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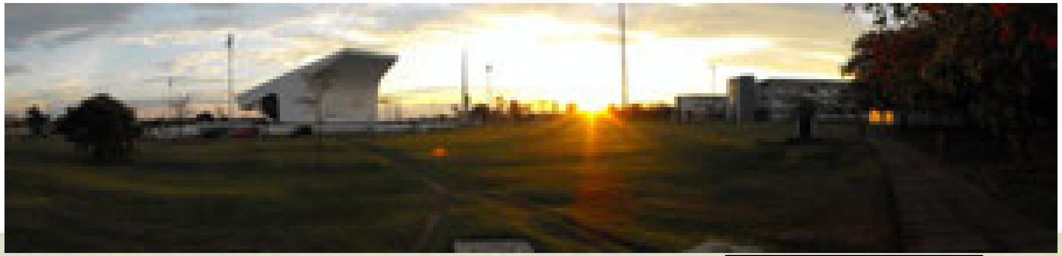
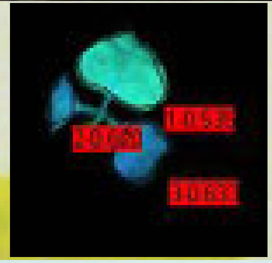
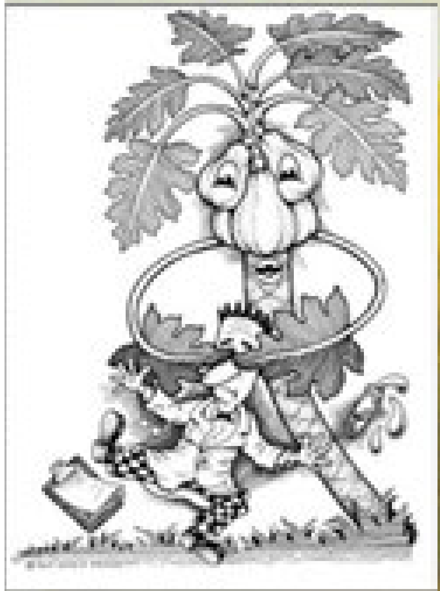
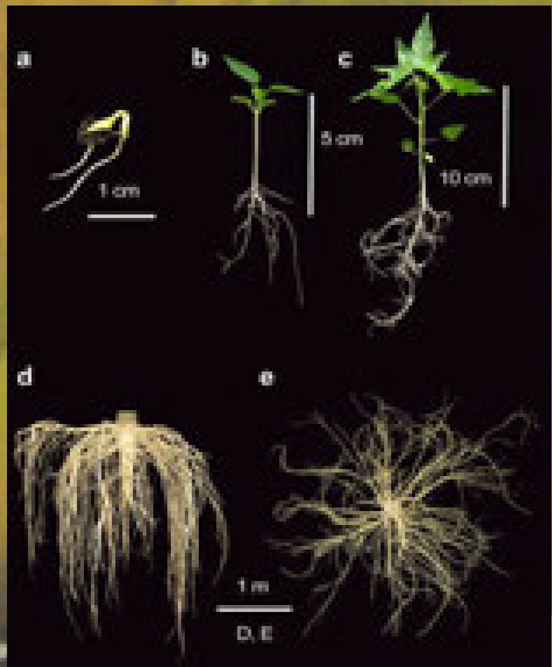
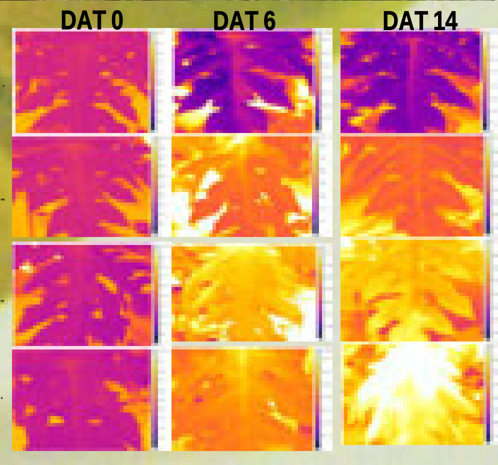






