POLITECNICO DI MILANO

The Abdus Salam International Centre for Theoretical Physics

Time-resolved NIRS and non-destructive assessment of food quality

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Winter College on Applications of Optics and Photonics in Food Science

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Non-destructive optical characterisation of internal optical properties and correlation with quality parameters

- Basic studies in apples, kiwifruits, nectarines, tomatoes, …
- Changes in optical properties during growth in Elstar apples and Tophit plums
- Texture in Jonagored apples, Braeburn apples and Pink Lady apples during storage

Non-destructive assessment of fruit maturity at harvest and correlation with quality parameters

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- Sensory attributes, aroma composition, ethylene production Ambra nectarines
- Softening prediction (based on biological age) in Spring Belle nectarines and in Tommy Atkins mangoes

Non-destructive detection of internal disorders and defects

- Browning in Granny Smith apples, Braeburn apples and Conference pears
- Watercore in Fuji apples
- Mealiness in Braeburn apples and Jonagored apples
- Chilling injuries in Jubileum plums and Morsiani 90 nectarines

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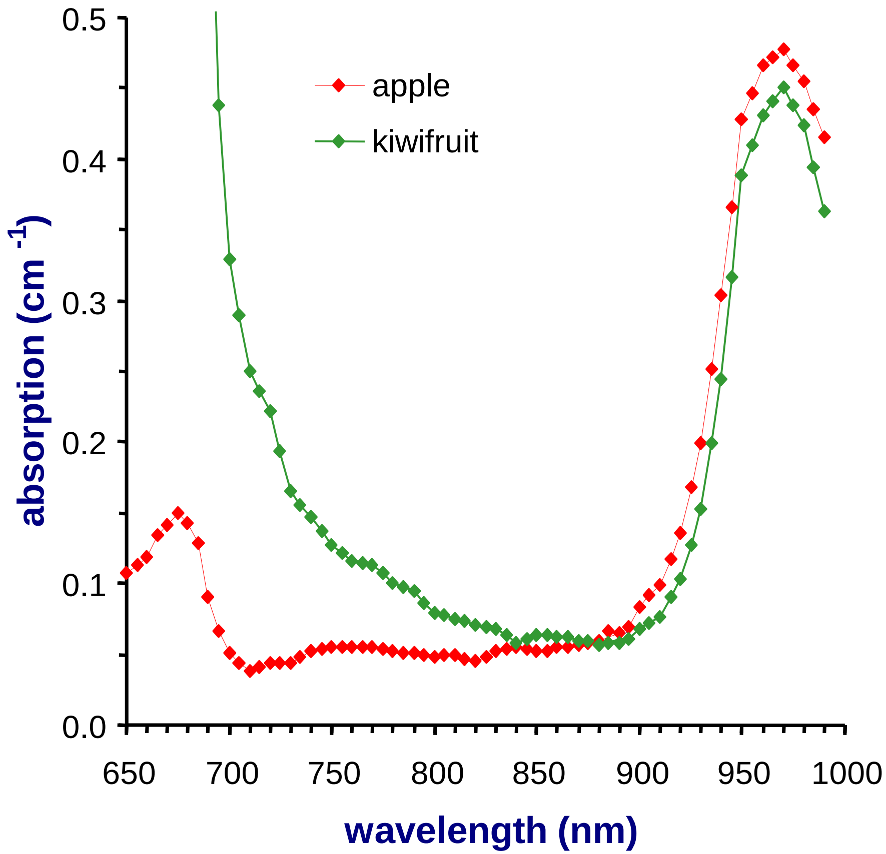
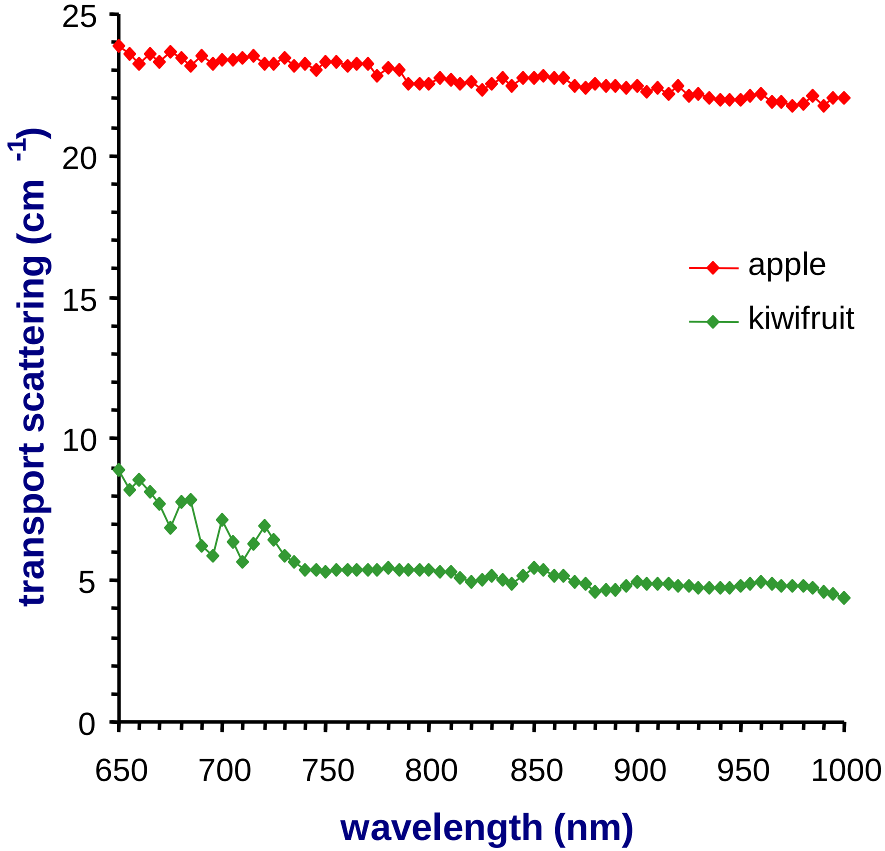
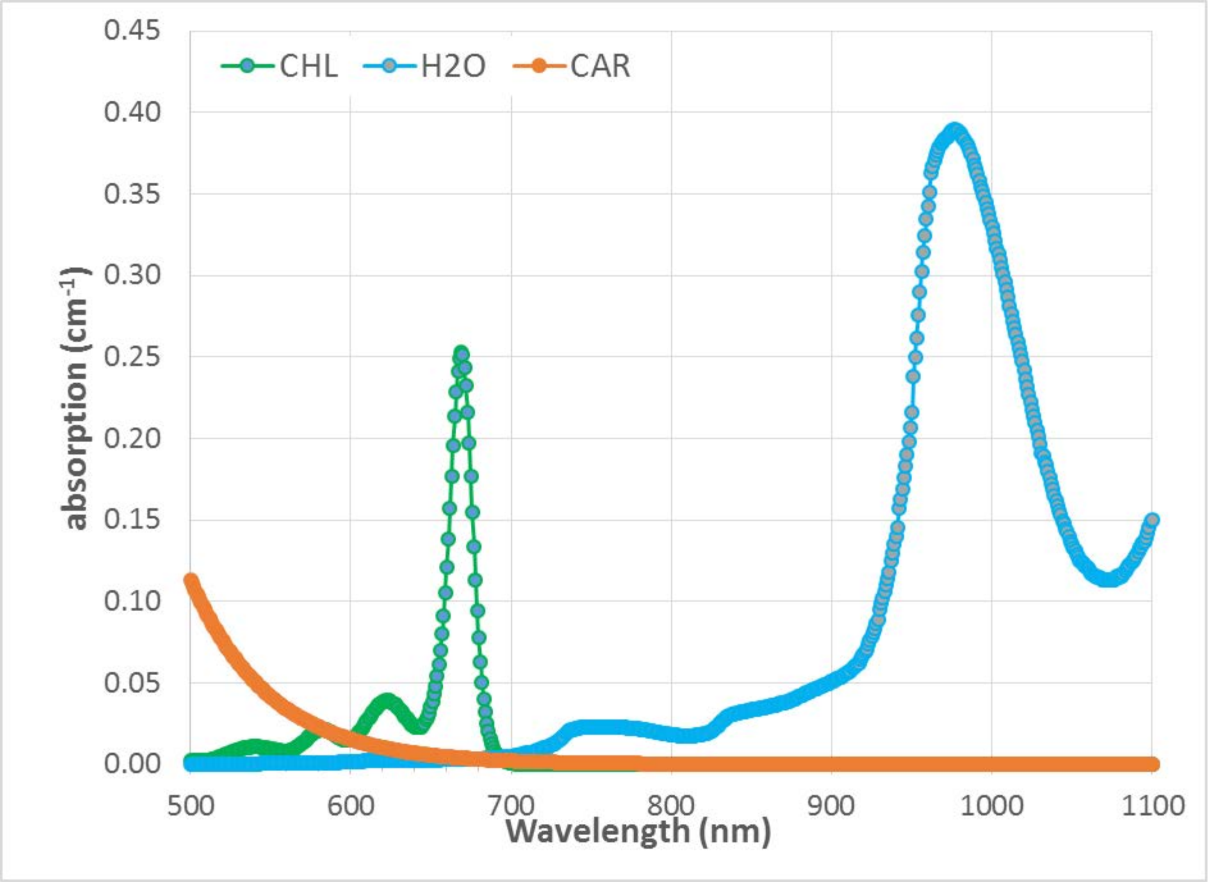
Optical characterization of foods absorption and scattering spectra



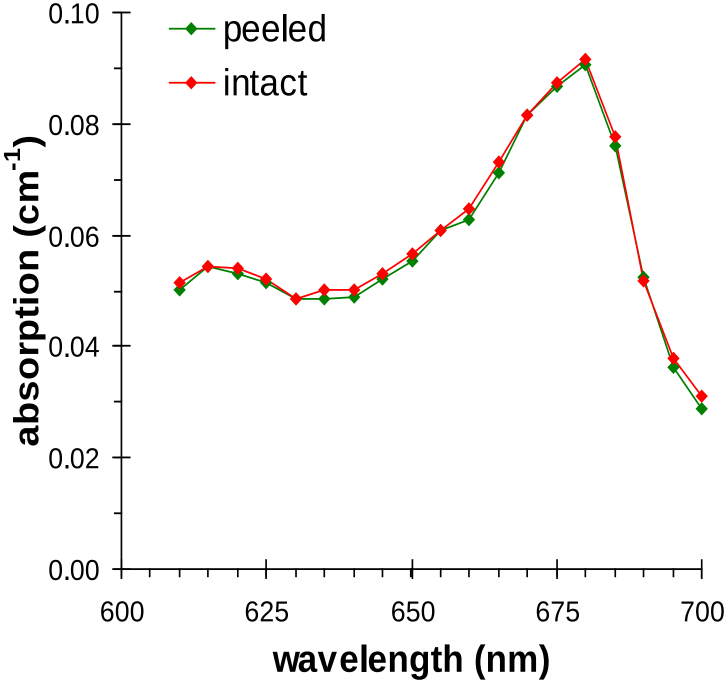


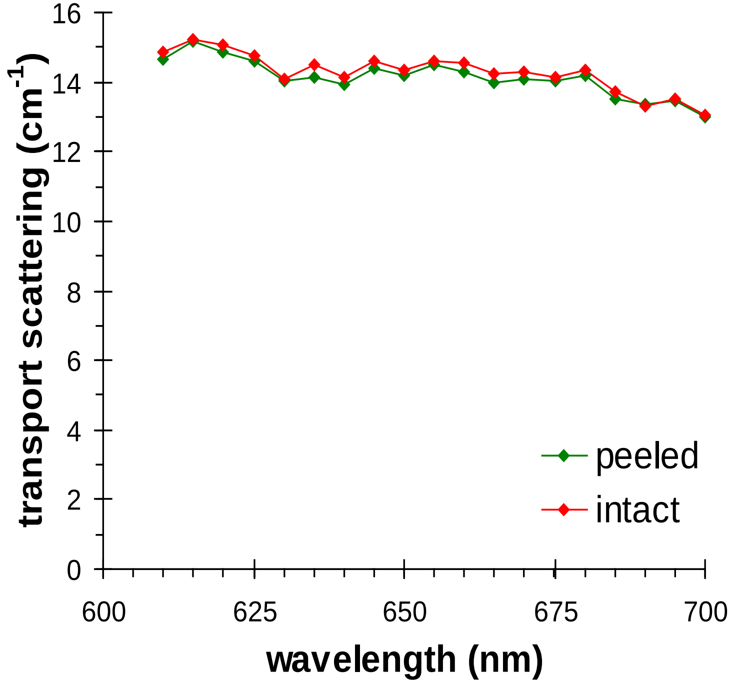
Cubeddu *et al.*, Applied Optics 40:538-543 (2001)

Light absorption in the NIR fruit



Optical characterization of foods
effect of skin: Apple (cv. Golden Delicious)

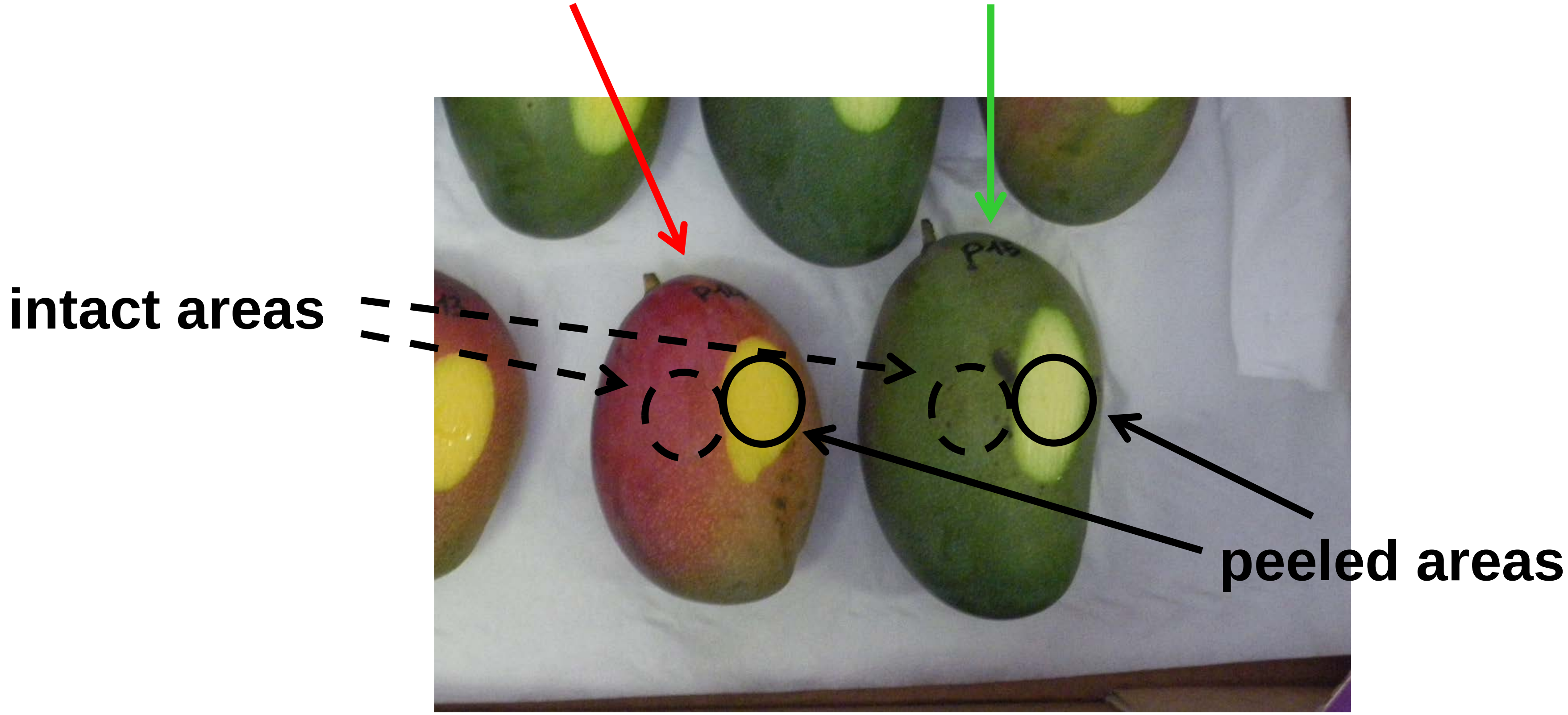




No effect of the skin on the spectra of absorption and reduced scattering coefficients

effect of skin: Mango (cv. Palmer)

- **Mangoes** (cv **Palmer**) harvested in **Minas Gerais** (Brazil) and transported by plane to Milan (Italy)
- **20 mangoes** selected
- 2 nearby regions on **red** (10 fruit) and **green** (10 fruit) side



