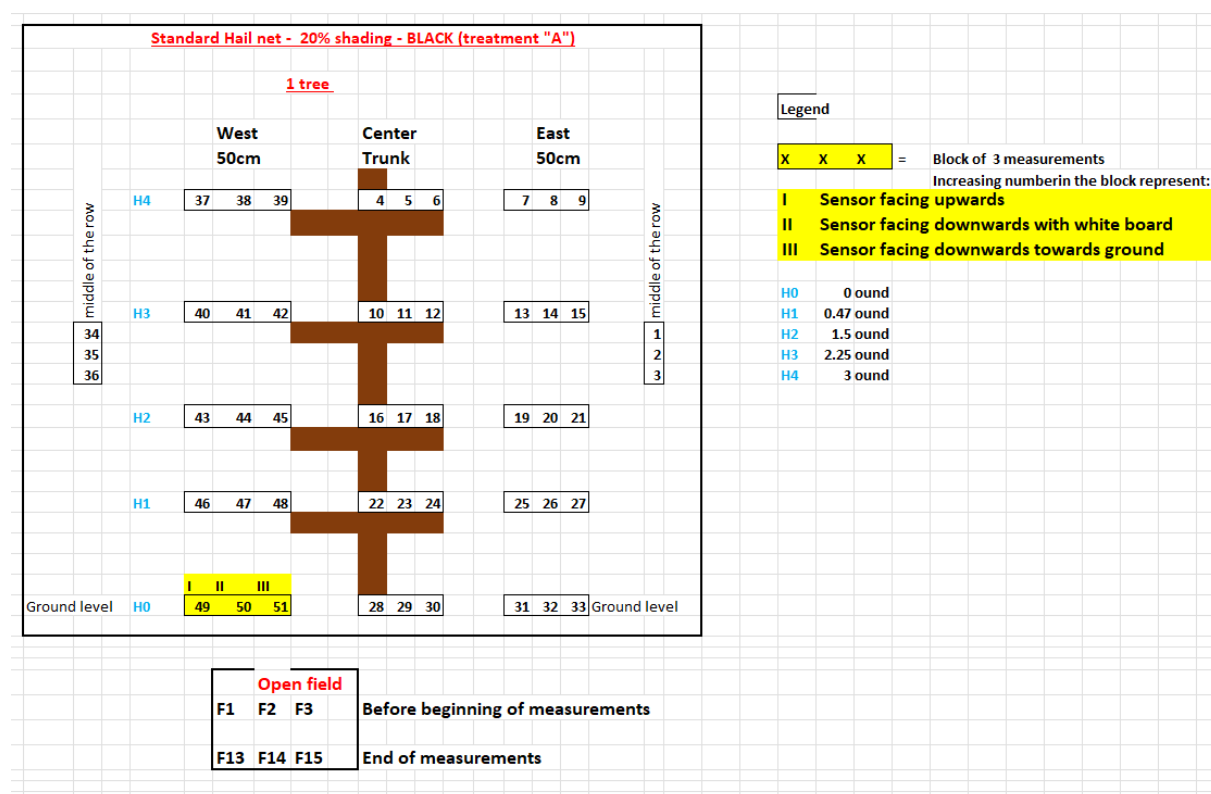
Training		spindle	spindle	spindle	spindle	spindle	spindle	spindle	spindle	spindle	spindle				spindle	spindle
Irrigation		100	100	100	100	100	100	100	100	100	100				70	70
Alluminium foil		ctrl	alum.foil	alum.foil	ctrl	alum.foil	ctrl	alum.foil							ctrl	alum.foil
Sunburn						sb		sb								
Calculation										ctrl	alum.foil	sunburn				
Thcouple_N		T1	T2	T3	T4	T5	T6	T7	T8				Date	000D	T1	T2
Date	000B															
14/07/2021	16:09:58	25.9	27.2	27.4	26.2	27	25.9	26.7	27.5	26.38	27.08	26.85	14/07/2021	16:09:49	29.5	27.7
14/07/2021	16:24:58	26	25.9	27.2	26	26.8	25.8	26.4	26.8	26.15	26.58	26.60	14/07/2021	16:24:49	28.6	27.3
14/07/2021	16:39:58	27	27.8	28.7	27.4	27.4	26.1	27.3	27.2	26.93	27.80	27.35	14/07/2021	16:39:49	29.8	28.5
14/07/2021	16:54:58	26.8	27	31.2	27.5	27.4	26.3	28.2	27.1	26.93	28.45	27.80	14/07/2021	16:54:49	31.2	28.5
14/07/2021	17:09:58	26.7	26.1	29.4	26.6	27	25.9	26.8	26.8	26.50	27.33	26.90	14/07/2021	17:09:49	29.7	27.6
14/07/2021	17:24:58	26.4	25.5	28.2	26.4	26.6	25.9	26.2	26.1	26.20	26.63	26.40	14/07/2021	17:24:49	29.2	27.5
14/07/2021	17:39:58	27	25.6	29	26.9	27	26.4	26.6	26.5	26.70	27.05	26.80	14/07/2021	17:39:49	30.7	29
14/07/2021	17:54:58	26.9	25.6	29	26.7	27	26.6	26.4	26.5	26.68	27.00	26.70	14/07/2021	17:54:49	30.8	27.7

Dataset structure

The dataset presents data grouped by treatments represented with a block of 11 columns where the first 7 rows represent the treatments' condition (*Training*, *Irrigation*) Presence of aluminum foil to induce the sunburn (*Aluminum foil*), *calculation*, *Thermocouple* and fruit identifier (*Thcouple_N*) and Date-time (*Date*).

Radiation measurements

Data regarding light radiation ("**Radiation measurements**" folder) were collected using an APOGEE SS-110 spectroradiometer, following the scheme reported in the "**Radiation Map**" file inside the parenth folder reported in the figure below. Data collection occurred on 30/06/2021 during a clear sunny day (around solar noon) and was done on a representative Spindle tree (i.e., "A" treatment; no data collection for P treatments has been done)



Data collection scheme

Per each height (H0-H4 ; n=5) and zone (n=3 : 50cm West; Center Trunk ; 50cm East) of the tree, a set of n.3 measures were taken with the following order: 1st sensor facing up towards the sky; 2nd sensor facing down towards a whiteboard kept at 20cm distance; 3rd sensor facing down towards the ground. This was done to possibly evaluate the different levels of light incidence and reflection altered by the environmental condition or standardized by the white painted board.

On each west and east side of the canopy a set of data was taken in the inter-row space, before starting the measurements on the tree, for information regarding the light environment surrounding the tree. Before and after the complete set of tree measurements a set of data was collected outside of the orchard for information regarding the outside.

Data are available in separated files, named as the code reported in the **Radiation Map** file, inside the dedicated folder.

2022 - UNIBO – Apple temperature and position datasets

Treatments

In relation to thermal and positional information of apple fruit (*Malus domestica*), 2 main plus 1 preliminary datasets (main: Dataset 1 or “TCouple” - “*Th.couple_data_2022_timeseries*” file - and Dataset 2 or “ThCAM” - “*SHEET_Th.CAM_HTI_2022*” file-; preliminary: Dataset 3 or “RGBD-T-System_APPLE_Pos&Temp_Dataset” file) were produced using different methodologies. For dataset 1 and 2, fruit temperature measurements were taken in 4 different training system*shading treatments. The irrigation treatment was stop since its effect was not as strong as the training system effect. Different canopy shapes influenced the onset of sunburn, rather than deficit irrigation on fully grown trees. The treatments were (Figure below):

A: Spindle training system (3.3 m x 1 m planting distances) * Black anti-hail net coerture (15-20% shading). Considered as “Standard Sunburn Susceptibility Situation” (N=4 trees).

E: Spindle training system (3.3 m x 1 m planting distances) *White anti -hail, -insect, -rain exclusion netting system (40-50% shading). Considered as “Low Sunburn Susceptibility Situation” (N=4 trees).

P: Planar Cordon training system (2 m x 3 m planting distances) *Grey anti-hail net coerture (15-20% shading). Considered as “Mid-High Sunburn Susceptibility Situation” (N=3 trees).

RST: Spindle training system (3.3 m x 1 m planting distances) * Open field (no netting / shading applied). “High Sunburn Susceptibility Situation” (N=4 trees).