Experimental protocol

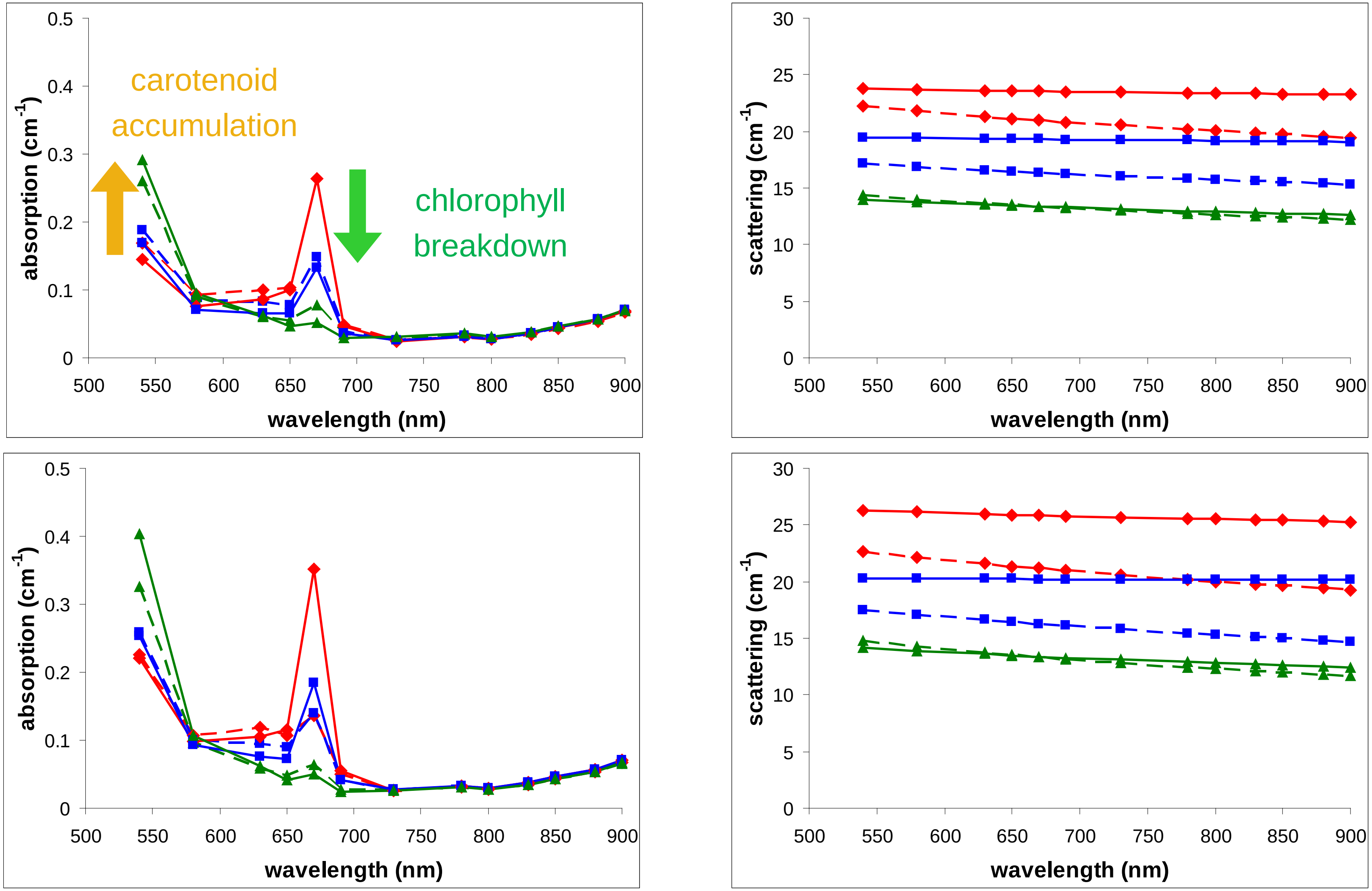
Measurements performed on both **pulp** and **skin**

- **TRS: 13 wavelengths** in the spectral range 540-900 nm
- **color measurements** with spectrophotometer (CM-2600d, Minolta):
    - spectral range: 360-740 nm;
    - color parameters: L*, a*, b* values → $C^* = [(a^*)^2 + (b^*)^2]^{-2}$
      → $H° = \arctan(b^*/a^*)$.
      → absorbance
- **days 1, 4 and 11** of shelf life: temperature → 20±2°C; RH → 75±5%

TRS measurements: Absorption and scattering spectra

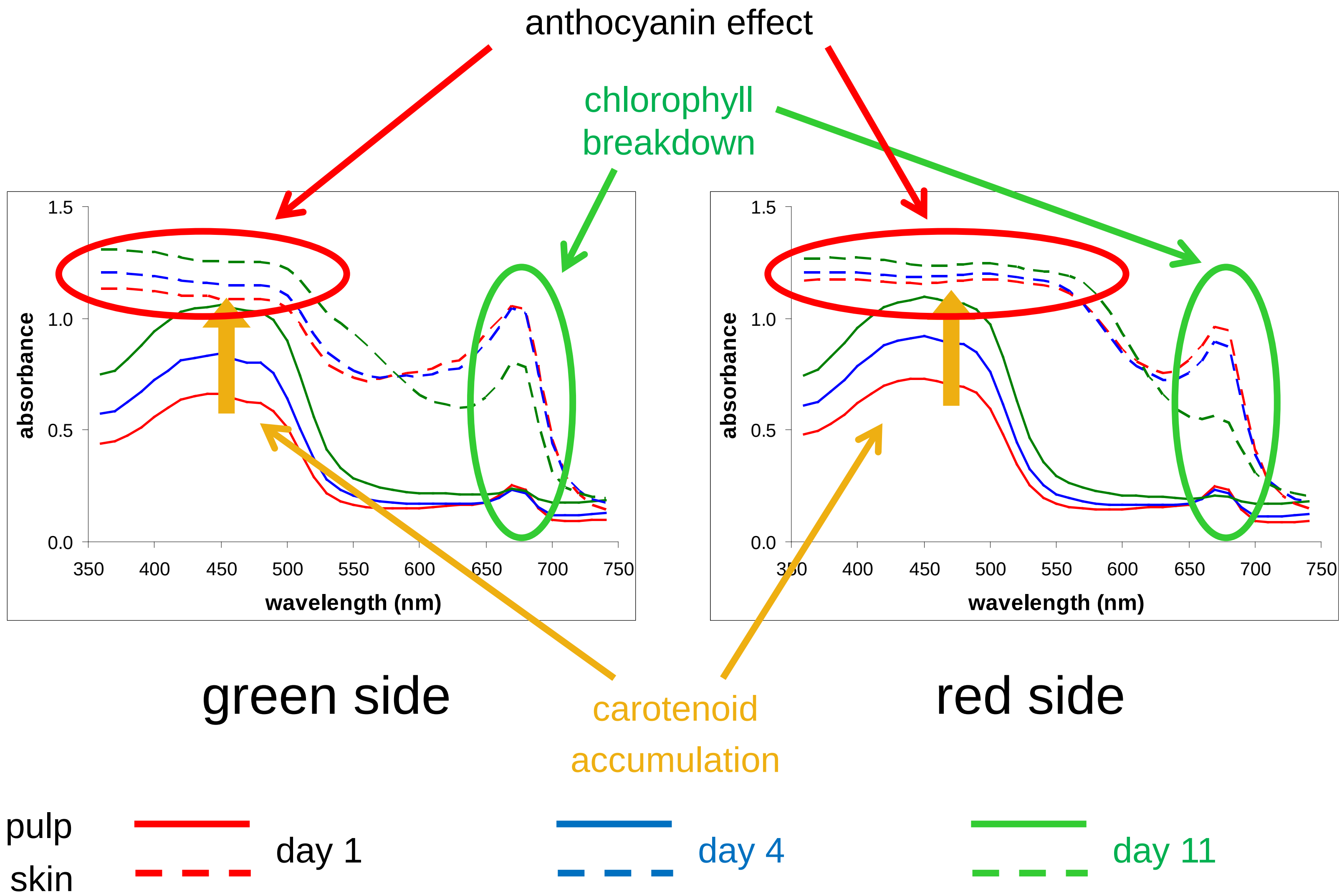
green side

red side



pulp
skin
day 1
day 4
day 11

Color measurements: Absorbance



Correlations: absorption coefficients *vs* color parameters

Pigment-related wavelengths: **540, 580 nm → carotenoids**
630, 650, 670, 690 nm → chlorophyll

good correlations between pulp color and μ_a from pulp and skin

	μ_a540p	μ_a580p	μ_a630p	μ_a650p	μ_a670p	μ_a690p	μ_a540s	μ_a580s	μ_a630s	μ_a650s	μ_a670s	μ_a690s
*L** pulp	-0.798	-0.597	0.313	0.438	0.566	0.431	-0.708	-0.009	0.560	0.600	0.452	0.541
*a** pulp	0.914	0.493	-0.565	-0.702	-0.725	-0.702	0.871	-0.041	-0.682	-0.742	-0.582	-0.717
*b** pulp	0.800	0.399	-0.563	-0.697	-0.689	-0.660	0.812	0.005	-0.573	-0.677	-0.282	-0.632
*C** pulp	0.816	0.416	-0.555	-0.689	-0.689	-0.659	0.825	0.012	-0.579	-0.682	-0.309	-0.635
H° pulp	-0.860	-0.417	0.620	0.763	0.749	0.724	-0.833	0.069	0.670	0.754	0.593	0.717
*L** skin	-0.378	-0.338	-0.012	0.036	-0.033	0.024	-0.354	-0.245	-0.096	0.036	0.198	0.075
*a** skin	0.702	0.556	-0.189	-0.263	-0.228	-0.248	0.555	0.128	-0.272	-0.321	-0.289	-0.354
*b** skin	-0.096	-0.203	-0.245	-0.221	-0.310	-0.246	-0.111	-0.320	-0.366	-0.243	0.006	-0.180
*C** skin	0.387	0.135	-0.429	-0.427	-0.510	-0.459	0.286	-0.339	-0.652	-0.578	-0.426	-0.509
H° skin	-0.494	-0.472	0.002	0.084	0.003	0.031	-0.492	-0.265	-0.008	0.087	0.194	0.108

p = μ_a measured on the pulp; s = μ_a measured through the skin

poor correlations between skin color and μ_a

Conclusions

From measurements on **exposed pulp** and on **skin**, it results that:

- **skin attenuates the TRS signal intensity**
- **skin does not affect the estimate of pulp optical properties**

Absorption spectrum features:

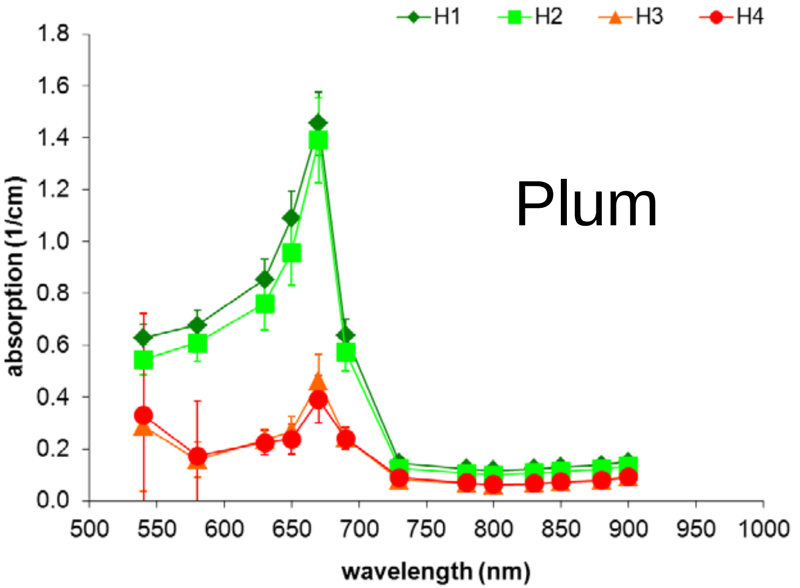
- **increase in the 540–600 nm range**
  → changes in the carotenoid content
  → **skin color measures are affected by other pigments**
- **decrease at 670 nm**
  → changes in the chlorophyll content

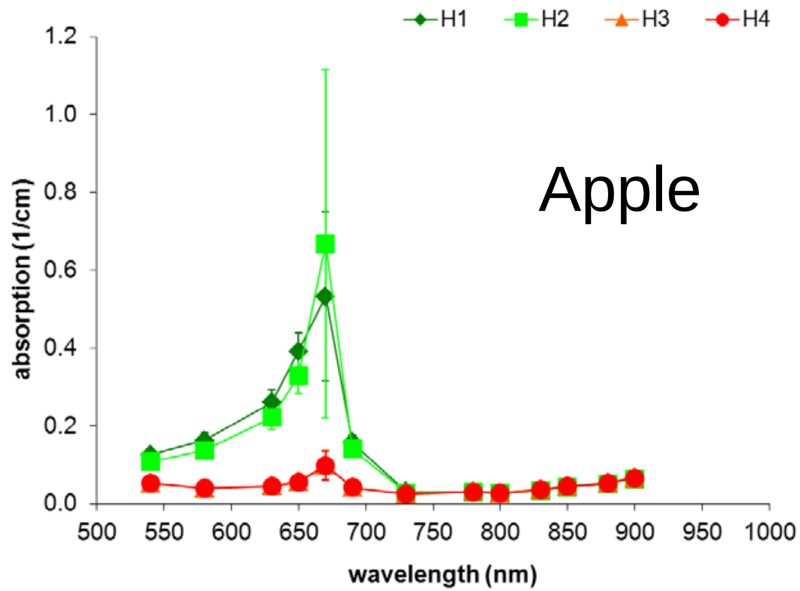
TRS non-destructive characterization of mango during ripening

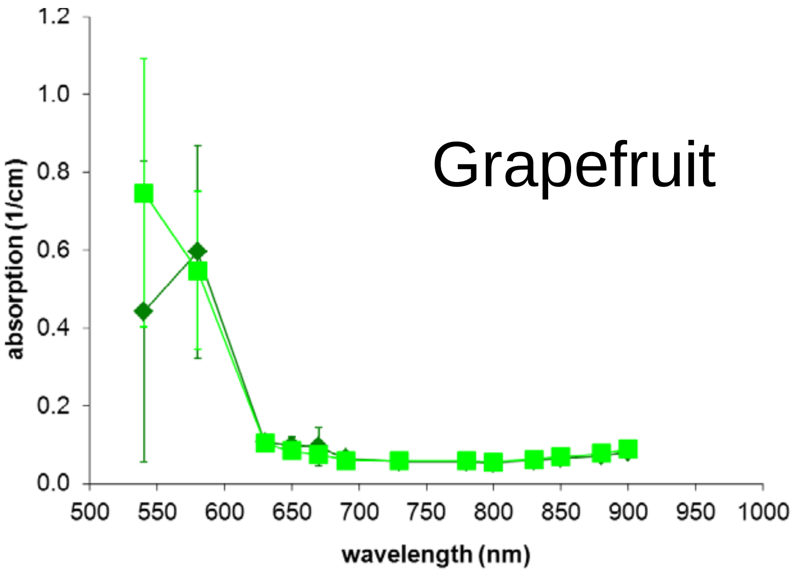
EPAMIG CRA CONSIGLIO PER LA RICERCA E LA SPERIMENTAZIONE IN AGRICOLTURA WAGENINGEN UNIVERSITY WAGENINGEN UR

Project TROPICO:
n.17077, Rif. AGRO–16, Regione Lombardia (Italy)

Optical properties during growth
Absorption spectra



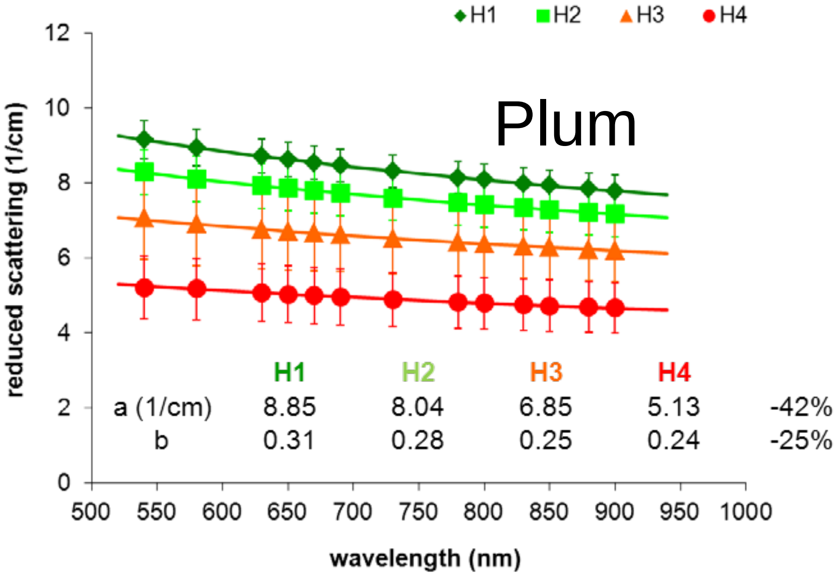


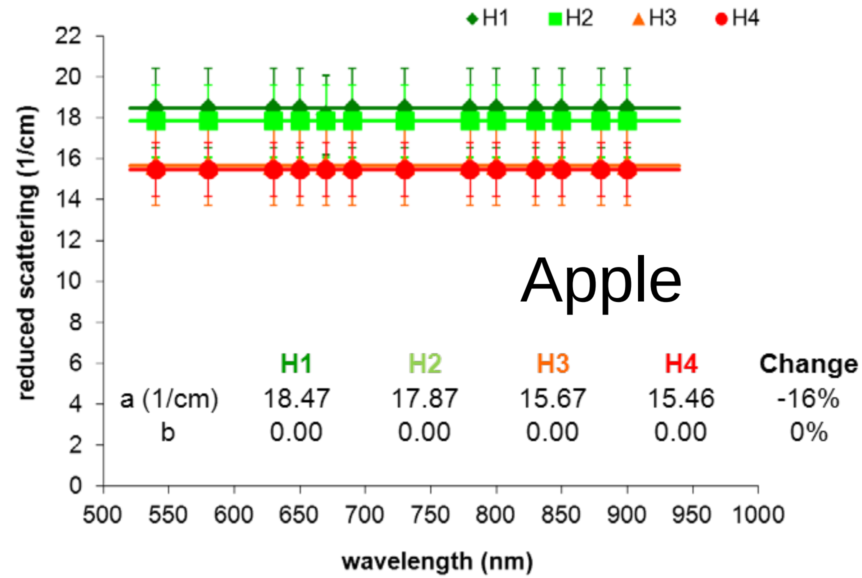


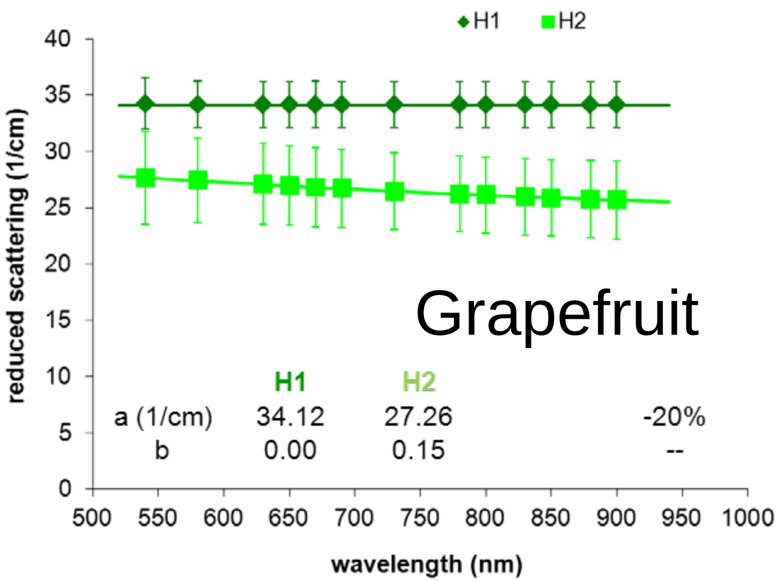
Chlorophyll breakdown in plum and apple, almost no changes in grapefruit.

Seifert *et al.* Physiologia Plantarum 53(2):327–336 (2015)

Optical properties during growth
Scattering spectra



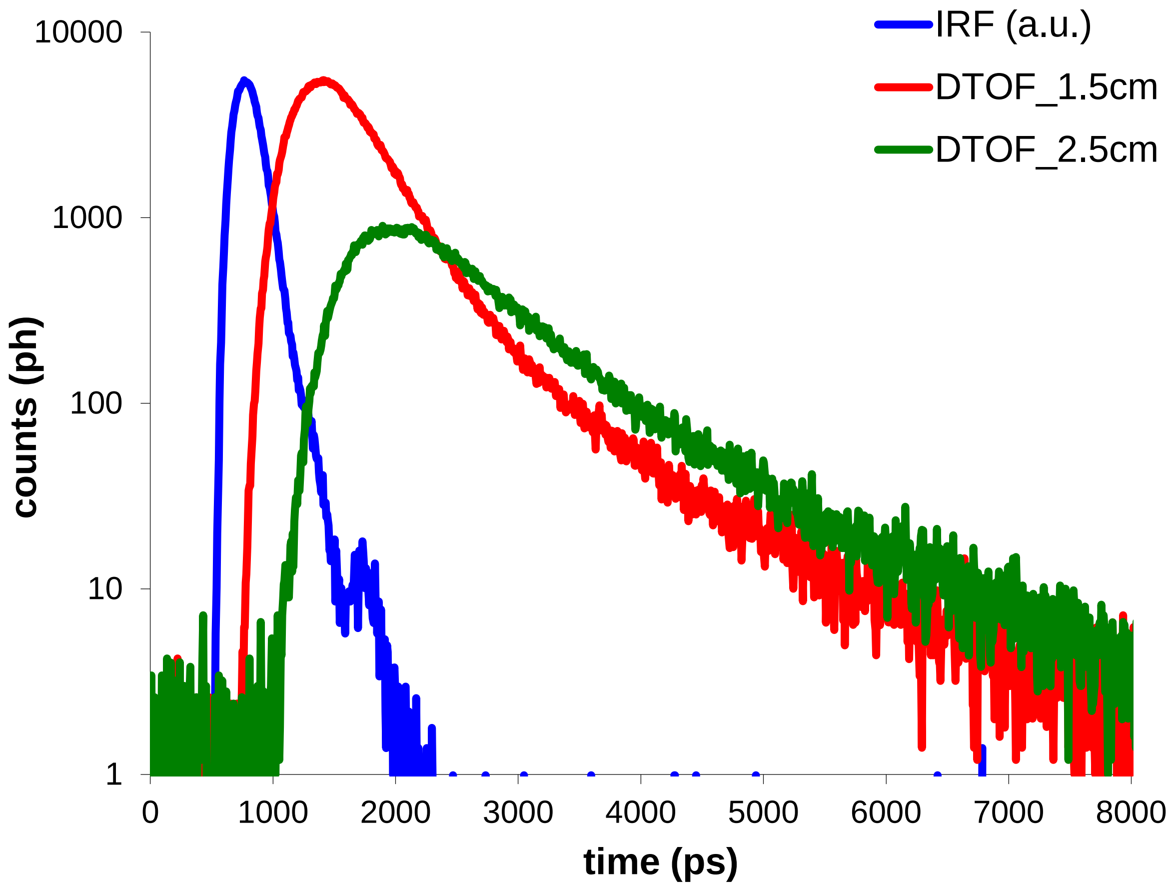


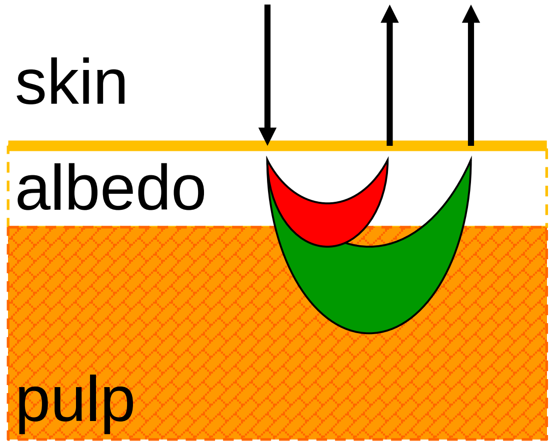


Large changes during growth in the scattering properties for plum and grapefruit, minor changes for apple.

Seifert *et al.* Physiologia Plantarum 53(2):327–336 (2015)

Optical properties
Effect of layered structure in grapefruit





Shorter distance: early photons travel in the albedo, late photons in the pulp

Longer distance: photon-path is mainly in the pulp

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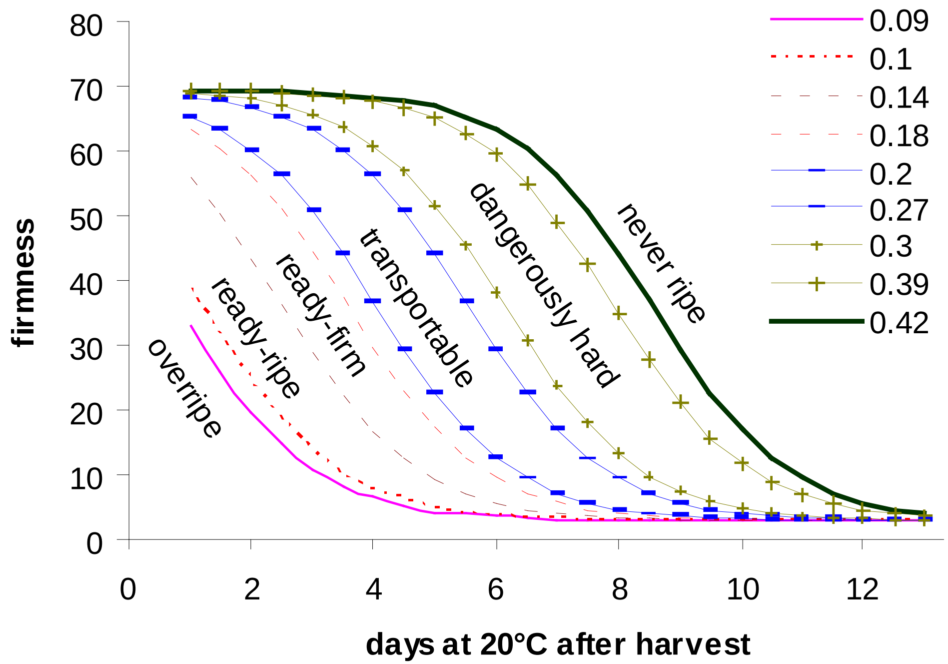
Kinetic model linking μ_a at 670 to firmness allowing softening prediction of individual fruit from μ_a measurement at harvest

$$F = \frac{F_{\max} - F_{\min}}{1 + e^{k_f \cdot (F_{\max} - F_{\min}) \cdot t + \Delta t_F^*}} + F_{\min}$$

$$\Delta t_F^* = \alpha \left(\log\left(\frac{\mu_{a,\max}}{\mu_a} - 1 \right) + \beta \right)$$

Biological shift factor



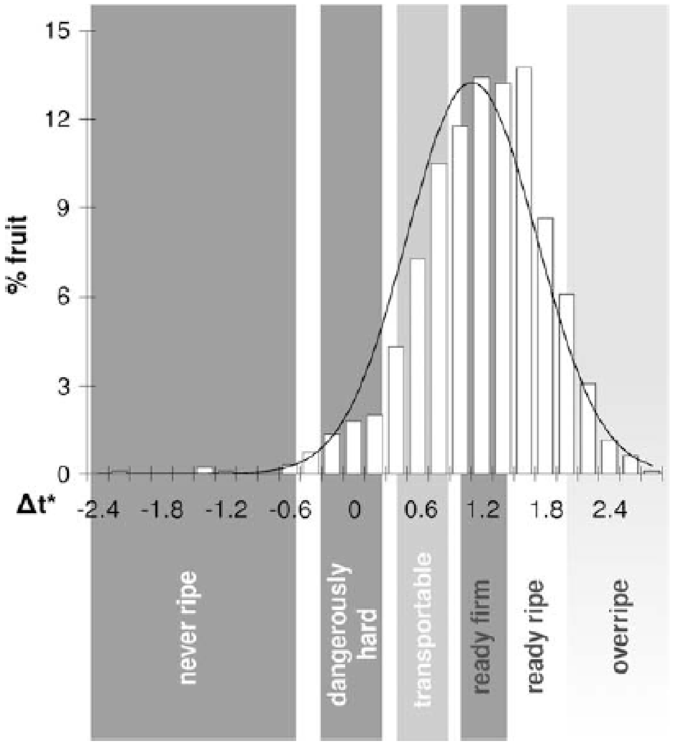
‘Spring Belle’ nectarines

Eccher Zerbini *et al.*, Postharvest Biology and Technology 39, 223-232 (2006)
Tijskens *et al.*, Int. J. Postharvest Technology and Innovation 1, 178-188 (2006)
Tijskens *et al.*, Postharvest Biology and Technology 45, 204-213 (2007)

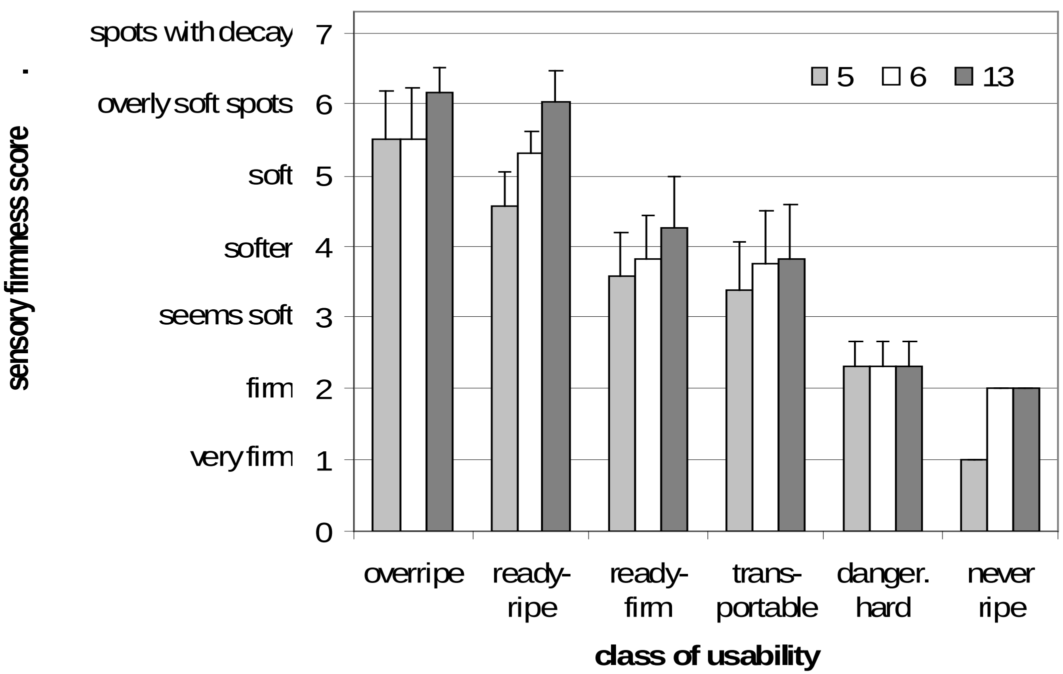
μ_a at 670 is an effective maturity index

Nondestructive assessment of maturity at harvest
Softening prediction in 'Spring Belle' nectarines

Distribution of biological shift factor at harvest with **Classes of usability**



Softness scores after transport and 5, 6, 13 days of shelf-life

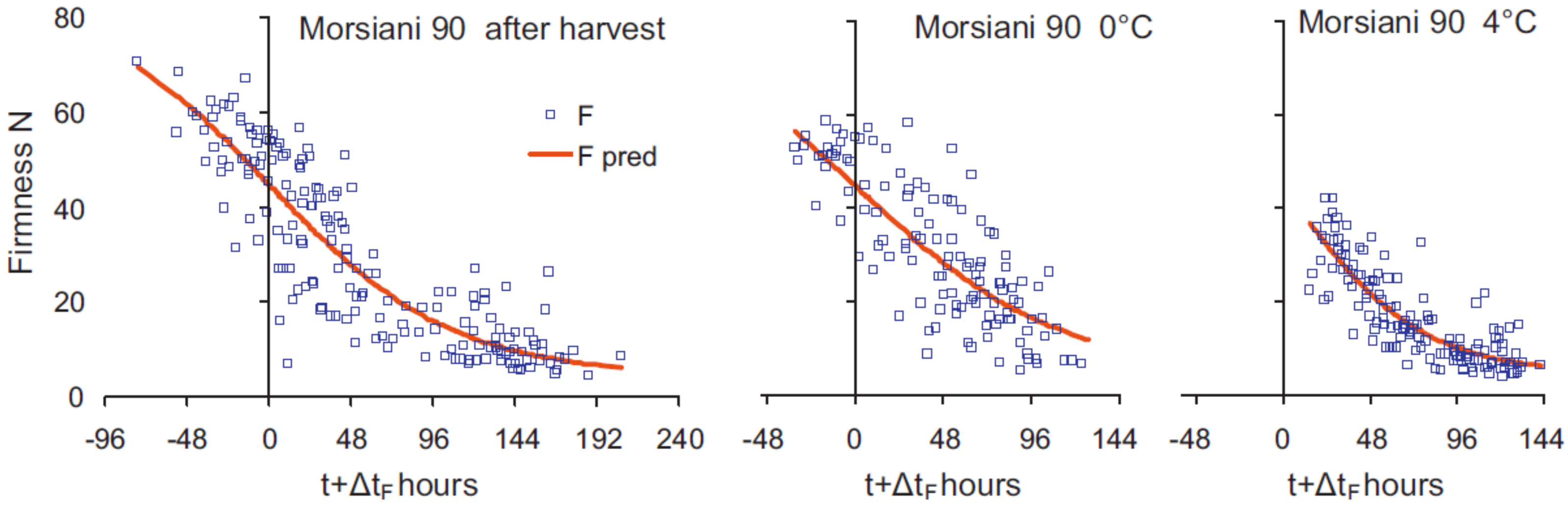


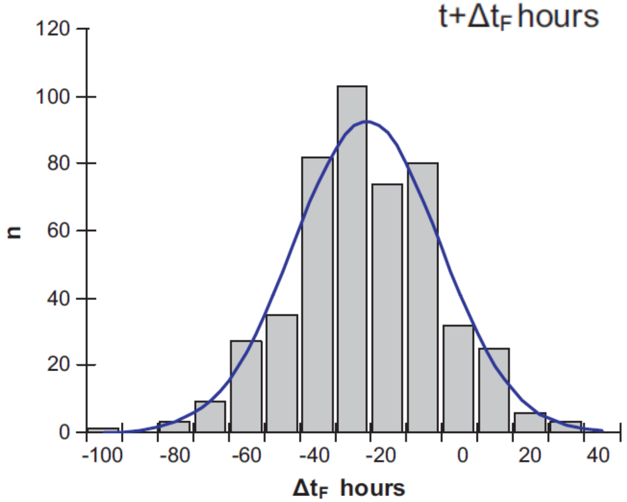
Classes of usability successfully tested in an export trial from Italy to Netherlands