A



E



P

RST

Treatments' conditions: **A** – “Standard Sunburn Susceptibility Situation”; **E** – “Low Sunburn Susceptibility Situation”; **P** – “Mid-High Sunburn Susceptibility Situation”; **RST** – “High Sunburn Susceptibility Situation”

The purpose of comparing these treatments was to investigate different environmental conditions in relation to sunburn damage susceptibility, collecting a wide range of data that can support further modelling and investigations of temperature, fruit position and sunburn damage.

For the preliminary Dataset 3, data collection occurred in a different orchard, not in trial, with similar environmental condition as the one of treatment A.

Fruit localization

The GPS coordinates (Latitude – ‘*Lat.*’, longitude - ‘*Long.*’, altitude - ‘*Altitude*’) of trees (N=15) carrying fruit under analysis were collected and stored in the file named “*GPS_Position_Apple&Tree_SHEET_2022_OK_EPSG4326.xlsx*”.

	TRT	Plant	Lat.	Long.	Altitude	GPS_log
	(identifier)	(identifier)	(decimal °)	(decimal °)	(m)	
1	A	1	44.549341	11.4163637	27.4128609	3
2	A	2	44.5493493	11.4163684	27.3893509	2
3	A	3	44.5493572	11.4163747	27.3370552	1
4	A	4	44.5493658	11.4163791	27.3224678	0
5	E	1	44.5492782	11.416566	27.43153	4
6	E	2	44.549286	11.4165722	27.4390678	5
7	E	3	44.5492946	11.4165769	27.3883114	6
8	E	4	44.5493025	11.416583	27.3965931	7
9	P	1	44.5475346	11.4140268	27.617794	11
10	P	2	44.5475583	11.4140436	27.5253334	10
11	P	3	44.5475837	11.414065	27.4316444	8
12	RST	4	44.5495055	11.416156	26.7332668	12
13	RST	3	44.5495082	11.4161608	26.7332668	13
14	RST	2	44.5496618	11.41628	26.9152107	14
15	RST	1	44.5496672	11.416286	26.8998127	15

‘Apple_TREE_GPS position’ sheet in “GPS_Position_Apple&Tree_SHEET_2022_OK_EPSG4326.xlsx” file

In the same file, for all the monitored fruit in datasets Tcouple (N=40) and ThCAM (N=108), their position was collected as X, Y, Z coordinates, in centimeter, using a standard measuring tape. X, Y, Z dimensions were considered respectively as the tree-row plane, the vertical plane perpendicular to the ground and the intra-row tree plane perpendicular to X (Fig. below). Positive and negative values of the coordinates were representing the fruit position in relation to the trunk (coordinate system's origin), with Y = 0 at ground level, +X or -X values for fruit positioned toward North or South respectively, and +Z or -Z values for fruit positioned toward East or West respectively, in respect to the trunk origin.



X, Y, Z coordinate system representation; the origin is represented by the trunk, with Y=0 at ground level.

The Figure below shows the file structure for both thermocouple and tagged fruit (i.e., fruit in ThCAM-dataset) position information. In add to 'X', 'Y', 'Z' coordinates and trees' GPS coordinates ('Lat.', 'Long.', 'Altitude',) and identifier ('Plant'), other information related to treatments ('Trattamento' and 'TRT') and internal identifier for tree position and block ('Block') are present. 'ThCouple_Node' and 'Th.couple_N' columns show if the fruit was equipped with a thermocouple (and if so, its number and the mounting node identifier of the WSN), while 'FruitTAG' one, represents the unique identifier of each fruit. 'Side', 'Canopy_Height_zone' and 'Canopy_Width_zone' columns represent the East or West side and the zone of the canopy in which the fruit was positioned.

Thermocouple position													
Trattamento (Identifier)	Block (Identifier)	TRT (Identifier)	ThCouple_Node (Identifier)	Th.couple_N (Identifier)	FruitTAG (Identifier)	Plant (Identifier)	Lat. (decimal °)	Long. (decimal °)	Altitude (m)	X (cm)	Y (cm)	Z (cm)	Side (Identifier)
Planar	Fila6	P	000D	1		1	44.547535	11.414027	27.61779404	95	122	0	e
Planar	Fila6	P	000D	2	101	1	44.547535	11.414027	27.61779404	-101	144.5	-4.5	w
Planar	Fila6	P	000D	3		1	44.547535	11.414027	27.61779404	137.5	158	-6.5	w
...
...
...
Rootstock	2	RST	000E	6		4	44.549506	11.416156	26.73326683	7	80	-4.5	w
Rootstock	2	RST	000E	7	67	3	44.549508	11.416161	26.73326683	47.5	106.5	-50	w
Rootstock	2	RST	000E	8		3	44.549508	11.416161	26.73326683	14.5	84	-27	w

Tagged fruit position														
Trattamento (Identifier)	Block (Identifier)	TRT (Identifier)	Lat. (decimal °)	Long. (decimal °)	Altitude (m)	Plant (Identifier)	Side (Identifier)	Canopy_Height_zone (Identifier)	Canopy_Width_zone (Identifier)	X (cm)	Y (cm)	Z (cm)	ThCouple_Node (Identifier)	FruitTAG (Identifier)
Rootstock	3	RST	44.5496672	11.416286	26.8998127	1	e	low	out	-30	55	36		1
Rootstock	3	RST	44.5496672	11.416286	26.8998127	1	e	low	in	-8.5	70	2.5		2
Rootstock	3	RST	44.5496672	11.416286	26.8998127	1	e	mid	out	19	128	26.5		3
...
...
...
Planar	Fila 6	P	44.5475837	11.414065	27.4316444	3	w	low	out	68	73.5	0		106
Planar	Fila 6	P	44.5475837	11.414065	27.4316444	3	w	mid	out	-33	134	0		107
Planar	Fila 6	P	44.5475837	11.414065	27.4316444	3	w	high	out	9	180	-20		108

Example of the structure of the 'ThCouple_Fruit Position' and 'Tagged_Fruit_Position' sheets present in the "GPS_Position_Apple&Tree_SHEET_2022_OK_EPSG4326.xlsx" file

For preliminary Dataset 3 no fruit positions were collected manually as reference.

Sunburn symptoms evaluation

For fruits of datasets Tcouple (N=40) and ThCAM (N=108) only, the occurrence of sunburn was evaluated 1-2 times per week (from 64 days after full bloom -DAFB-, occurred on 10th of April, till the harvest occurred on 114 and 120 DAFB – i.e., 02/08 and 08/08), so to individuate when first sunburn symptoms appeared (‘*Sunburn Damage*’ in figure below). During the season (at 95, 102 and 109 DAFB), also color and chlorophyll degradation information were collected using a Minolta Colorimeter (CR400, Konica-Minolta, Japan) and a DA-Meter (DA-Meter, Sinteleia srl, Bologna – Italy) , on a sample of the fruit in trial (N = 24 to 40 in base of the treatment). At harvest, a sample of fruit (N = 33 to 51 in base of the treatment) was evaluated again for color (i.e., ‘*L*(C)*’, ‘*a*(C)*’, ‘*b*(C)*’, ‘*C*(C)*’, ‘*h(C)*’ color coordinates in Fig. below) and chlorophyll degradation (‘*DA-meter*’, in figure below), as well as for a more in-detail sunburn damage presence (‘*Sunburn level*’, in Fig. below); this to give valuable information for further investigation and modelling of apple sunburn induction and relation with fruit and environmental temperature dynamics. Data regarding sunburn symptoms evaluated both during the season and the harvest are stored in the “*Sunburn_data_SB+Minolta+Dameter_2022.xlsx*” file (Fig. below).