Eccher Zerbini *et al.*, Biosystems Engineering 102, 360-363 (2009 in press)

Nondestructive assessment of maturity at harvest
Softening prediction in ‘Morsiani 90’ nectarines

Predicted firmness and measured firmness according to the biological shift factor model



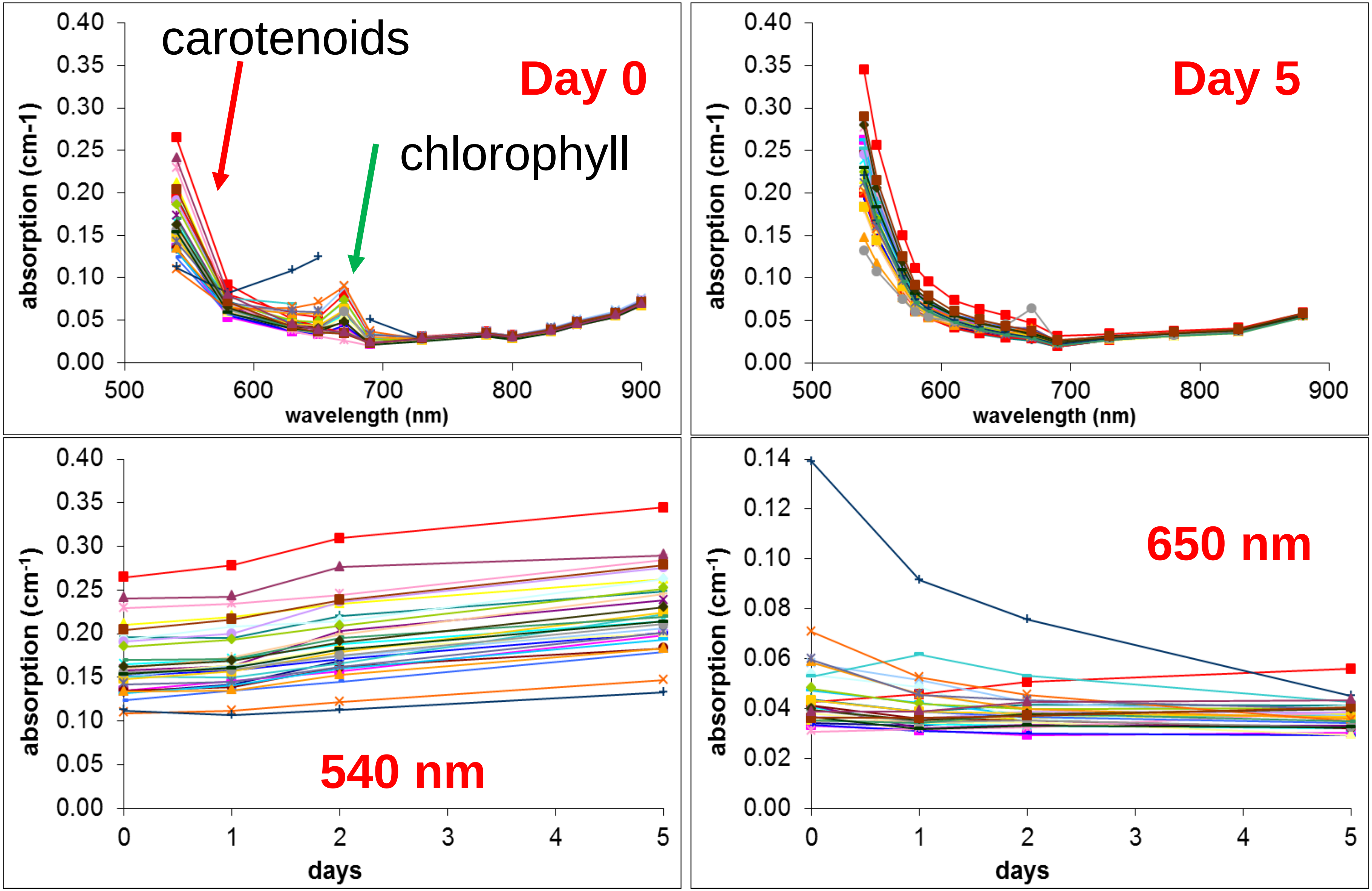


Distribution of biological shift factor

The measured points are shifted in time according to the biological shift factor based on μ_a at harvest

Eccher Zerbini *et al.*, Postharvest Biology and Technology 62, 275-281 (2011)

Maturity at harvest and shelf life in Tommy Atkins mangoes



Maturity at harvest and shelf life in “Tommy Atkins” mangoes

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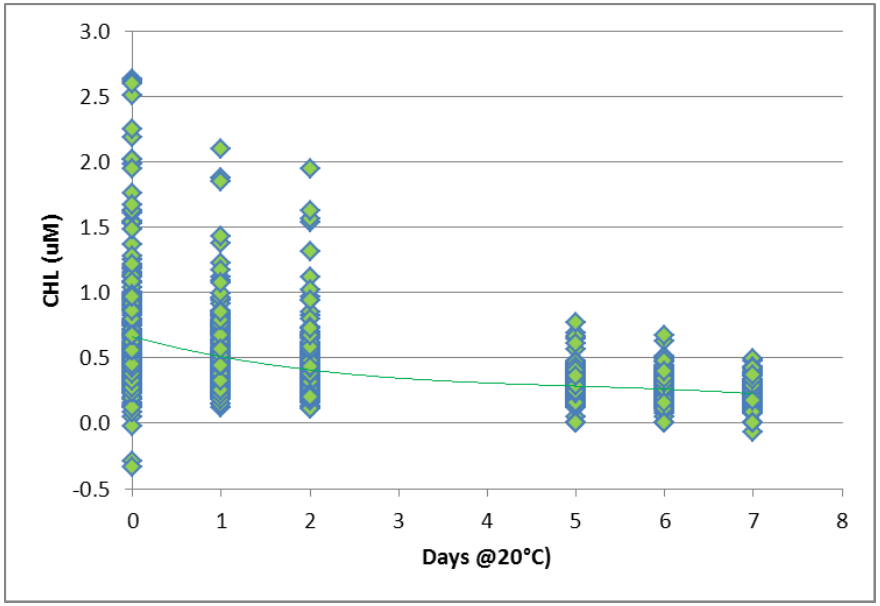
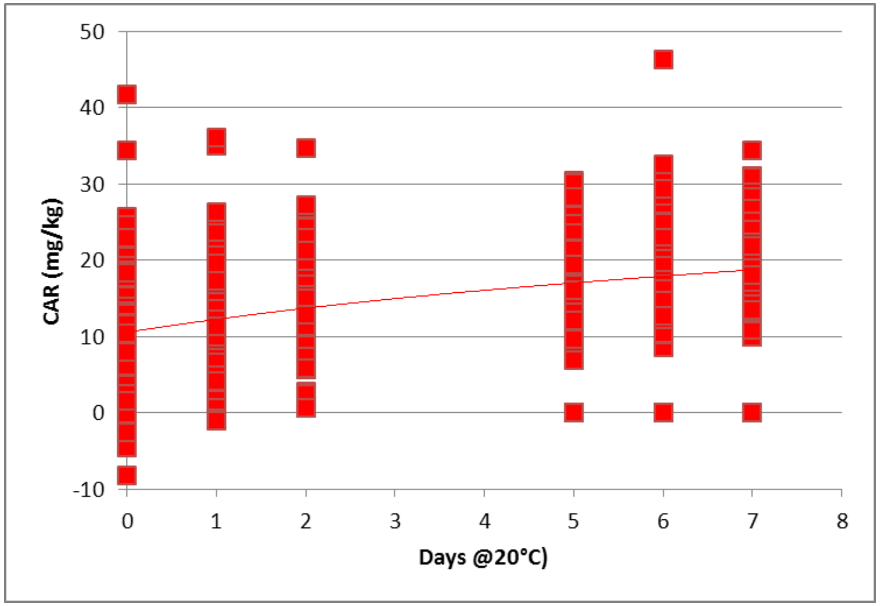
chlorophyll



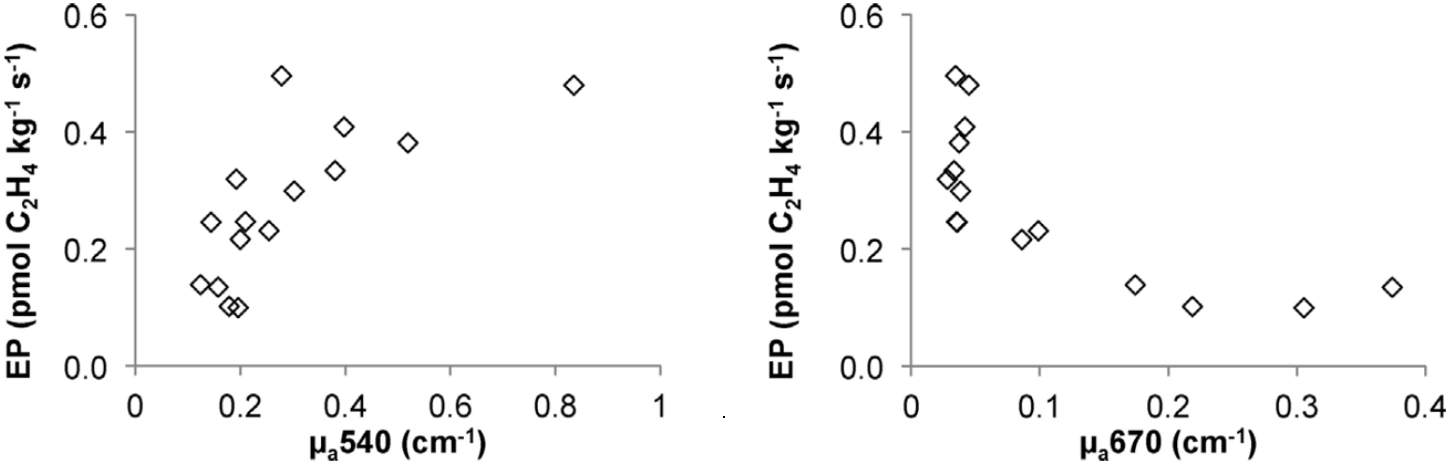
carotenoids



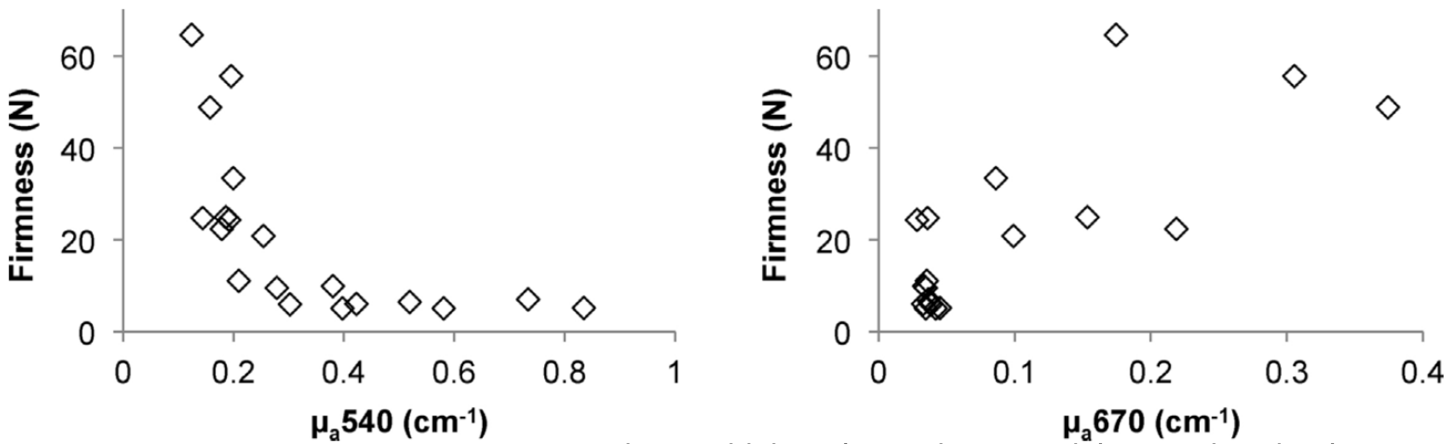
Chlorophyll-a and carotenoids estimation from TRS

Open problem: extinction coefficient for carotenoids *in vivo*

Ethylene production at harvest

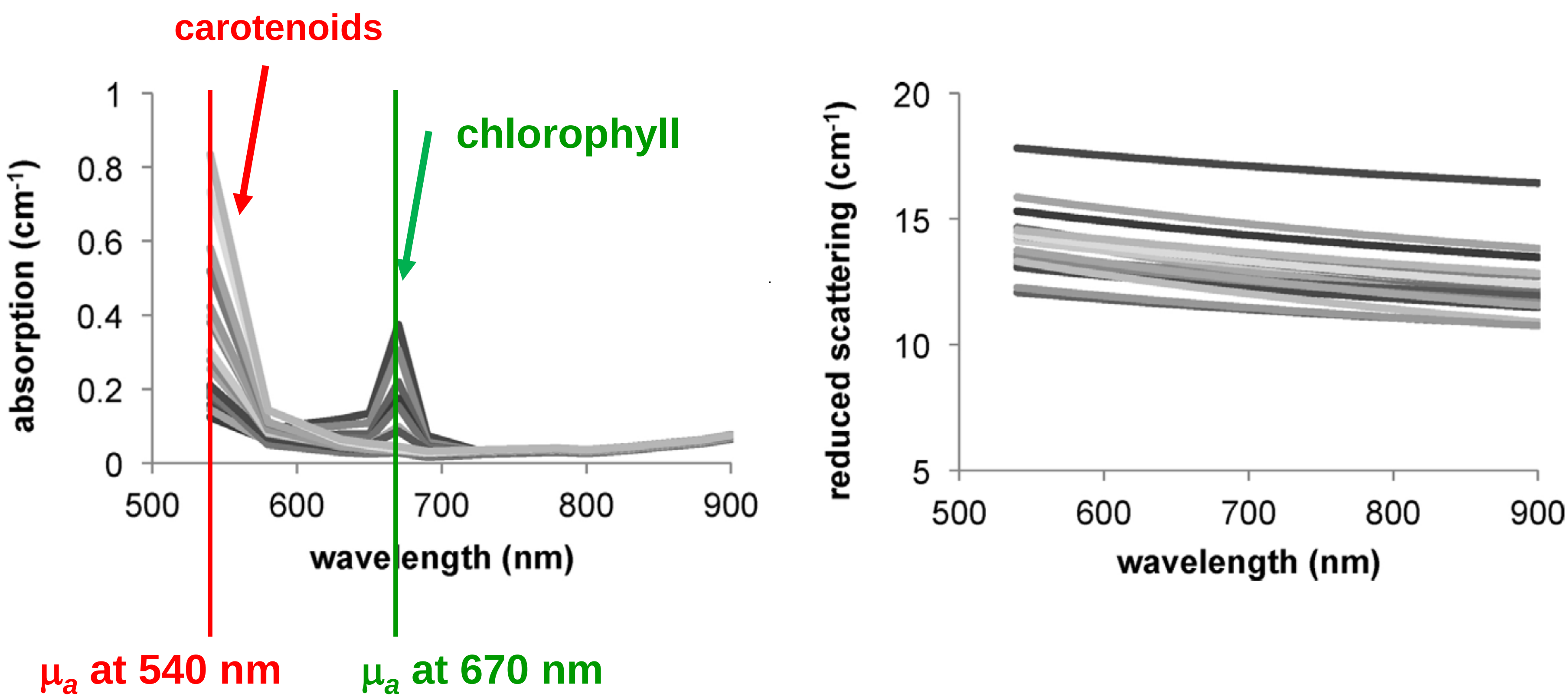


Firmness at harvest



Eccher Zerbini *et al.*, Postharvest Biology and Technology 101, 58-65 (2015)