Date (dd/mm/yyyy)	Sunburn Damage (identifier)	Sunburn level (damage scale)	L*(C)	a*(C)	b*(C)	C*(C)	h(C)	DA-meter
14/07/2022			70.23	1.68	38.51	38.5466276	85.2685054	1.377
14/07/2022			72.15	-7.125	41.5	42.1071921	99.7458657	1.545
...
...
21/07/2022	s		63.99	14.355	32.31	35.53	66.61	1.115
21/07/2022	s		58.16	15.925	33.64	37.46	64.625	1.373
21/07/2022	s		56.64	25.685	25.48	36.235	44.895	1.234
...
...
02/08/2022	s	sb1-3	64.24	15.11	38.59	41.475	68.585	
02/08/2022	s	sb1-3	59.9	20.13	33.04	38.7	58.655	0.8006
08/08/2022			59.81	21.33	35.23	45.285	58.4	0.3397
08/08/2022	s	sb1-3	51.31	31.77	27.72	42.155	41.105	0.2885

“Sunburn_data_SB+Minolta+Dameter_2022.xlsx” file structure: in add to all the fruit localization information, the file contains the columns shown in the picture and described in the text.

In Fig. , are shown the sunburn related information, present in the file in add to the positional fruit information already described. Columns were described in the text above if not for ‘*Date*’ which represent the date of data collection. Detailed information can be found in the ‘*README-Legend*’ sheet of the described file.

Fruit temperature and weather data

For all the presented datasets, seasonal local weather data were available and shared (“*Weather_data_IN&OUT_Orchards.xlsx*” file).

Fruit temperature data were collected following different methodologies as presented below in each of the dataset description.

Dataset 1 (Tcouple) – Continuous thermal measurements

From 64 DAFB (14/06) to fruit harvest 114 DAFB (02/08), Gala apple fruit were continuously monitored (data resolution 15 min, data presented as hour average) for their temperature using calibrated thermocouples (Tcouple) (model: ‘Type K’ Tcouple, WiNet srl, Cesena – Italy) connected to a wireless sensor network (WSN) (WiNet srl, Cesena – Italy).

For treatments A, E, P, four highly exposed fruit on each side (east and west) were selected, at medium height, for monitoring their temperature, on 4 different plants (N = 8 per treatment, 2 per tree). For RST treatment the fruit number was doubled (N = 16 on 4 per trees).

Tcouple were fixed to the fruit using medical tape on the back / less exposed fruit side to keep cable in position, while the Tcouple itself was maintained in position thanks to the high cable plasticity. Tcouple was always touching the fruit, without damaging it, as shown in Fig. below. Tcouple was checked 1 – 2 per week for their correct positioning. This dataset is made available in the “Th.couple_data_2022_timeseries.xlsx” file.



Detail of thermocouple mounted on apple fruit

The dataset presents, per each treatment, the structure shown in Fig. below: From row 1 to 5, are reported information related to treatment (*TRT*), WSN node utilized (*ThCouple_Node*), mounting *Side* (row 3 – East or West) and *Canopy_Width_zone* (row 4 – external or internal) of the Tcouple on the tree. Row 6 reports the *Date* and *time* columns of the timeseries, while columns *1* to *8* represent the hour average of fruit temperature, in Celsius degrees, recorded each of the 1-to-8 mounted Tcouple. Fruit positions were not included in this dataset directly, as well as sunburn damage, but they are stored in the different files described above, which can be linked by the unique *ThCouple_Node***Th.couple_N* values.

1		TRT	RST	RST	RST	RST	RST	RST	RST	RST
2		ThCouple_Node	000B	000B	000B	000B	000B	000B	000B	000B
3		Side	W	W	W	W	E	E	E	E
4		Canopy_Width_zone	int	ext	ext	int	int	ext	int	ext
5		Th.couple_N								
6	Date	time	1	2	3	4	5	6	7	8
7	14/06/2022	00:00:00	15.95	18.27	16.20	17.25	17.03	17.63	17.20	17.40
8	14/06/2022	01:00:00	15.38	17.28	15.58	16.43	16.55	17.05	16.53	16.47
9	14/06/2022	02:00:00	15.25	16.88	15.55	16.17	16.30	16.80	16.37	16.22
...
29	14/06/2022	22:00:00	18.00	19.90	18.40	19.10	19.15	19.75	19.33	19.15
30	14/06/2022	23:00:00	16.53	18.60	16.80	17.68	17.23	18.15	17.67	17.82
31	15/06/2022	00:00:00	14.77	17.00	15.05	15.98	16.23	16.72	16.05	16.12
32	15/06/2022	01:00:00	14.25	16.40	14.63	15.55	15.93	16.17	15.68	15.63
33	15/06/2022	02:00:00	14.00	16.02	14.27	15.20	15.20	15.73	15.28	15.23
...
1161	01/08/2022	23:00:00	21.15	22.98	20.93	21.98	22.38	22.83	22.40	22.00

Tcouple dataset structure

Dataset 2 (ThCAM) – Discrete thermal measurements.

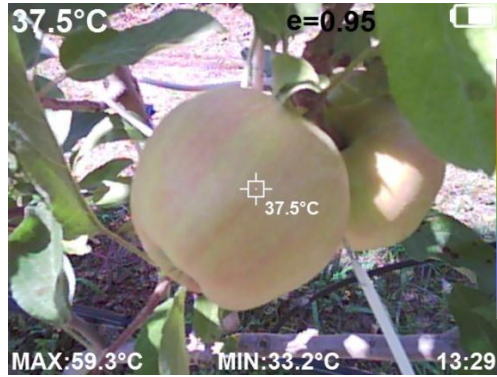
This dataset was created manually measuring fruit temperature of 27 tagged fruit in each of the A, E, P and RST treatments. In each treatment, the 27 fruits were chosen, on three plants (9 per plant), at 3 heights (low -mid- high) and 3 canopy positions (west side -inner part -east side). The total number of monitored fruit was 108.

Fruit temperature data were collected 5 times during the 2022 season (93, 101, 112, 119 and 131 DAFB). Per each time, temperature collection occurred three times per day (morning -midday - afternoon) in a time window of 1.5h approx. to collect all 108 tagged fruit data.

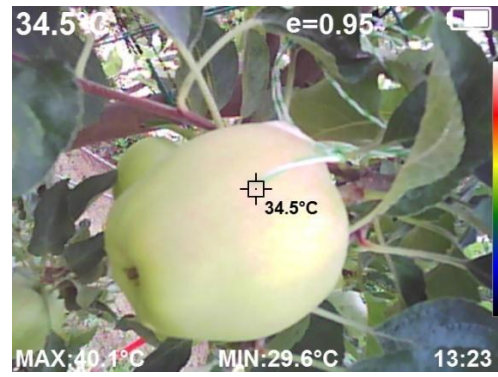
Temperature measurements were collected utilizing a semi-professional grade thermal camera (HTI–HT-A9, Xintai Instrument Co., Ltd., China; <https://hti-instrument.com/products/ht-a9-thermal-imager>). Temperatures were carefully collected trying to always frame the fruit in the scene center, at 30-50 cm distance max, and placing the thermal pointer to collect temperature on the most exposed area of the fruit, considering its position (Fig. below).



HTI Thermal cam



Tagged fruit data collection



Tcouple dataset fruit data collection

From left: Detail of the thermal camera utilized; Detail of temperature collection of a tagged fruit without Tcouple; Detail of temperature collection of fruit equipped with Tcouple.

During these measurements days, fruit of the Tcouple dataset were also measured with the HTI thermal camera to investigate possible correlations or errors between the two utilized sensors (as shown above). Considering Tcouple as the reference, the comparison of these sensors resulted with a RMSE (root mean square error) = ± 5.04 °C, and a mean error = + 4.14 °C. A regression analysis performed on the collected data showed a $R^2 = 0.775$. The obtained regression model was used to correct the thermal camera reading (*ThCAM-Corrected*) and resulted in halving RMSE (= ± 2.17 °C) and nulling the mean error (= +0°C). Further investigations will be done searching for correlation between temperature estimation errors and air temperature which could have altered ThCAM readings (*ThCAM*).

This dataset was uploaded as “*SHEET_Th.CAM_HTI_2022.xlsx*” file.