Optical properties at harvest



Eccher Zerbini *et al.*, Postharvest Biology and Technology 101, 58-65 (2015)

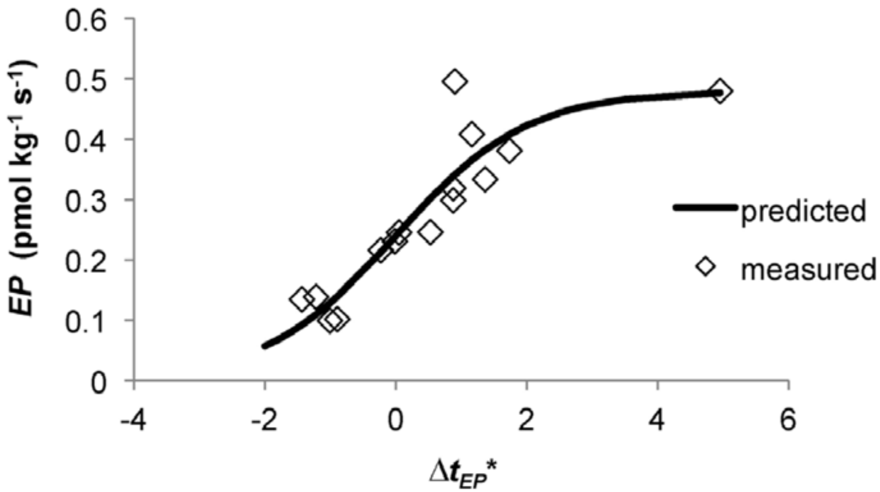
Biological shift factor model

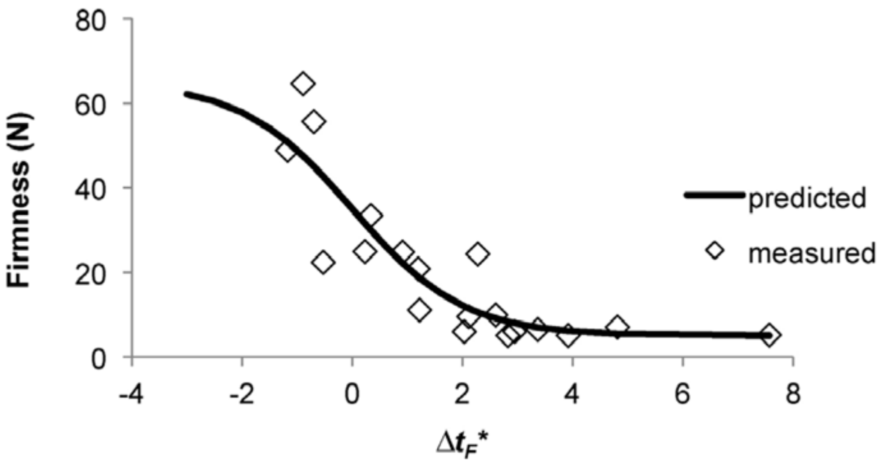
$$EP = \frac{EP_{\max}}{1 + \exp(-\Delta t_{EP}^*)}$$

$$F = F_{\min} + \frac{F_{\max} - F_{\min}}{1 + \exp(\Delta t_F^*)}$$

$$\Delta t_{EP}^* = \alpha_{540}\left(\log\frac{\mu_{a,\max}^{540} - \mu_{a,0}^{540}}{\mu_{a,0}^{540} - \mu_{a,\min}^{540}}\right) + \alpha_{670}\left(\log\frac{\mu_{a,\max}^{670} - \mu_{a,0}^{670}}{\mu_{a,0}^{670} - \mu_{a,\min}^{670}}\right) + \beta$$

$$\Delta t_F^* = \alpha_{F,540}\left(\log\frac{\mu_{a,\max}^{540} - \mu_{a,0}^{540}}{\mu_{a,0}^{540} - \mu_{a,\min}^{540}}\right) + \alpha_{F,670}\left(\log\frac{\mu_{a,\max}^{670} - \mu_{a,0}^{670}}{\mu_{a,0}^{670} - \mu_{a,\min}^{670}}\right) + \beta_F + k_A A + k_B B$$





Ethylene production and firmness predicted by biological shift factor

Eccher Zerbini *et al.*, Postharvest Biology and Technology 101, 58-65 (2015)

Differently from nectarines and mangoes apples ripening is not correlated only to chlorophyll content

Many factors are involved in the ripening process in apples

A more complex model is need to describe the maturity

An important parameter for quality in apples is fruit texture

- The apple texture is linked to fruit structure at molecular, micro and macroscopic levels
- Crispiness, juiciness and mealiness are bound to mechanical and acoustic properties of the pulp
- Different apple texture are characterized by different pulp optical properties

Pulp optical properties measured by TRS ⟺ Fruit texture measured through mechanical-acoustic and sensory analysis

Non-destructive evaluation of apple quality
Experimental protocol for season 2015/2016

- Cultivar ‘**Gala**’:
  - 270 apples
  - Measurements during shelf-life at harvest, after 2 and 4 months of CA storage

- Cultivar ‘**Kanzi**’:
  - 270 apples from Laimburg + 270 apples from Schludern
  - Measurements during shelf-life at harvest, after 3 and 6 months of CA storage

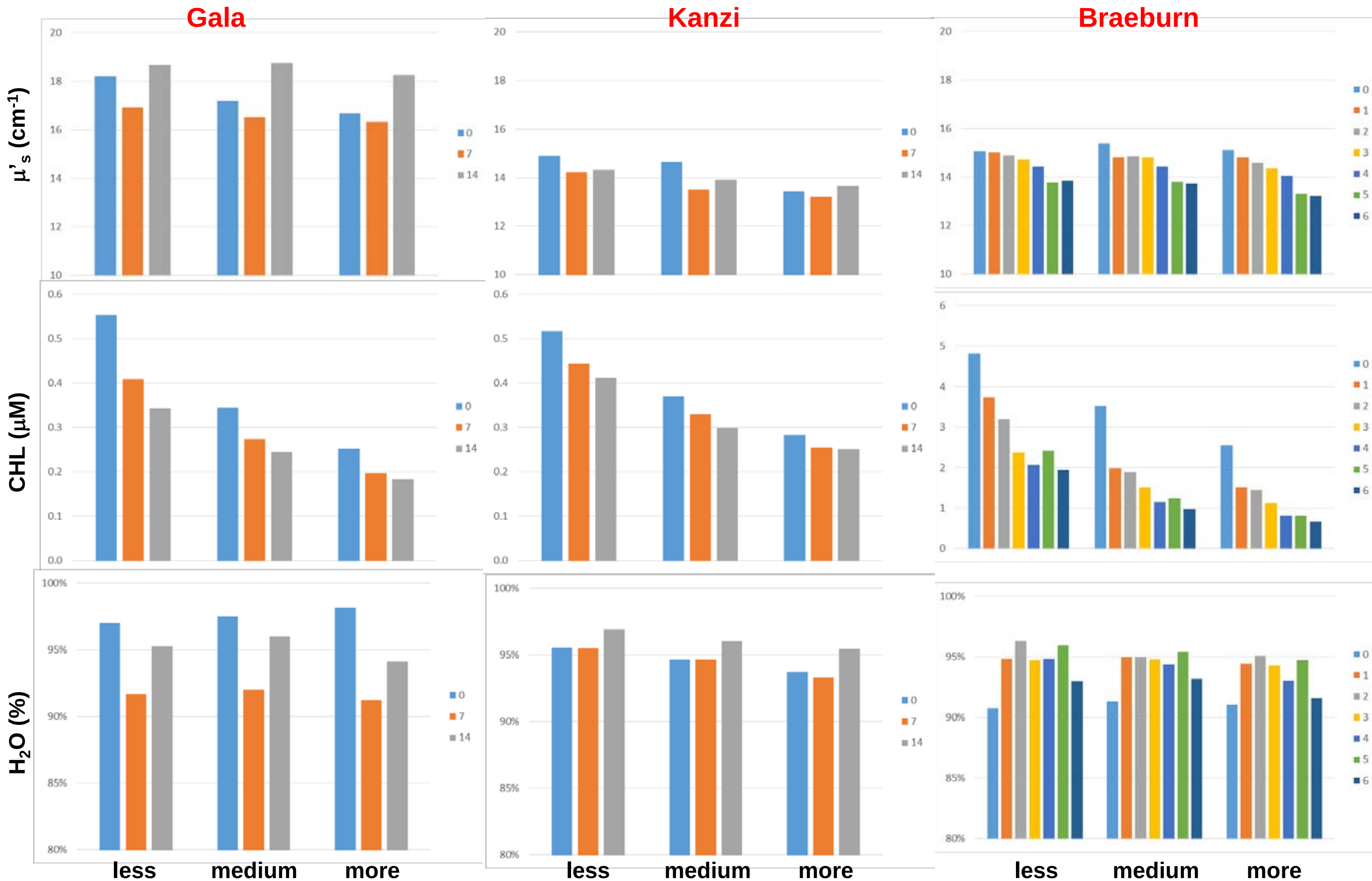
- Cultivar ‘**Braeburn**’:
  - 1320 apples
  - Harvested for 7 weeks (ripening on the tree) from inner and outer parts of the canopy
  - Measurements at harvest and after 2 of CA storage

MONALISA LAIMBURG

***MONALISA* Project:**
Monitoring key environmental parameters in the alpine environment involving science, technology and application

Non-destructive evaluation of apple quality
TRS measurements

- 3 maturity levels according to the chlorophyll content: less, medium, more
- Measurements of shelf-life at harvest



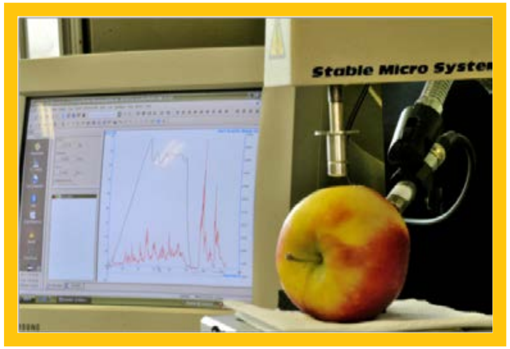
Non-destructive evaluation of apple quality
Texture Analysis

- **SENSORY PROFILES** (firm, juicy, mealy, crispy)
- **Relative intercellular space volume (RISV)** computed according to:

  RISV = 100 × [1-(df/dj)]   where df=fruit density and dj=fruit juice density.

- **MECHANICAL and ACOUSTIC PROPERTIES**

  measured by using a TA-XT plus Texture Analyzer equipped with an acoustic emission detector (AED) which simultaneously profile a mechanical force displacement together with the corresponding acoustic response



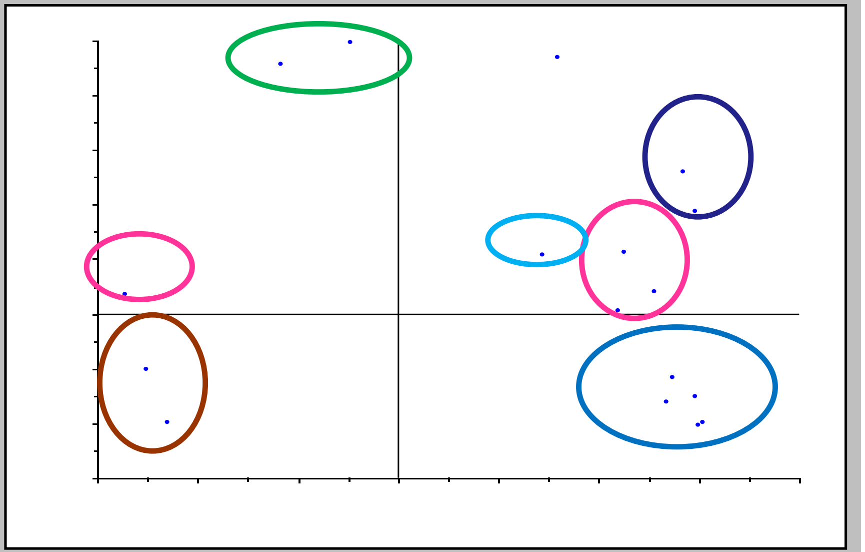
MECHANICAL parameters		ACOUSTIC parameters	
Fmax	Maximum Force	MEAN	Average sound
St	Stiffness	LD	Linear distance
W	Work	PK	N°peaks
		acMAX	Max value of ac. peaks
		acFmax	Value of ac.peaks at Fmax

- **NON destructive compression test**: each apple was compressed between two steel parallel plates to a fixed deformation of 1 mm (speed of 25 mm/min) and the modulus of deformability (Ed) was computed according to:

$$\frac{E_d}{1-\mu^2} = \frac{F}{(d_L/2)^{3/2}\, D^{1/2}}$$

where: F is the force at 1 mm of compression (N),
dL is the total deformation (mm),
D is the fruit diameter (mm);
μ is the Poisson's ratio (0.3)

TRS optical properties and fruit texture

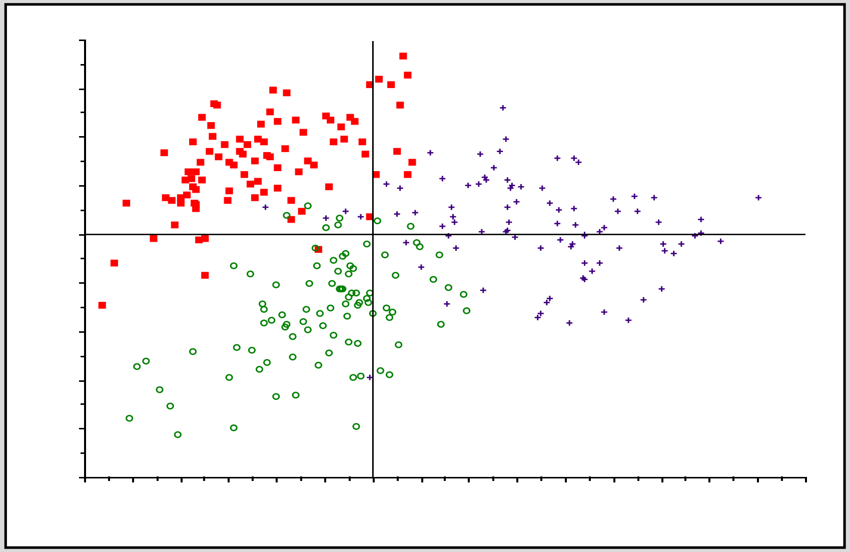


In the PCA plot:

•**CHL content** measured by TRS is positively related to Ed

•**μ'_s (MUS)** measured by TRS is positively related to RISV and mealiness and negatively to mechanical and acoustic parameters and to **water content (H2O)** measured by TRS

•sensory firmness, crispness and juiciness are positively related to mechanical and acoustic parameters



•PC1 distinguished Kanzi from Braeburn and Gala

Kanzi had a compact, firm and crispy texture with higher H2O content and lowest MUS and RISV

•PC2 distinguished Braeburn from Gala

Braeburn had higher CHL content, lowest acoustic parameters and a mealy texture

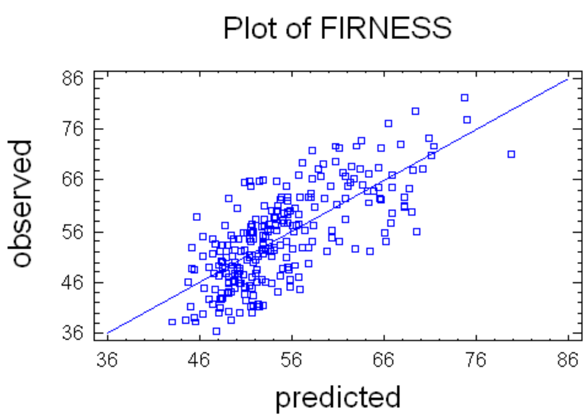
Gala had higher MUS and RISV, easily deformable, moderately firm and crisp

Firmness prediction from TRS optical properties

Multiple Linear Regression model

(MUS=scattering value; CHL=chlorophyll content; H_2O=water content; µa670H=µa670 at harvest)

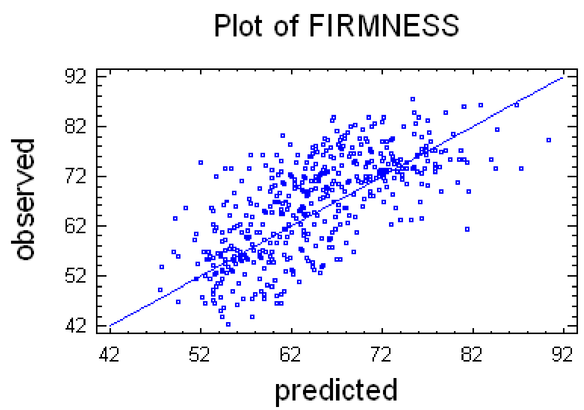
Gala



firmness = 2.35 - 1.58*MUS + 42.96*CHL + 69.82*H2O

R^2 adj = 0.53

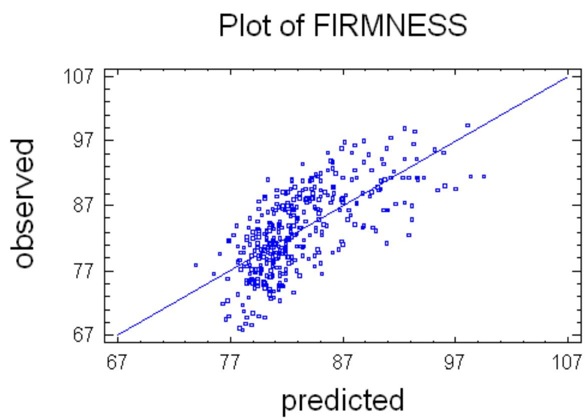
Kanzi *after storage*



firmness = 161.77 + 16.50*CHL - 110.6*H2O - 1.30*MUS + 482.1*μ_a670H

R^2 adj = 0.58

Braeburn



firmness = 59.82 + 1.18*MUS + 3.24*CHL

R^2 adj = 0.47

These models are significant at *P*<0.0001 but explain only about 47-58% of the variability of the three cultivars

Relationships between apple texture and TRS optical properties – Gala

• TRS PARAMETERS DIFFERED WITH SENSORY PROFILES

	CHL µM-1	H2O %	µ's cm-1
W1	0.395 a	93.9 a	17.3 a
W2	0.382 ab	92.3 b	16.8 a
W3	0.325 bc	92.1 b	17.1 a
W4	0.270 c	92.1 b	17.4 a

•CLUSTER ANALYSIS ON SENSORY ATTRIBUTES

Cluster number and sensory profiles	firm	juicy	mealy	crispy	Nobs
W1 - very firm, juicy and crispy. Not mealy	76	68	19	59	53
W2 - firm and juicy	65	46	24	45	72
W3 - quite firm, juicy, crispy, mealy	43	44	32	31	69
W4 - mealy	27	32	46	17	76

• DISCRIMINANT ANALYSIS

Non-destructive TRS parameters (chlorophyll and water contents, scattering) were used as explanatory variables to discriminate the sensory profiles obtained by Cluster Analysis

CLASSIFICATION TABLE at harvest

		Predicted Cluster			
actual CLUSTER	Group Size	**W1**	**W2**	**W3**	**W4**
W1	36	**86.1**	0.0	5.6	8.3
W2	14	28.6	**28.6**	35.7	7.1
W3	24	25.0	4.2	**62.5**	8.3
W4	16	12.5	6.3	37.5	**43.8**

At harvest: only 63.3% well-classified fruit, even if very firm and juicy apples were well-classified in 86.1% of the cases

After storage: the performance of the model worsened (34.4%%)

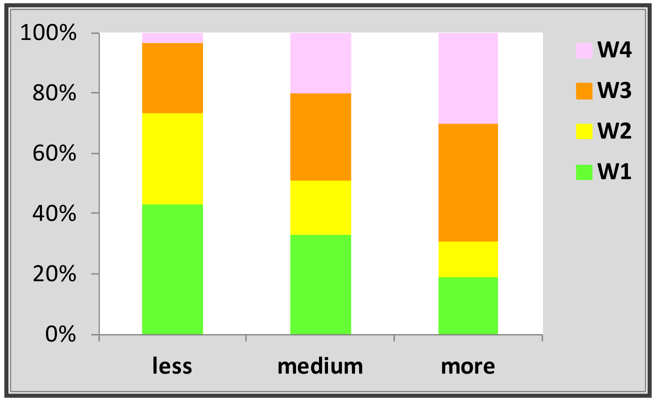
All data: the performance of the model was 41.1%

Non-destructive evaluation of apple quality
Main results

Relationships between apple texture and TRS maturity class

•GALA

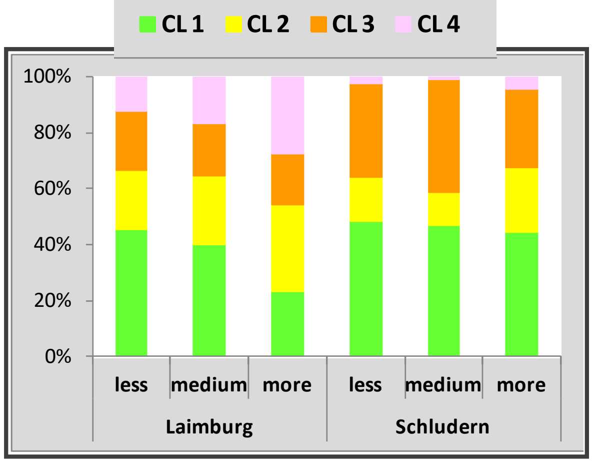
	μ'a670 cm-1	firmness N	acPK n°	Ed N/mm2
less	0.045 a	61.5 a	40.2 a	6.8 a
medium	0.026 b	54.5 b	38.7 a	6.6 ab
more	0.017 c	49.8 c	28.5 b	6.1 c



•KANZI

Laimb	μ'a670 cm-1	firmness N	acPK n°	RISV %
less	0.038 a	61.0 a	57.4 a	15.5 c
medium	0.027 b	57.1 b	55.0 ab	16.0 b
more	0.019 c	54.8 b	49.0 b	16.4 a

Schlud	μ'a670 cm-1	firmness N	acPK n°	RISV %
less	0.054 a	75.3 a	66.7 ab	17.1 b
medium	0.042 b	74.6 a	70.8 a	17.6 ab
more	0.031 c	71.5 b	65.4 b	18.0 a



Cluster number and sensory profiles	firm	juicy	mealy	crispy	Nobs
CL1 - very firm, juicy and crispy	78	73	18	68	223
CL2 - quite firm and juicy but less crispy	52	60	23	41	115
CL3 - firm but quite crispy and less juicy	70	48	20	58	143
CL4 - mealy	30	41	42	26	58

Both for Gala and Kanzi, fruit classified at harvest according to μ_a670 had different firmness, crispness (acPK) deformability and RISV and developed different sensory profiles.

Gala: less mature apples were characterized by high % of firm and very firm texture;
more mature apples had the highest % of mealy texture

Kanzi – Laimburg: less mature apples had the highest % of firm and crispy texture (CL1) and the lowest of mealy
more mature apples had the highest % of mealy texture and of apples with low cispyness (CL2);
Schludern: the % of very firm, juicy and crispy apples (CL1) was evenly distributed among the 3 classes;
more mature apples showed the highest % of low juicy texture (CL3) and of mealy.

Non-destructive evaluation of apple quality
TRS perspectives

- **Feasibility** (now)
    - we demonstrate the possibility to perform spectral TRS measurements on apples with a portable instrumentation
    - non-destructive assessment of flesh chlorophyll content and scattering properties
    - Outcome for optical properties:
        - low correlation with firmness: ~50% (Magness Taylor)
        - better correlations with sensory profiles in some cases: contrasted results

- **Potential** (future)
    - instrumental viewpoint: there is room for smaller (more portable) instrument with reduced number of wavelengths (probably 2)

- **Gaps to be covered** (technological)
    - measurements speed: now TRS measures are too slow for inserting TRS in a sorting line. Instrument developments and feasibility test are needed

- **Alternatives**
    - possibility to non-destructively predict sensory characteristics of apples

Non-destructive evaluation of apple quality
TRS measurements in the orchards

Development of a transportable TRS set-up for measurements in the orchards

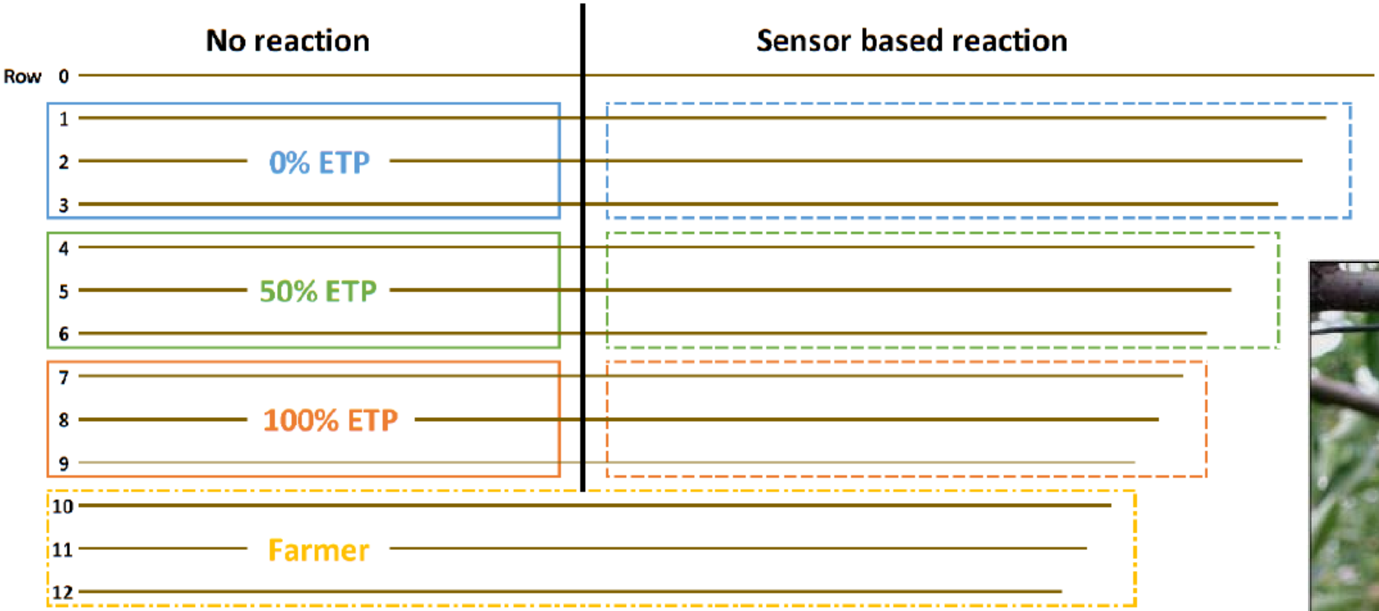
Photo of the TRS set-up

USER-PA Project:
Usability of environmentally sound and reliable techniques in precision agriculture

Experimental protocol

- Apple, cv. “Gala Brookfield”
- Orchards in Changins (Switzerland)
- 21 trees = 3 trees x 7 irrigation sectors
  (at least 4 apples from each tree)

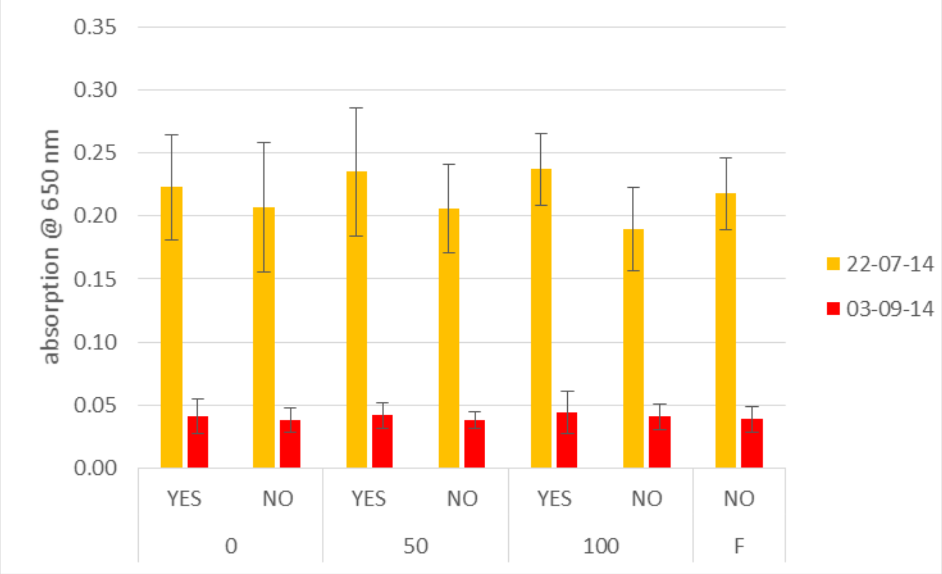
	25/06/2014	22/07/2014	03/09/2014
# fruit	108	105	126



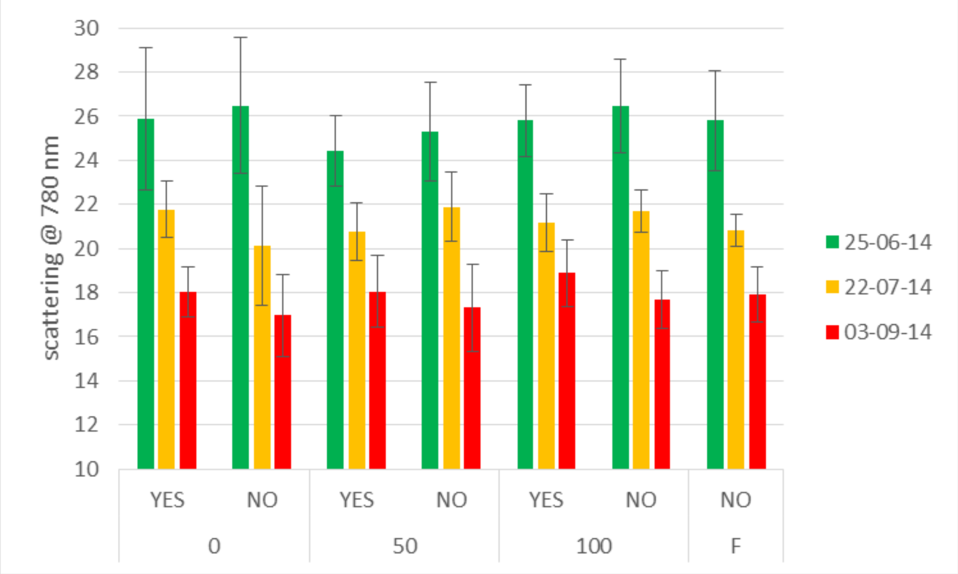
ETP = potential evapotranspiration

Preliminary results of field trials 2014

Absorption coefficient



Scattering coefficient



Chlorophyll absorption and scattering decrease during fruit growth
(agreement with Seifert *et al.* Physiologia Plantarum 53(2):327–336 (2015)

No changes with irrigation due to excess raining in season

Conclusions

A portable TRS setup was developed to allow TRS measurements in the orchards

TRS measurements in the orchards are feasible

- need to shield the fruit from sun light during measurement
- June seems too early for reliable chlorophyll absorption measurements

Results are in agreement with previous measurements on harvested fruits

- chlorophyll absorption in the fruit pulp decreases during growth
- scattering changes may affect readings by continuous wave optical sensors

Non-destructive optical characterisation of internal optical properties and correlation with quality parameters

- Basic studies in apples, kiwifruits, nectarines, tomatoes, …
- Changes in optical properties during growth in Elstar apples and Tophit plums
- Texture in Jonagored apples, Braeburn apples and Pink Lady apples during storage

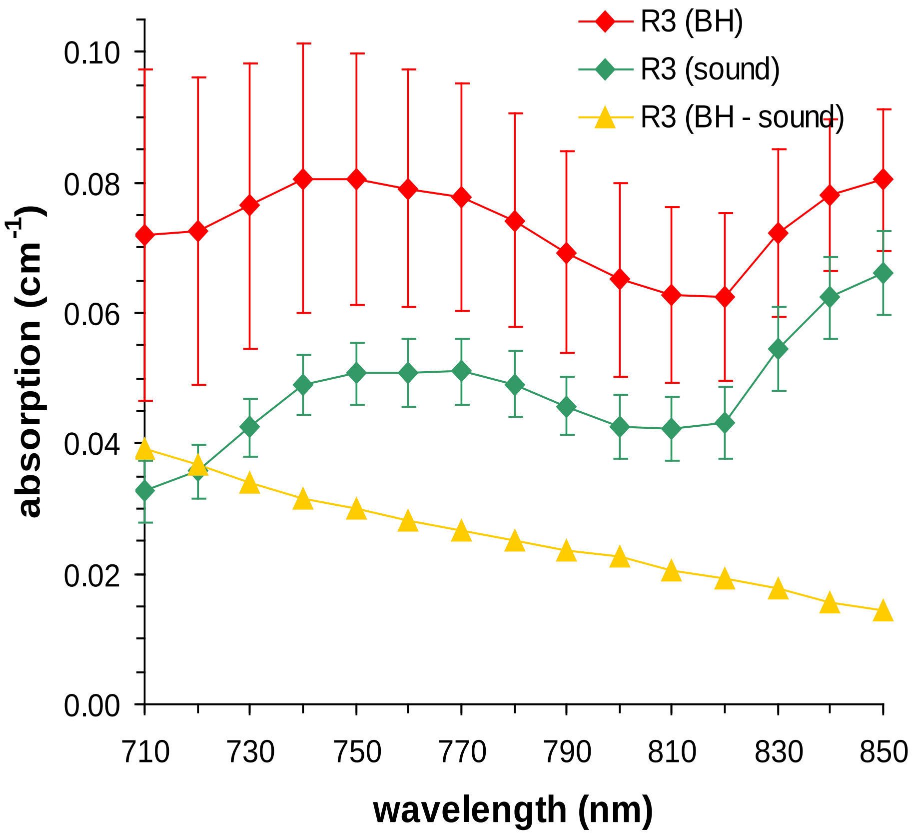
Non-destructive assessment of fruit maturity at harvest and correlation with quality parameters