0	Date	start time	end time	timeTRT	Sunburn Damage	ThermalCAM	ThCAM -Corrected
1	(dd/mm/yyyy)	(hh:mm:ss)	(hh:mm:ss)	(identifier)	(identifier)	(°C)	(°C)
2	22/06/2022	09:45:00	11:35:00	morning		27.00	25.97
3	22/06/2022	09:45:00	11:35:00	morning		26.30	25.49
...
...
155	19/07/2022	13:05:00	14:05:00	midday		45.70	38.68
156	19/07/2022	13:05:00	14:05:00	midday		39.50	34.47
...
...
1404	01/08/2022	15:45:00	17:00:00	afternoon		43.80	37.39
1405	01/08/2022	15:45:00	17:00:00	afternoon		42.60	36.57

ThCAM dataset structure

in Fig. Above are shown the adding information to all the fruit localization data described above, for the ThCAM dataset. ‘Date’, ‘start time’ and ‘end time’ show the date and time frame in which fruit temperatures were collected; ‘timeTRT’ represent the timing treatment as morning, midday, afternoon time. ‘Sunburn Damage’ shows when a sunburn symptom was identified in field for the first time (with no classification level). ‘ThermalCAM’ and ‘ThCAM -Corrected’ are respectively fruit temperature values collected with HTI thermal camera and then corrected with the extracted

regression aforementioned (i.e., ThCAM vs TCouple). This information can be found in the *ThermalCAM_measurements* sheet of the file.

In the same dataset file, a second sheet is included (called *ThCAM_vs_Thcouple Calib*), where fruit temperature of only those fruit equipped with thermal couple was collected to obtain the just mentioned regression model. In this sheet, in add to the all the columns just presented, '*T_ThCouple*' shows the temperature recorded by Tcouple for the same fruit and timing of HTI thermal camera measurements; metrics computed between Tcouple and ThCAM measurements are then presented as absolute and percentual errors (respectively '*T_Error (ThCAM-ThC)*' and '*T_Error%(ThCAM-ThC)*'), and then the related average errors ('*meanERR*' and '*meanERR%*') and RMSEs ('*RMSE*' , '*RMSE%*'). In add absolute error and related average error and RMSE were computed after ThCAM temperature regression correction (respectively '*T_ErrorADJ(ThCAM-Corrected-ThC)*' , '*meanERR_ADJ*' , '*RMSE_ADJ*'). More in-detail description can be found in the dataset file directly, in the sheet named "*README-Legend*".

Dataset 3 (RGB-D/T-system) – Fruit thermal scanning dataset – PRELIMINARY

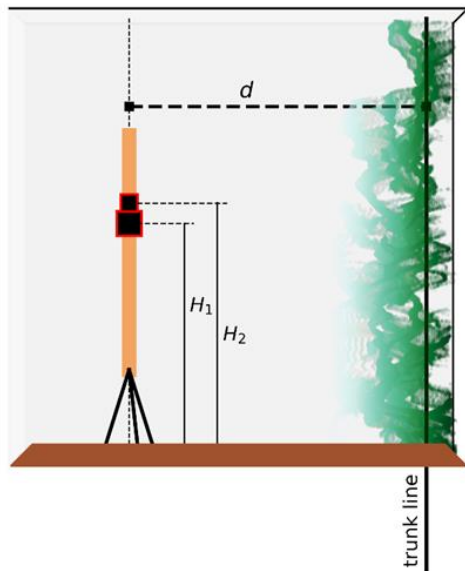
This preliminary dataset was obtained through the utilization of the RGB-D/T-system developed and presented at https://github.com/ECOPOM/SHEET_RGBD-T_system (version [v1.1.1](#))

To summarize, RGB-D/T-system utilized consists in a sensor fusion platform, based on a depth and a thermal camera, from which were extracted single fruit thermal and positional information. The RGB-D/T system performances resulted in:

- A thermal-to-RGB alignment RMSE / mean error of ± 9.17 / $+4.5$ pixels and ± 4.17 / $+0.17$ pixels, on *x-axis* and *y-axis* respectively;
- A thermal information extraction process presenting a correlation of $r > 0.92$ compared to the thermal reference at 2.80 m distance and preliminary results on fruit temperature extraction resulted in a RMSE/mean error ranging in between $\pm 3.43 : \pm 10.36$ °C / $-0.96 : -9.79$ °C, for grape (at 2.30 m distance), and $\pm 1.38 : \pm 6.72$ °C / $-0.95 : +6.59$ °C, for apples (at 2.80 m distance);
- A preliminary fruit 3D positional error of 0.10/0.15 m approx. at 2.80 m distance.

The entire system worked properly, for data collection, only around August 2022, so after the harvest of apples monitored in the trial. The first field data collection useful to test and evaluate the developed system was done during August-September 2022.

Field data collection consisted of a brief video recording (3 seconds approx.) of a single tree, through the ROS workflow from both the cameras. In base of the species (apple, grape) a different recording protocol was utilized, due to the different plant training system.



Cameras positioning during the field data collection. Cameras are placed parallel to the tree row plane at a “d” distance. Field data collection height was measured in the middle point between H1 and H2 (i.e., center camera height from the ground).

For apple trees, trained as “thin” spindle, the tripod was positioned in front of the tree trunk at 2.80 m distance (*Z dimension*, perpendicular to the tree-row plane - Fig. above), with cameras parallel to the tree-row plane (*X dimension*). Considering the possible tree height, after the tripod positioning, two height recordings occurred: one at 1.40 m (h1) and one at 2.50 m (h2) from the ground (*Y dimension*, elevation from the ground - Fig. 21). The system was levelled thanks to the three level bubbles present.

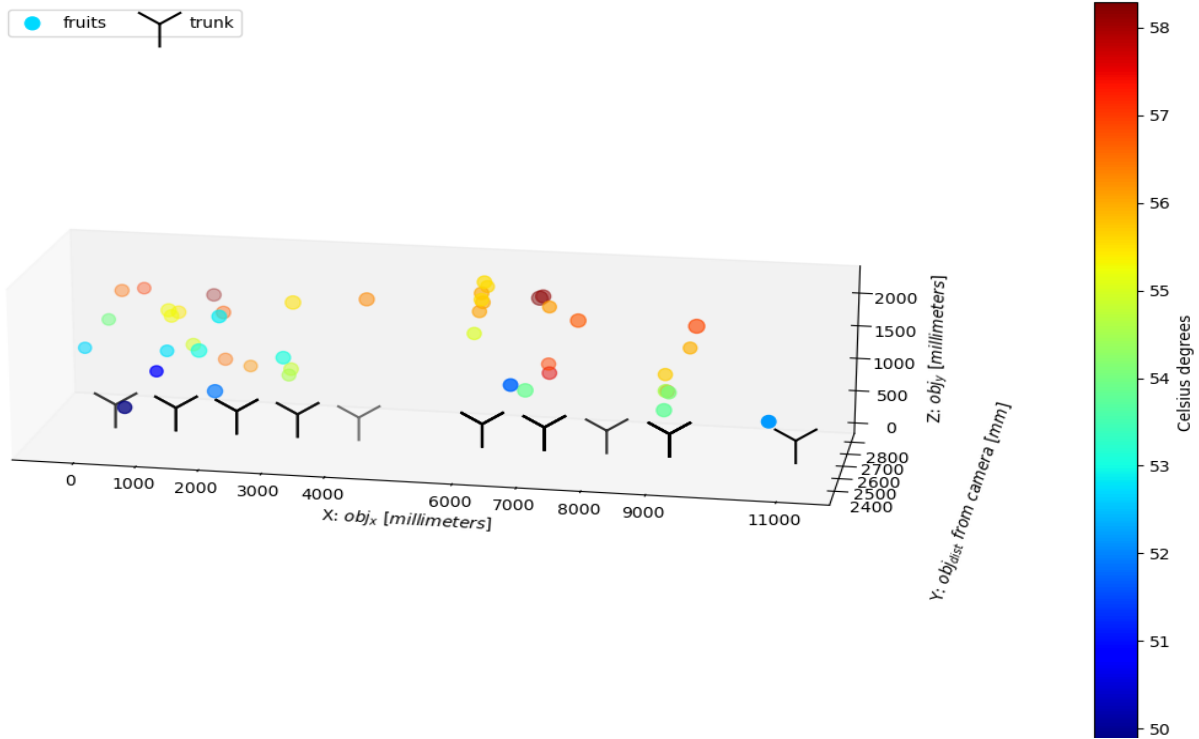
The system positioning and height*distance were set according to the lowest camera FoV (thermal camera: 32°) so to include in the scene as much part of the tree as possible, while not reducing excessively the real object pixel resolution (i.e., actual mm/pixel). With the presented distance*height, the area framed by the thermal camera was of 1.55 x 1.55 meters, with 5.6mm/pixel as object resolution. Since the tripod was positioned in front of the trunk, the area framed in respect of the trunk was of ± 0.77 m, along *X dimension*, considering the trunk in the middle ($X/2$) of the framed scene. These dimensions were enough to frame one entire tree in width and having a minimum reliable analysis resolution of 11.2 x 11.2 mm (i.e., analysis of a 2 x 2 pixels matrix). Considering camera’s height, h1 framed approx. from 0.60 m to 2.20 m from the ground, while h2 framed from 1.70 m to 3.30 m from the ground.

With this approach data were collected on 6 trees presenting red fruit (cv Gala) and 6 trees presenting green fruit (cv Fuji) for a total of 24 tree recordings (12 trees* 2 heights).

Initial idea of the proposed protocol was to exploit the $X/2$ trunk position, to ease the positional information extraction, while the two-height recording were taken to later investigate the possibility to merge the collected images, obtaining information on the whole tree fruit distribution in one step, compared to multiple height recording analysis.

As above-mentioned, The presented dataset (Dataset-3) was obtained from apple fruit not related to the presented treatments, but placed in a similar environmental condition as the treatment A. Since the processing pipeline to align and merge data extracted from both “h1” and “h2” recordings was still under development, data in this dataset are related only to “h1” recordings, where the trunk of the tree was visible in each picture.

The dataset was uploaded as “*RGBD-T-System_APPLE_Pos&Temp_Dataset.xlsx*” file and it includes only information of those fruits correctly detected and that passed all the process filtering steps explained in “Deliverable No D2.2 – Continuation” ([here](#)). In total, 10 out of 12 tree images were correctly analyzed, obtaining thermal and positional information for a total of 46 fruit. The two missing images were not analyzed due to the non-falling in the thermal camera field of view of the detected fruits and/or no fruit detection at all. A graphical representation of the obtained results is present in Fig., reported below.



Apple fruit temperature 3D representation at “orchard level”, with fruit position relative to a defined orchard origin, and temperature represented by color-scale.

As already explained reference data (i.e., actual fruit temperature and position) to test system performances on this dataset were missing due to the late development of the RGB-D/T system; so no performances evaluation for data collected in this dataset can be presented.

Due to the dimension of the tabular data, no figure can be presented here, but the RGB/T-System dataset is structured in seven different sections (*sec0* to *sec6*) which present, per each detected fruit, what follows:

- *Sec0* presents the ‘name’ of the analyzed image and its internal identifier (‘ID_tree’) as well as the ‘label’ class number of the object detected by the YOLO algorithm used for fruit detection;
- *sec1* reports minimum (min), mean and maximum (max) temperature directly extracted from the thermal camera after the “D2.2 – Continuation” process (respectively, ‘Tmin_SEEK’, ‘Tmean_SEEK’, ‘Tmax_SEEK’);
- *sec2* reports six different min, mean and max temperature, those result from the distance correction of *sec1* data according to each of the two correction equations utilized (‘_corr_avg’ and ‘_corr_max’);
- *sec3* contains ‘X’, ‘Y’, ‘Z’, coordinates in millimeters (‘_mm’) relative to an arbitrary orchard origin (of 0,0,0 mm coordinates), both for detected fruit and tree trunk (‘_trunk_’), to work at orchard level scale, plus the original distance measured by the depth camera (‘Z_cam_’) both for fruit and trunk;
- *sec4* presents X, Y, Z coordinates relative to the trunk origin (with absolute values) for the analyzed fruit, as well as the trunk origin (i.e., 0, 0, 0);
- *sec5* presents the X, Y, Z relative ranges used to convert the fruit localization from relative to mm, and viceversa, allowing also the change between single tree and orchard scale level;

- *sec6* shows additional information as tree side of data collection (*'Tree_wall'* – east or west), the cardinal orientation toward the X-axis (*'Card_dir'*) and a preliminary estimated fruit size (*'Estim_fruit_diam_mm'*) useful for further implementation of the system.

A more in-detail description is present inside the dataset file in the *'readme'* and *'REFERENCE crs'* sheets.

Considering the preliminary testing of the platform (performances reported [here](#)), due to the current possible high error of the system (up to ± 10.36 °C and ± 0.15 m), we suggest avoiding using data from this dataset to train model for investigating sunburn dynamics. However, this preliminary dataset is presented, and shared, so to have feedbacks for possible improvements and to make other partners able to evaluate it.

Radiation measurements

Data regarding light radiation (*"Radiation measurements"* folder) were collected using an APOGEE SS-110 spectroradiometer, following the scheme reported in the *"Files map"* file inside the parent folder, similarly to what reported for the season 2021. Data collection occurred on 25/07/2022 during a clear sunny day (around solar noon) and was done on a representative tree per each of the treatment (i.e., "A" - ANTIHAIL NET; "E"- EXCLUSION NET; "P" - PLANAR; "RST"). For the RST treatment, radiation measurements were collected before and after the defoliation of some areas of the tree to induce fruit sunburn, investigating the effect of a quick and wide change in the fruit microclimatic environment.

For this season instead of a set of 3 measures for each tree height*zone (height n=5; zone n=3), only 1 measure was taken, with the sensor facing upwards. In addition, only the measures out of the orchard environment were taken before and after the tree-point data collection (not inter-row light environment was collected).

Data are available in separated files, named as the code reported in the *"Files map"* file, inside the dedicated folder.

2023 - UNIBO – Apple temperature and position datasets

Treatments

For data collection of the 2023 season, 2 main datasets (Dataset 1 or “TCouple” - “*Apple_Thermocouples_raw*” and “*Thermocouples+Weather data_1h_ave*” files - and Dataset 2 or “ThCAM” - “*Sheet2023_FruitPOS_ThCAM_SB_Color_DA*” file - “ThCAM_msrs” sheet). Fruit temperature measurements were taken in the 4 different training system*shading treatments similar to the one used in 2022 season. The treatments were (Figure below):

A: Spindle training system (3.3 m x 1 m planting distances) * Black anti-hail net coverage (15-20% shading). Considered as “Standard Sunburn Susceptibility Situation” (N= 3 trees).

E: Spindle training system (3.3 m x 1 m planting distances) *White anti -hail, -insect, -rain exclusion netting system (40-50% shading). Considered as “Low Sunburn Susceptibility Situation” (N= 3 trees).

P: Planar Cordon training system (2 m x 3 m planting distances) *Grey anti-hail net coverage (15-20% shading). Considered as “Mid-High Sunburn Susceptibility Situation” (N= 3 trees).

RST or ‘no cover’: Spindle training system (3.3 m x 1 m planting distances) * Open field (no netting / shading applied). “High Sunburn Susceptibility Situation” (N= 6 trees).

The purpose of comparing the same treatments of 2022 season was to increase the robustness of the data collection, to better investigate the effect of the tested environmental conditions in relation to sunburn damage susceptibility.



A



E



P



RST

Treatments' conditions: **A** – “Standard Sunburn Susceptibility Situation”; **E** – “Low Sunburn Susceptibility Situation”; **P** – “Mid-High Sunburn Susceptibility Situation”; **RST** or ‘no cover’ – “High Sunburn Susceptibility Situation”

Fruit localization

In season 2023, the GPS coordinates of the trees hanging the fruit were not collected since they appeared not to be useful from the previous season, despite this they could be added in the future since the position of the plants is known. In the *"Sheet2023_FruitPOS_ThCAM_SB_Color_DA"* file - *"Fruit_Tcouple_Pos"* sheet can be found the position of all monitored fruit ($n = 27$ per trt "A", "E", "P" and $n = 54$ per "RST"; $n = 135$ in total). Fruit position was collected as X, Y, Z coordinates, in centimeters, using a standard measuring tape. X, Y, Z dimensions were considered respectively as the tree-row plane, the vertical plane perpendicular to the ground and the intra-row tree plane perpendicular to X (Fig. below). Positive and negative values of the coordinates were representing the fruit position in relation to the trunk (coordinate system's origin), with $Y = 0$ at ground level, +Z or -Z values for fruit positioned toward East or West respectively, in respect to the trunk origin. For X coordinates the data were collected with an opposite approach compared to the 2022 season, with +X or -X values for fruit positioned toward South or North respectively.