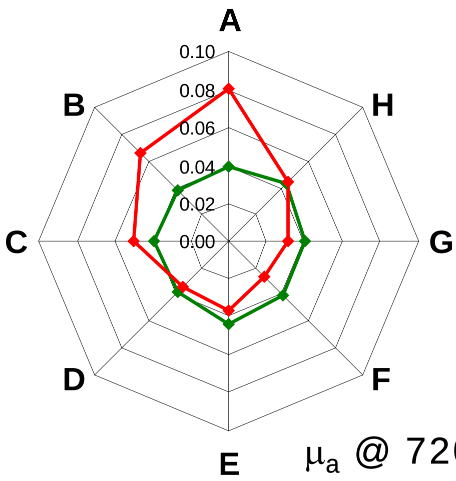
- Basic studies in apples, kiwifruits, nectarines, peaches, mangoes, …
- Sensory attributes, aroma composition, ethylene production Ambra nectarines
- Softening prediction (based on biological age) in Spring Belle nectarines and in Tommy Atkins mangoes

Non-destructive detection of internal disorders and defects

- **Browning in Granny Smith apples, Braeburn apples and Conference pears**
- **Watercore in Fuji apples**
- **Mealiness in Braeburn apples and Jonagored apples**
- **Chilling injuries in Jubileum plums and Morsiani 90 nectarines**

Nondestructive detection of internal defects
Brown heart in Conference pears



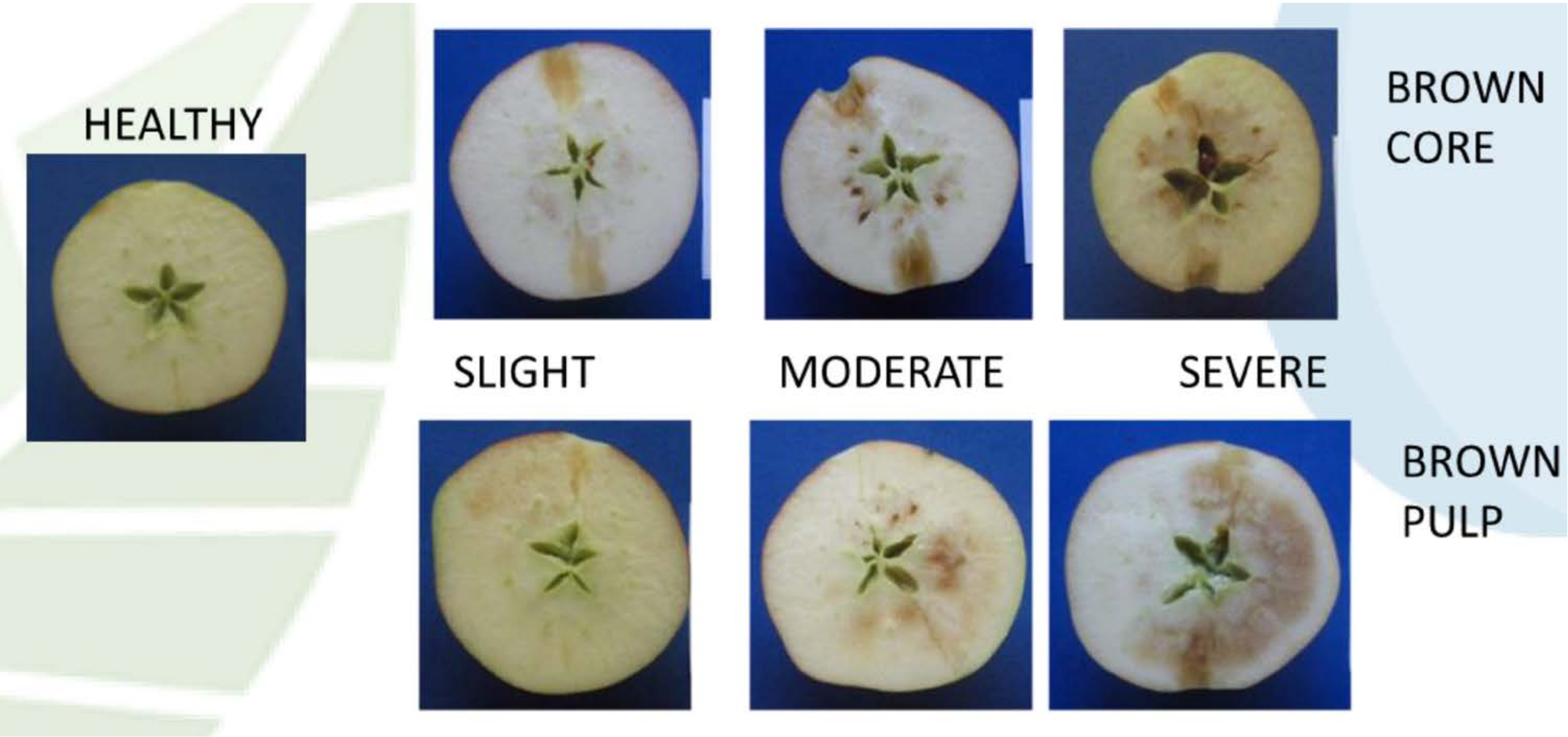


μ_a @ 720 nm

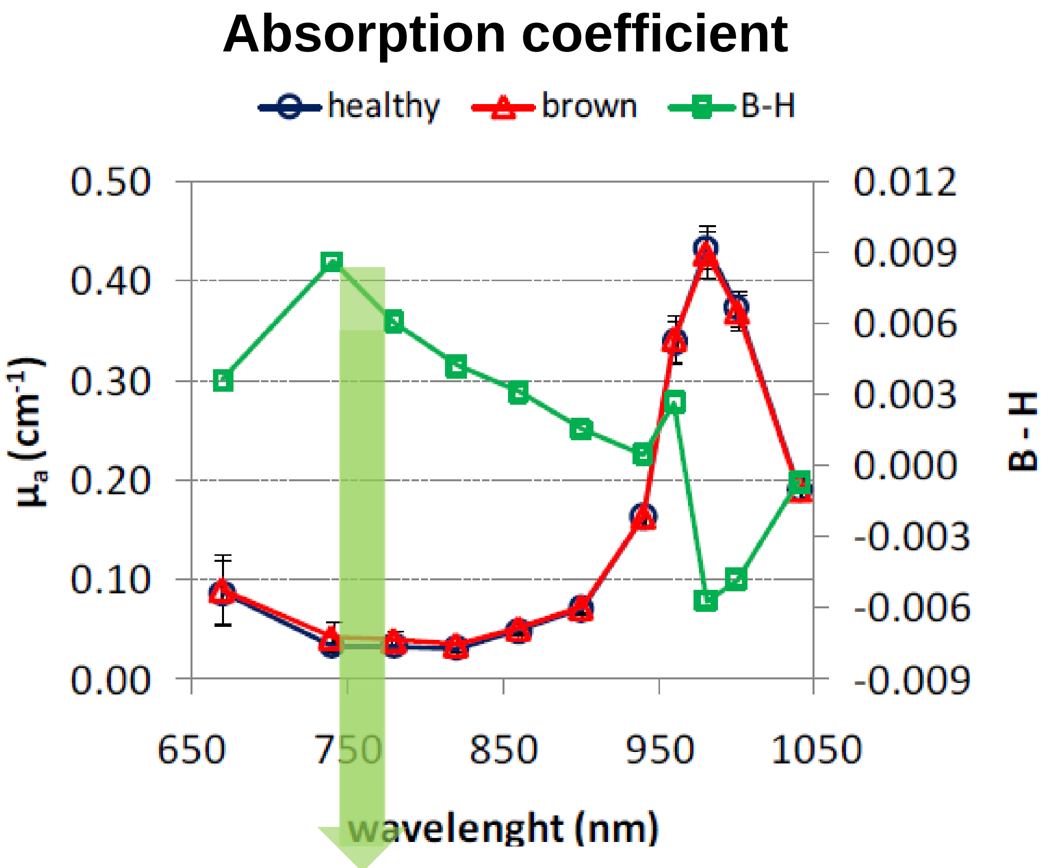
Brown heart for μ_a @ 720 nm > 0.04 cm^{-1}

Eccher Zerbini *et al.*, Postharvest Biology and Technology 25:87-99 (2002)

Internal browning in "Braeburn" apples



Non-destructive detection of internal defects
Internal browning in “Braeburn” apples



Largest differences between healthy and browned apples at 740-780 nm

μ_a @ 740-780 nm can be selected to distinguish healthy from browned apples

Classification table according to internal browning presence

Year	TRS variables	Classification table				
		Actual class	Group size	Healthy	Brown core	Brown pulp
2009	μ_a670, μ_a 740–1040, μ_s'780	Healthy	140	**56.4**	43.6	0.0
		Brown core	72	20.8	**66.7**	12.5
		Brown pulp	27	7.4	18.5	**74.1**
	μ_a780, μ_s'780	Healthy	140	**44.3**	55.7	0.0
		Brown core	72	19.4	**61.1**	19.4
		Brown pulp	27	7.4	18.5	**74.1**
2010	μ_a780, μ_s'780	Healthy	39	**89.7**	10.3	0.0
		Brown core	89	53.9	**42.7**	3.4
		Brown pulp	112	9.8	15.2	**75.0**

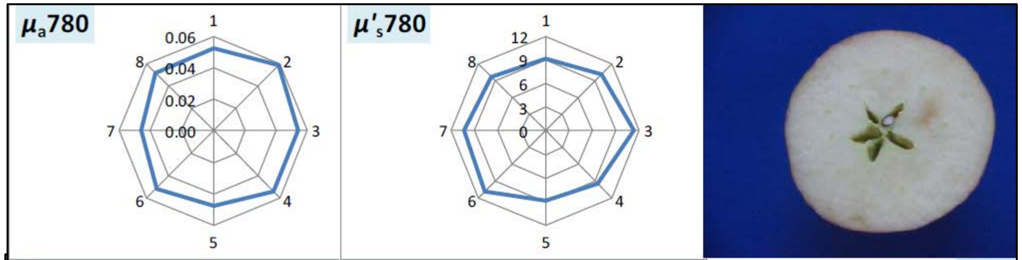
Classification models

Percentage of well classified apples

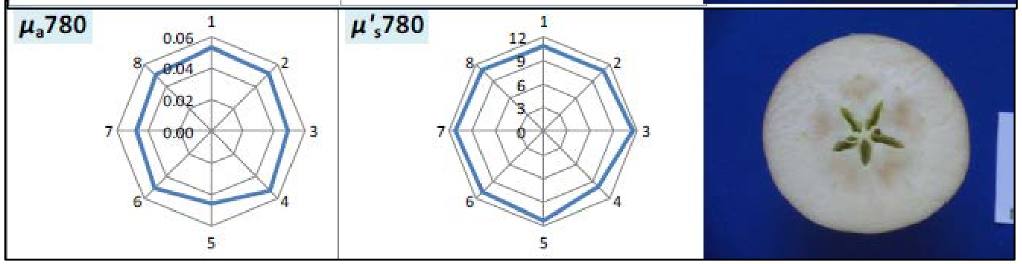
Overall, healthy apples and apple with internal browning are classified well in about 70% of the cases

Vanoli *et al.*, Postharvest Biology and Technology 91:112-121 (2014)

Non-destructive detection of internal defects
Internal browning in “Braeburn” apples

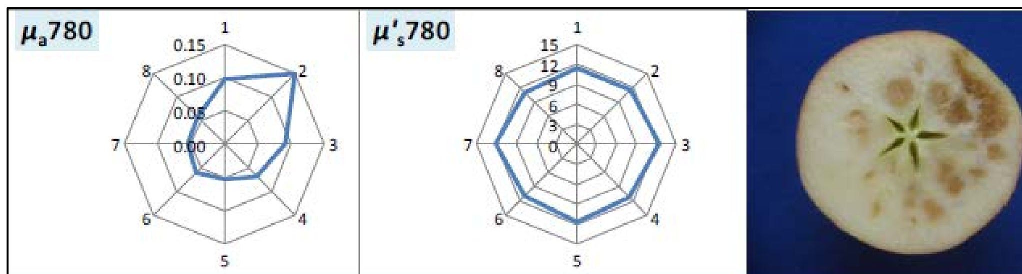


Brown core – well classified

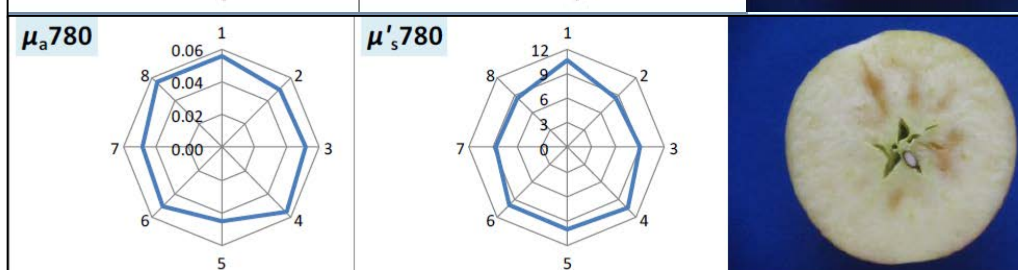


Brown core – misclassified

Brown pulp – well classified



Brown pulp – misclassified



Low temperature disorders limit the storage life of peaches and nectarines under refrigeration.

Chilling injury (CI) is classified as internal breakdown

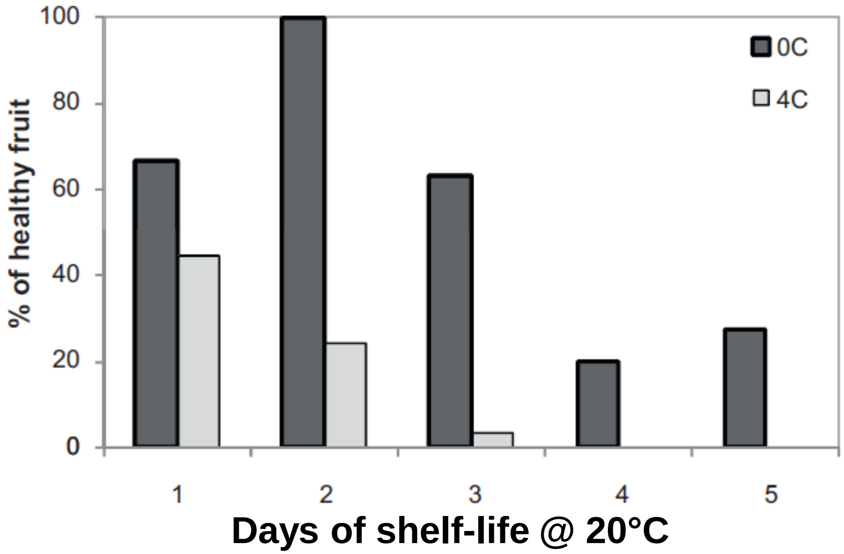
Wooliness

Internal browning

Internal bleeding (flesh reddening)