X, Y, Z coordinate system representation; the origin is represented by the trunk, with $Y=0$ at ground level.

The Figure below shows the file structure for fruit position information. In add to 'Fr_X_N-S', 'Fr_Y_Height', 'Fr_Z_E-W' coordinates and identifier ('Plant'), other information related to treatments ('Trattamento' and 'TRT') are present. 'ThCouple_Node' and 'Th.couple_N' columns show if the fruit was equipped with a thermocouple (and if so, its number and the mounting node identifier of the WSN), while 'FruitTAG' one, represents the unique identifier of each fruit. 'Side', 'Canopy_Height_zone' and 'Canopy_Width_zone' columns represent the East or West side and the zone of the canopy in which the fruit was positioned.

Trattamento	TRT	ThCouple_Node	Th.couple_N	Side	Canopy_Height_zone	Canopy_Width_zone	Plant	FruitTAG	Fr_Y_Height	Fr_Z_E-W	Fr_X_N-S
(identifier)	(identifier)	(identifier)	(identifier)	(identifier)	(identifier)	(identifier)	(identifier)	(identifier)	(cm)	(cm; -W, +E)	(cm; -N, +S)
Antigrandine	A			E	L	O	3	1	70	52	18
Antigrandine	A			E	L	I	3	2	87	12	-23
Antigrandine	A			E	M	O	3	3	111	27	33
Antigrandine	A			E	M	I	3	4	149	8	0
Antigrandine	A			E	H	O	3	5	266	27	10
Antigrandine	A			E	H	I	3	6	250	0	18
Antigrandine	A			E	L	O	2	7	73	56	20
Antigrandine	A			E	L	I	2	8	83	17	14
Antigrandine	A	1	1	E	M	O	2	9	138	52	6
Antigrandine	A			E	M	I	2	10	156	13	0
Antigrandine	A			E	H	O	2	11	232	29	-5
Antigrandine	A			E	H	I	2	12	238	10	2
Antigrandine	A	1	2	E	L	O	1	13	92	58	38
Antigrandine	A			E	L	I	1	14	86	14	-11
Antigrandine	A	Coordinatore	6	E	M	O	1	15	161	20	34
Antigrandine	A			E	M	I	1	16	163	0	-8
Antigrandine	A	1	3	E	H	O	1	17	224	33	-19
Antigrandine	A			E	H	I	1	18	227	-7	5
Antigrandine	A			W	L	O	1	19	75	-62	13
Antigrandine	A	1	4	W	M	O	1	20	160	-34	10
Antigrandine	A			W	H	O	1	21	213	-21	-11
Antigrandine	A	1	5	W	L	O	2	22	53	-54	0
Antigrandine	A	Coordinatore	5	W	M	O	2	23	120	-58	18
Antigrandine	A	1	6	W	H	O	2	24	215	-26	32
Antigrandine	A			W	L	O	3	25	108	-33	-5
Antigrandine	A			W	M	O	3	26	179	-47	0
Antigrandine	A			W	H	O	3	27	217	-20	15
Scoverto	no cover			F	I	O	1	28	94	73	32

Example of the structure of the 'Sheet2023_FruitPOS_ThCAM_SB_Color_DA file - Fruit_Tcouple_Pos sheet'

More information can be found in the "README-Legend" sheet of the "Sheet2023_FruitPOS_ThCAM_SB_Color_DA" file.

Sunburn symptoms evaluation

For fruits of datasets Tcouple (N=36) and ThCAM (N=99), the occurrence of sunburn and their symptoms level was evaluated 1-2 times per week from 20/06 to 07/08), so to track sunburn appearance and symptoms evolution ('SB_msrs' sheet in the "Sheet2023_FruitPOS_ThCAM_SB_Color_DA" file). Data regarding sunburn symptoms evaluated both during the season and the harvest are stored in the "SB_msrs" file (Fig. below). Here per each date of measurements (1st row), the sunburn level (Sb_level) presented by the fruit was recorded based on the following damage scale, redefined exploiting the Felicetti et al, (2008 ; <https://doi.org/10.21273/JASHS.133.1.27>) work:

- Empty values: no damage presence
- 'pre': fruit with initial evidence of symptoms that could evolve to sunburn damage but that are still not considered damaging the fruit quality.
- 'bleaching': fruit discoloration that can evolve to browning of certain levels ('sb1' - 'sb4') or up to 'necrosis'.
- 'sb1', 'sb2', 'sb3', 'sb4': evolution of sunburn damage related to fruit browning. From the lowest (sb1) to the highest sever symptoms level (sb4) before evolving to necrosis.
- 'necrosis': fruit necrosis induced by 'sb' evolution.

For data collected at the harvest, 'sb2', 'sb3', and 'sb4' damage levels were considered as single damage classes 'sb2'-sb4' as done by Felicetti et al. (2008), since all these damage levels were considered to be decreasing the fruit quality, while 'pre' and 'sb1' could be considered as damage levels not significantly reducing the selling price of the fruit.

	10/07/2023	11/07/2023	13/07/2023	18/07/2023	20/07/2023	25/07/2023	27/07/2023	01/08/2023	07/08/2023-Harvest
FruitTAG	Sb_level	Sb_level	Sb_level	Sb_level	Sb_level	Sb_level	Sb_level	Sb_level	Sb_level
(identifier)	(identifier)	(identifier)	(identifier)	(identifier)	(identifier)	(identifier)	(identifier)	(identifier)	(identifier)
1		pre	pre	pre	pre	sb1	sb1	sb1	
2									
3									
4									
5					pre	pre	sb1	sb1	
6							sb1	sb1	
7			pre	pre	sb1	sb1	sb1	sb1	sb1
8			sb1	sb1	sb1	pre	pre	pre	
9			sb1	sb1	sb1	sb1	sb1	sb1	
10									
11			sb1	sb1	sb1	sb2	sb2	sb3	sb2-4
12	Pre sb1		pre sb1	sb1	sb1	sb1	sb2	sb2	
13	sb1		sb1	sb1	sb1	sb1	sb1	sb1	sb1
14									
15				pre	pre	pre	pre	sb1	
16									
17			pre	pre	pre	sb1	sb1	sb1	sb2-4
18			pre	sb1	sb1	sb1			
19			pre	sb1	sb1	sb2	sb1	sb1	
20			sb1	sb1	sb1	sb2	sb1	sb1	
21			pre	pre	sb1	sb1	sb1	sb1	sb1

“SB_msrs” sheet data structure in the “Sheet2023_FruitPOS_ThCAM_SB_Color_DA.xlsx” file: in add to the ‘FruitTAG’ fruit identifier, the file contains the columns shown in the picture and described in the text.

During the season, also color (**‘Color_msrs’ sheet** in the in “Sheet2023_FruitPOS_ThCAM_SB_Color_DA” file) and chlorophyll degradation information (**‘DA_msrs’ sheet** in the in “Sheet2023_FruitPOS_ThCAM_SB_Color_DA” file) were collected using a Minolta Colorimeter (CR400, Konica-Minolta, Japan) and a DA-Meter (DA-Meter, Sinteleia srl, Bologna – Italy), on all the monitored fruit in orchard (n=135). Chlorophyl degradation data can be found in **‘DA-meter’ sheet** (presenting the same data structure shown in the figure above for ‘SB_msrs’), while color information can be found in **‘Color_msrs’ sheet** which reports color information (i.e., ‘L*(C)’, ‘a*(C)’, ‘b*(C)’, ‘C*(C)’, ‘h(C)’ columns) per each date of measurements (**‘Date’** clomun) with the data structure reported in the figure below.

FruitTAG	Date	L(C)	a*(C)	b*(C)	h(C)
(identifier)	(dd/mm/yyyy)	(LAB_cie_coord)	(LAB_cie_coord)	(LAB_cie_coord)	(LCH_coord)
1	16/06/2023	36.1	31.75	5.97	10.65
2	16/06/2023	48.39	17.33	21.29	50.86
3	16/06/2023	38.67	33.28	9.18	15.42
4	16/06/2023	58.92	1.19	28.27	87.60
5	16/06/2023	33.09	33.18	4.31	7.40
6	16/06/2023	46.24	21.38	12.86	31.03
7	16/06/2023	40.04	29.01	8.69	16.68
8	16/06/2023	45.06	25.99	-46.13	299.39
9	16/06/2023	46.39	17.52	-5.95	341.24
10	16/06/2023	48.31	9.97	27.14	69.83
11	16/06/2023	35.5	26.43	6.47	13.76
12	16/06/2023	37.52	30.59	9.03	16.45
13	16/06/2023	46.36	19.65	17.41	41.54
14	16/06/2023	43.36	20.79	15.18	36.14
15	16/06/2023	44.33	19.91	13.26	33.67
16	16/06/2023	46.3	7.71	43.19	79.88
17	16/06/2023	33.68	34.85	5.81	9.47

“Color_msrs” sheet data structure in the “Sheet2023_FruitPOS_ThCAM_SB_Color_DA.xlsx” file: in add to the ‘FruitTAG’ fruit identifier, the file contains the columns shown in the picture and described in the text.

More information can be found in the **“README-Legend”** sheet of the **“Sheet2023_FruitPOS_ThCAM_SB_Color_DA”** file.

Fruit temperature and weather data

For all the presented datasets, seasonal local weather data were collected only for out-of-the-orchard condition in 2023 season (i.e., no microclimatic data for the treatment were not collected as done for 2022 season). Weather data were made available in '**Weather data raw**' file (which contains all the raw weather data) and in '**Thermocouples+Weather data_1h_ave**' file (which contains the hour average of the raw data together with apple fruit temperature recorded by thermocouples.)

Fruit temperature data were collected following different methodologies as presented below in each of the dataset description.

Dataset 1 (Tcouple) – Continuous thermal measurements

From 20/06 to fruit harvest 07/08, Gala apple fruit were continuously monitored (data resolution 15 min, data presented as hour average) for their temperature using calibrated thermocouples (Tcouple) (model: 'Type K' Tcouple, WiNet srl, Cesena – Italy) connected to a wireless sensor network (WSN) (WiNet srl, Cesena – Italy).

For treatments A, E, P, four exposed fruits on each side (east and west) were selected, at low, medium and high height, for monitoring their temperature (N = 8 per treatment). For RST (or no cover) treatment the fruit number was increased to 6 per each side of the tree (N = 12).

Tcouple were fixed to the fruit as done for 2022 season, using medical tape on the back / less exposed fruit side to keep cable in position, while the Tcouple itself was maintained in position thanks to the high cable plasticity. Tcouple was always touching the fruit, without damaging it, as shown in Fig. below. Tcouple was checked 1 – 2 per week for their correct positioning.



Detail of thermocouple mounted on apple fruit

The dataset presents, per each treatment, the structure shown in Fig. below: at row 1 an alert state the presence of errors and outliers to be managed for further analysis, from row 2 to 8, are reported information related to sunburn damage of the fruit at the harvest ('DAMAGE'), treatment ('TRT'), 'Canopy_Width_zone' (external or internal), mounting 'SIDE' (East or West) and 'Canopy_Height_zone' (low, middle, high), 'FruitTAG' with the unique fruit identifier. At row 9, the first 7 columns are related to weather data matched per hour of the day to the Tcouple readings; 'Ext.air temp', 'RH', 'Wind speed', 'PAR ($W m^{-2}$)' were recorded per each 'DAY' and hour ('TIME').

After this columns, each treatment presents a block of 8 columns in which at row 9 are reported the 'ThCouple_Node' (i.e., the id of the router recording the Tcouple values) followed by the Tcouple number ('1', '2', '3', '4', '5', '6').

After the column '6', before the following treatment block of columns, are reported the 'DAY' and hour ('TIME') columns for ease of reading.

## ATTENTION: ThCouple_Node '7' overestimates temperature from 25-26/06/2023. Data are not corrected here. For further analysis the mean error of the node is used to correct te														
DAMAGE											undamaged	sb2-4	undamaged	undamaged
TRT							no cover							
Canopy_Width_zone											int	ext	int	int
SIDE											east	east	east	west
Canopy_Height_zone											middle	high	high	middle
FruitTAG											49	62	63	61
Ext.air temp	RH	Rain mm	Wind speed	PAR (W m ⁻²)	DAY	TIME	ThCouple_Node	1	2	3	4	5	6	7
	25.48	33.07	0.00	2.94	0.00	20/06/2023	00:00	7	571.80	26.00	24.77	26.81	26.07	25.62
	24.43	34.82	0.00	2.11	0.00	20/06/2023	01:00	7	571.80	25.40	24.24	26.46	25.43	24.96
	24.30	34.35	0.00	1.28	0.00	20/06/2023	02:00	7	571.80	24.49	23.40	25.67	24.62	24.07
	22.07	43.45	0.00	1.27	0.00	20/06/2023	03:00	7	571.80	23.62	22.49	24.72	23.80	23.26
	22.07	42.93	0.00	2.07	0.00	20/06/2023	04:00	7	571.80	22.50	21.42	23.57	22.67	22.05
	21.22	44.60	0.00	1.40	7.90	20/06/2023	05:00	7	571.80	22.29	21.63	23.46	22.44	21.93
	21.78	45.60	0.00	0.65	103.10	20/06/2023	06:00	7	571.80	24.87	26.81	27.19	24.75	24.41
	24.30	43.40	0.00	1.11	284.25	20/06/2023	07:00	7	571.80	28.61	32.52	32.05	28.02	28.50
	27.13	34.80	0.00	2.57	441.68	20/06/2023	08:00	7	571.80	30.24	37.38	33.95	30.07	29.71
	27.72	35.00	0.00	3.72	603.70	20/06/2023	09:09	7	571.80	32.30	40.08	39.05	32.57	31.43
	28.92	32.20	0.00	3.75	752.55	20/06/2023	10:09	7	571.80	34.98	40.70	37.72	36.95	32.90
	29.63	30.10	0.00	3.14	749.05	20/06/2023	11:09	7	-37.58	34.23	37.02	35.00	37.70	32.50
	30.53	28.28	0.00	3.41	808.60	20/06/2023	12:09	7	-38.85	34.38	36.80	33.90	35.50	33.05
	31.20	30.70	0.00	2.66	837.85	20/06/2023	13:09	7	-35.65	34.50	35.17	33.78	34.43	33.03
	32.02	27.28	0.00	2.34	781.13	20/06/2023	14:09	7	-47.63	35.48	33.70	34.00	34.22	33.75
	32.57	27.70	0.00	2.08	701.75	20/06/2023	15:09	7	-57.73	36.05	33.20	34.27	34.45	34.30
	33.55	25.53	0.00	3.06	542.82	20/06/2023	16:09	7	-44.45	34.27	32.50	34.00	33.83	33.83
	32.88	28.70	0.00	5.67	345.60	20/06/2023	17:09	7	-30.22	33.17	31.55	32.98	33.03	32.87
	31.75	28.13	0.00	7.41	240.75	20/06/2023	18:09	7	-20.10	30.98	29.88	31.50	31.17	30.80
	30.67	33.43	0.00	3.35	98.50	20/06/2023	19:09	7	-15.58	28.73	27.97	29.72	29.10	28.57
	28.90	37.32	0.00	1.10	11.43	20/06/2023	20:09	7	-20.15	26.20	25.35	27.22	26.67	25.93
	26.62	41.85	0.00	0.52	0.00	20/06/2023	21:09	7	-28.57	24.17	23.30	25.50	24.75	23.93
	24.97	45.60	0.00	0.13	0.00	20/06/2023	22:09	7	-31.73	23.42	22.55	24.78	23.68	23.13
	25.20	40.83	0.00	1.37	0.00	20/06/2023	23:09	7	-32.90	23.28	22.20	24.22	23.32	22.92

Tcouple dataset structure (2023)

This dataset is made available in the “**Thermocouples+Weather data_1h_ave.xlsx**” file. As reported in the file, these data are presented as hour average, but in “raw” format: errors and outliers are still present and should be managed for further analysis.

Dataset 2 (ThCAM) – Discrete thermal measurements.