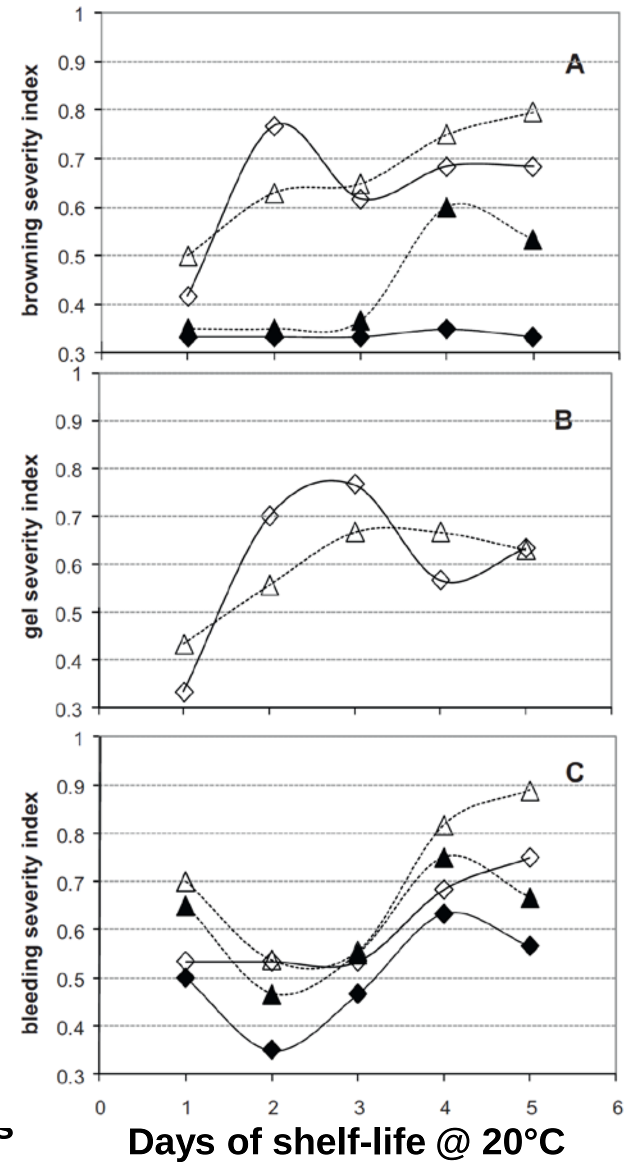
Fruit stored @ 0°C and 4°C for 4 weeks

Percentage of healthy fruit during shelf life



In fruit stored @ 4°C after 4 days there were no healthy fruit

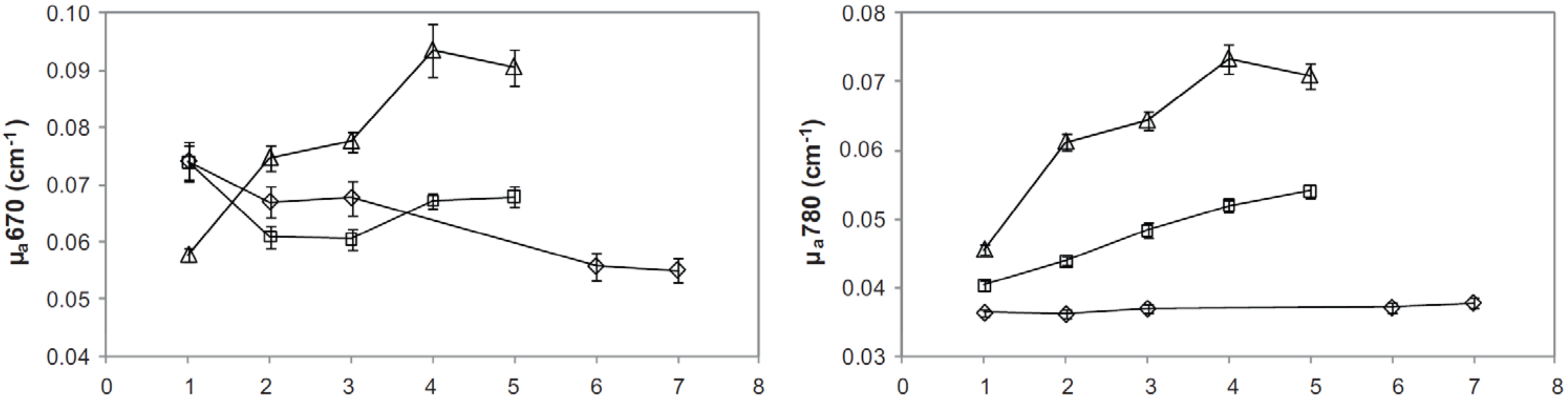
Close symbols → 0°C
Open symbols → 4°C



Severity index
0.3 → no fruit with defect
1.0 → all fruit with defects

Absorption coefficients

Diamonds → after harvest   Squares → after 0°C   Triangles → after 4°C



Days of shelf-life @ 20°C

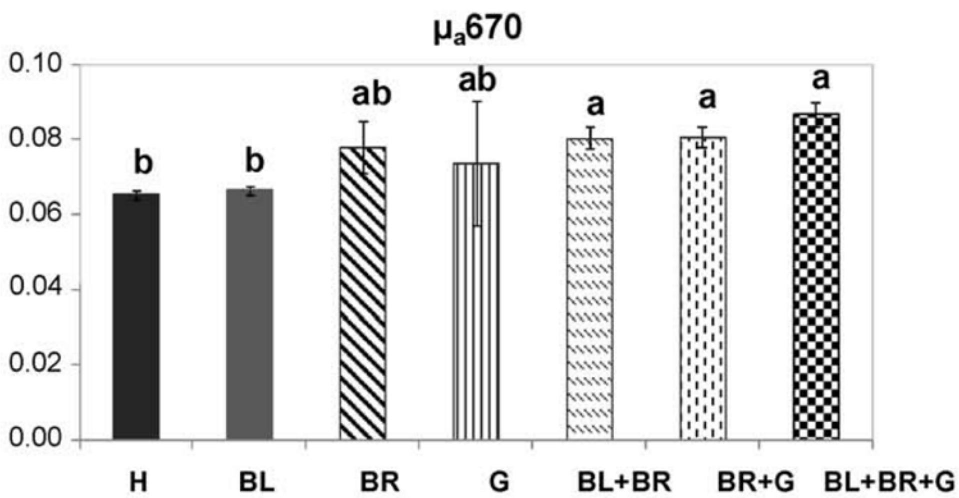
At harvest, μ_a @ 670 nm decreases due to fruit ripening

After storage @ 0°C, μ_a @ 780 nm increases

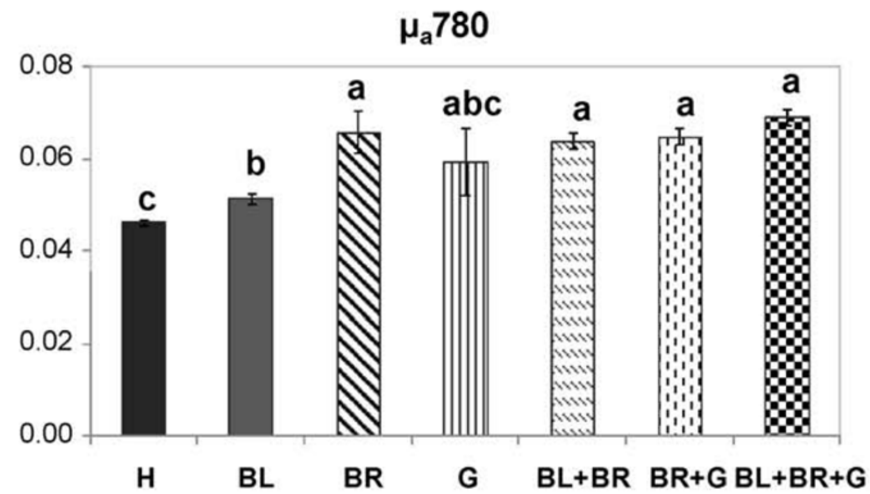
After storage @ 4°C, μ_a @ 670 nm and μ_a @ 780 nm increase

Lurie *et al.*, Postharvest Biology and Technology 59:211-218 (2011)

Absorption coefficients @ 670 and 780 nm



N_{fruit}	104	77	5	2	43	16	48



N_{fruit}	104	77	5	2	43	16	48

H – Healthy
BL – Internal bleeding
BR – Internal browning
G – Gel breakdown

μ_a @ 780 nm can distinguish healthy fruit from chilling injured ones

Lurie *et al.*, Postharvest Biology and Technology 59:211-218 (2011)

Chilling injury in stored plums

During cold storage plums are susceptible to developing **internal disorders**:

- **Flesh browning**
- **Jellying** (gel-like glassy structure)

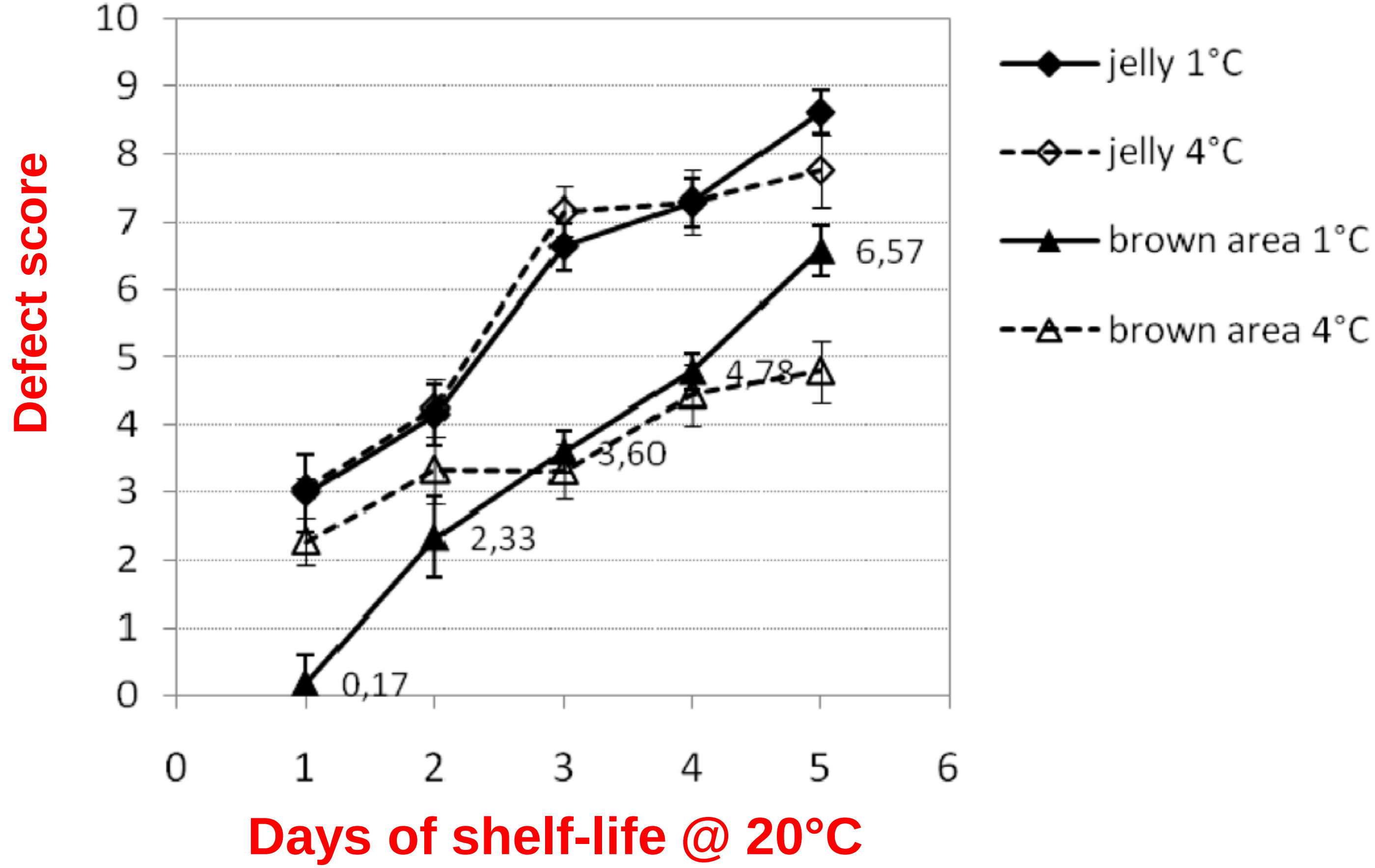
CI depends on cultivar, fruit maturity, orchard factors and storage temperature.

Healthy "Jubileum" plums

Flesh browning

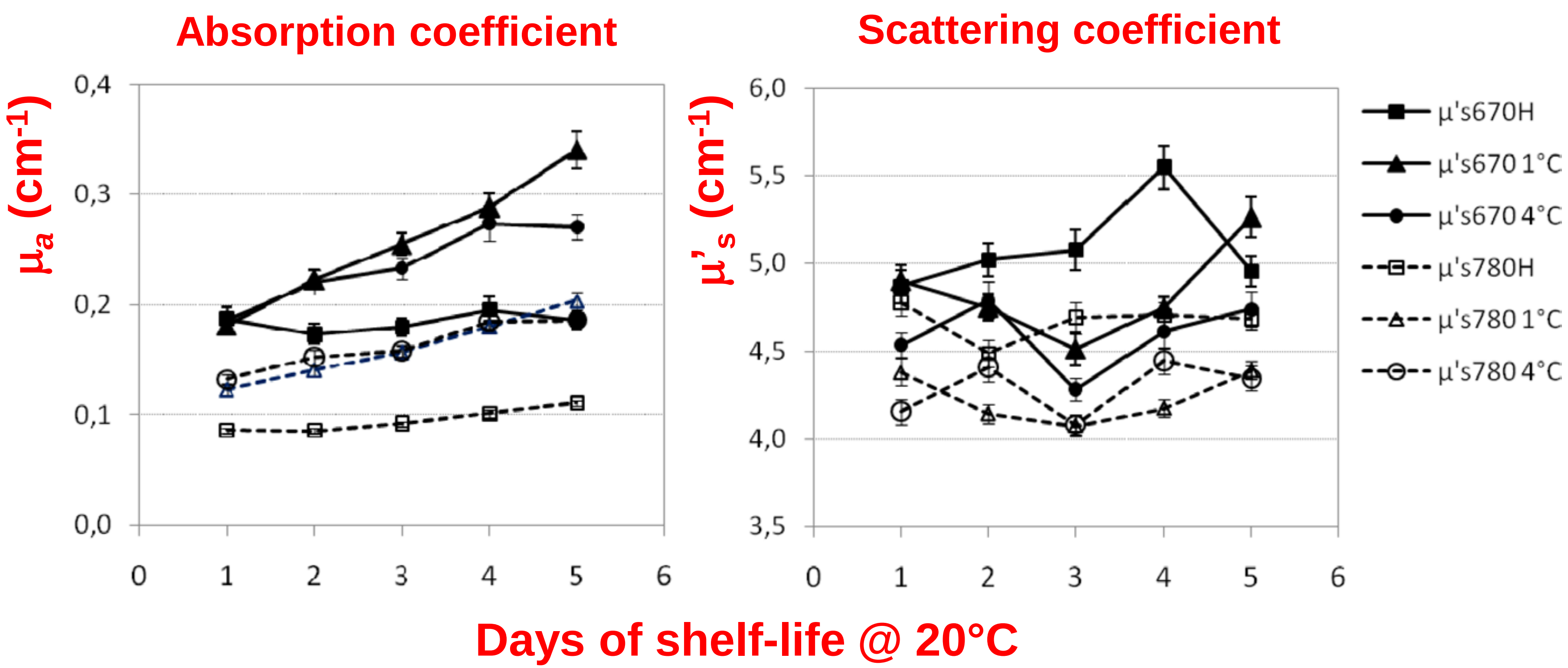
Jellying

Fruit stored @ 1°C and 4°C for 3 weeks



The amount of jellying and internal browning was graded on a scale ranging from 0 = healthy to 10 = 100% of affected area.

Vangdal *et al.*, Acta Horticolturae 945:197-203 (2012)



After storage, μ_a @ 670 nm and μ_a @ 780 nm increase during shelf life

This trend reflects the development of CI

Vangdal *et al.*, Acta Horticolturae 945:197-203 (2012)

Correlation coefficients between internal disorders and TRS parameters after storage at 1°C and 4°C (n = 275).

Parameters		Jellying (0-10 scale)	Browning area (0-10 scale)
TRS parameters	$\mu_a 670$	0.68***	0.77***
	$\mu_a 780$	0.70***	0.76***
	$\mu'_s 670$	-0.01 n.s.	0.03 n.s.
	$\mu'_s 780$	-0.06 n.s.	-0.09 n.s.

*** p<0.001; n.s.=Not significant correlation at 5% level.

- **μ_a @ 670 nm and μ_a @ 780 nm can distinguish healthy fruit from those affected by internal disorders**
- **Reduced scattering coefficients not influenced by CI development**

Vangdal *et al.*, Acta Horticolturae 945:197-203 (2012)

Photonics for Food @ PoliMi
Research activities

Projects

- DIFFRUIT, EU FP4, 1996-1999
- TRS APPLE, MAFF (UK), 2000
- AGROTEC, MIUR (I), 2000-2002
- CUSBO, LASERLAB, EU FP5+FP6+FP7, 2004-2014
- INSIDEFOOD, EU FP7 2009-2013
- TROPICO, Regione Lombardia (I), 2010-2012
- 3D Mosaic, EU ICT-AGRI, 2011-2013
- USER-PA EU ICT-AGRI 2013-2016
- MONALISA 2014-2016

Publications (2001-2013)

- >30 papers published on peer reviewed international journals
- >30 papers on international books and proceedings
- >30 talks on international conferences

Collaborations

- CREA-IT, Milan (I), Anna Rizzolo, Maristella Vanoli, Maurizio Grassi
- Laimburg (I), Angelo Zanella
- Agricultural Research Organization, Bet Dagan (Israel), Susan Lurie, Victor Alchanitis
- Wageningen Universiteit (NL), Pol Tijskens, Olaf Van Kooten, Rob Schouten
- Planteforsk, Lofthus (N), Eivind Vangdal
- Potsdam (D), Manuela Zude-Sasse
- Leuven (B), Bart Nicolai, Bert Verlinden, Wouter Sayes, Pieter Verboven, Maarten Hertog
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  - Maristella Vanoli
  - Maurizio Grassi
  - (Paola Eccher Zerbini)

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