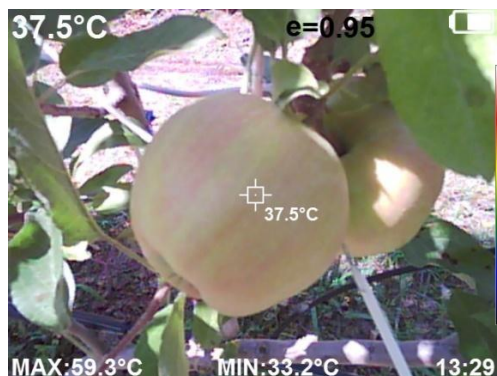
This dataset was created manually measuring fruit temperature of 27 tagged fruit in each of the A, E, P treatments and 54 fruits in the RST or ‘no cover’ treatment. 9 fruits per plant were chosen, on three plants (6 for RST treatment only), at 3 heights (low -mid- high) and 3 canopy positions (west side -inner part -east side). The total number of monitored fruit was 135. The 36 fruit of the Tcouple dataset presented above, couple were included in this dataset to make possible a comparison between the method utilized.

Fruit temperature data were collected 6-7 times during the 2023 season (16/06, 23/06-26/06, 11/07, 18/07, 27/07, 01/08). Per each time, temperature collection occurred three times per day (morning - midday -afternoon) in a time window of 1.5h approx. to collect all 135 tagged fruit data. Only for 11.07 collection, during the most intense heatwave, temperature data were collected 5 times during the day at morning – pre_midday - midday – post_midday – afternoon.

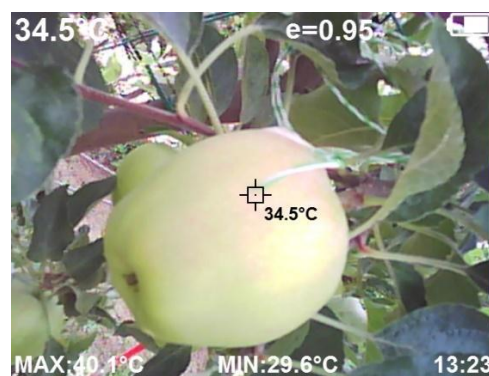
Temperature measurements were collected, as presented for 2022 dataset, utilizing a semi-professional grade thermal camera (HTI–HT-A9, Xintai Instrument Co., Ltd., China; <https://hti-instrument.com/products/ht-a9-thermal-imager>). Temperatures were carefully collected trying to always frame the fruit in the scene center, at 30-50 cm distance max, and placing the thermal pointer to collect temperature on the most exposed area of the fruit, considering its position (Fig. below).



HTI Thermal cam



Tagged fruit data collection



Tcouple dataset fruit data collection

From left: Detail of the thermal camera utilized; Detail of temperature collection of a tagged fruit without Tcouple; Detail of temperature collection of fruit equipped with Tcouple.

During this season, the comparison between thermocouple and thermal camera collected was not done; this remain possible by comparing data presented in Dataset -1 for the same day and hour.

This dataset (Dataset-2) was made available in the '*ThCAM_msr*' sheet of the "*Sheet2023_FruitPOS_ThCAM_SB_Color_DA*" file.

In the Fig. below are shown the information for the ThCAM dataset. The first 5 columns show data regarding treatments ('*Trattamento*' , '*TRT*') '*Canopy_Width_zone*', '*Canopy_Height_zone*' and mounting '*SIDE*' . '*Date*' , '*start time*' and '*end time*' show the date and time frame in which fruit temperatures were collected; '*timeTRT*' represent the timing treatment as morning, (pre-midday) , midday, (post-midday), afternoon time. '*FruitTAG*' show the unique fruit identifier which connect each fruit among all the collected dataset and information. '*msr_time*' is a punctual measure of the time at which a particular fruit were measured, used to improve precision when needed. '*note*' reports observation (i.e., on 23/06 it started rain in the afternoon). '*ThermalCAM*' is fruit temperature values collected with HTI thermal camera.

More in-detail description can be found in the dataset file directly, in the sheet named "*README-Legend*".

Trattamen	TRT	Side	Canopy_Height_zone	Canopy_Width_zone	Date	start time	end time	timeTRT	FruitTAG	msr_time	note	ThermalCAM
(identifier)	(identifier)	(identifier)	(identifier)	(identifier)	(dd/mm/yyyy)	(hh:mm:ss)	(hh:mm:ss)	(identifier)	(identifier)	(hh:mm:ss)	(note)	(°C)
Antigrandine	A	E	L	O	16/06/2023	09:05:00	10:06:00	morning	1	09:05:00		31.20
Antigrandine	A	E	L	I	16/06/2023	09:05:00	10:06:00	morning	2			28.20
Antigrandine	A	E	M	O	16/06/2023	09:05:00	10:06:00	morning	3			35.70
Antigrandine	A	E	M	I	16/06/2023	09:05:00	10:06:00	morning	4			26.10
Antigrandine	A	E	H	O	16/06/2023	09:05:00	10:06:00	morning	5			36.00
Antigrandine	A	E	H	I	16/06/2023	09:05:00	10:06:00	morning	6			28.80
Antigrandine	A	E	L	O	16/06/2023	09:05:00	10:06:00	morning	7			30.60
Antigrandine	A	E	L	I	16/06/2023	09:05:00	10:06:00	morning	8			31.30
Antigrandine	A	E	M	O	16/06/2023	09:05:00	10:06:00	morning	9			36.10
Antigrandine	A	E	M	I	16/06/2023	09:05:00	10:06:00	morning	10			35.10
Antigrandine	A	E	H	O	16/06/2023	09:05:00	10:06:00	morning	11			29.20
Antigrandine	A	E	H	I	16/06/2023	09:05:00	10:06:00	morning	12			33.60
Antigrandine	A	E	L	O	16/06/2023	09:05:00	10:06:00	morning	13			33.50
Antigrandine	A	E	L	I	16/06/2023	09:05:00	10:06:00	morning	14			24.60
Antigrandine	A	E	M	O	16/06/2023	09:05:00	10:06:00	morning	15			34.80
Antigrandine	A	E	M	I	16/06/2023	09:05:00	10:06:00	morning	16			27.50
Antigrandine	A	E	H	O	16/06/2023	09:05:00	10:06:00	morning	17			33.90
Antigrandine	A	E	H	I	16/06/2023	09:05:00	10:06:00	morning	18			25.60
Antigrandine	A	W	L	O	16/06/2023	09:05:00	10:06:00	morning	19			24.30
Antigrandine	A	W	M	O	16/06/2023	09:05:00	10:06:00	morning	20			24.10
Antigrandine	A	W	H	O	16/06/2023	09:05:00	10:06:00	morning	21			26.20
Antigrandine	A	W	L	O	16/06/2023	09:05:00	10:06:00	morning	22			23.80
Antigrandine	A	W	M	O	16/06/2023	09:05:00	10:06:00	morning	23			23.80
Antigrandine	A	W	H	O	16/06/2023	09:05:00	10:06:00	morning	24			22.50
Antigrandine	A	W	I	O	16/06/2023	09:05:00	10:06:00	morning	25			23.70

2023 ThCAM dataset structure

Radiation measurements

Data regarding light radiation (“Radiation measurements” folder) were collected using an APOGEE SS-110 spectroradiometer, following the scheme reported in the “Files map” file (figure below) inside the parent folder, exactly as reported for the season 2022. Data collection occurred on 20/07/2022 during a clear sunny day (around solar noon) and was done on a representative tree per each of the treatment (i.e., “E”- 1.Exclusion net; “A” – 2.Antihail net; “RST” – 3.NO COVER; “P” – 4.PLANAR).

	NO COVER		
file nr	file nr	position	card.point high
1	EXTERNAL-BEGINNING		
2		internal	top canopy
3		external east	top canopy
4		internal	high
5		external east	high
6		internal	medium
7		external east	medium
8		internal	low
9		external east	low
10		internal	ground lev
11		external east	ground lev
12		external west	top canopy
13		external west	high
14		external west	medium
15		external west	low
16		external west	ground lev
17	EXTERNAL-END		

For 2023 season instead per each tree height*zone (height n=5; zone n=3), only 1 measure was taken, with the sensor facing upwards. Before and after this measurements, out-of-the-orchard light environment data were collected (no inter-row light environment data was collected).

Data are available in separated files, named as the code reported in the “Files map” file, inside the dedicated folder.