Ecophysiology of papaya
(Carica papaya L)





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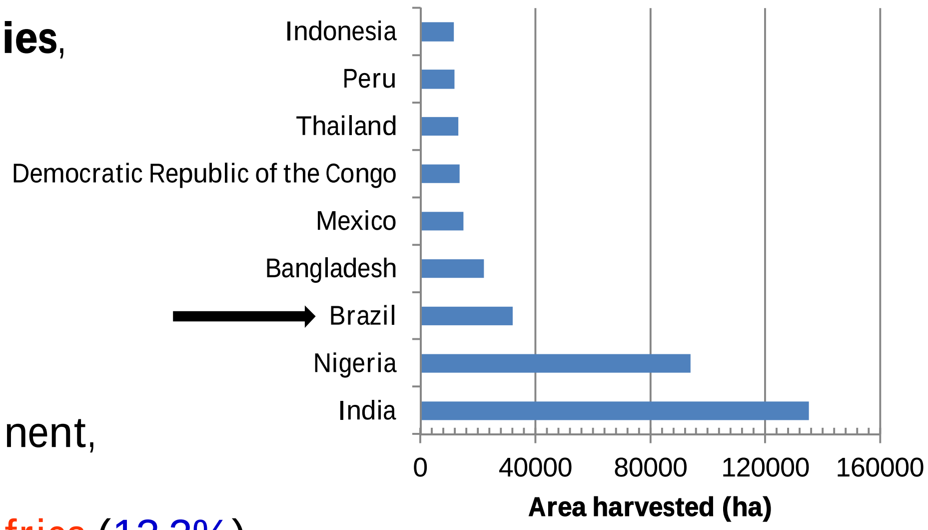
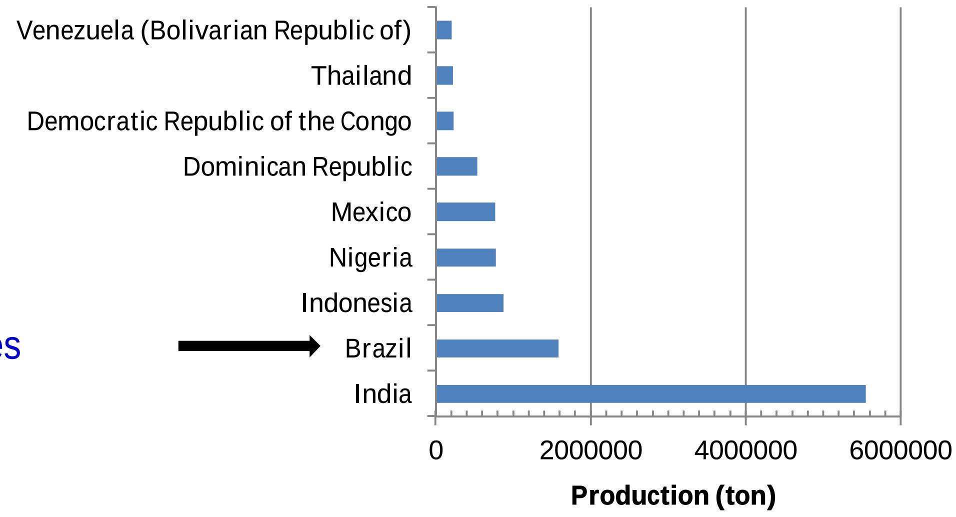
Papaya (*Carica papaya* L.) is a principal horticultural crop of tropical and subtropical regions (Campostrini et al, 2010).

Papayas are produced in about **60 countries**, with the bulk of production occurring in developing economies!



Faostat 2015:
Area harvested in the world: 441,042 ha
Brazil: 31,989 ha (**7.3%**)

Asia is the largest papaya-producing continent, providing 55.5% of the total production, followed by South America (23.0%) and Africa (13.2%)

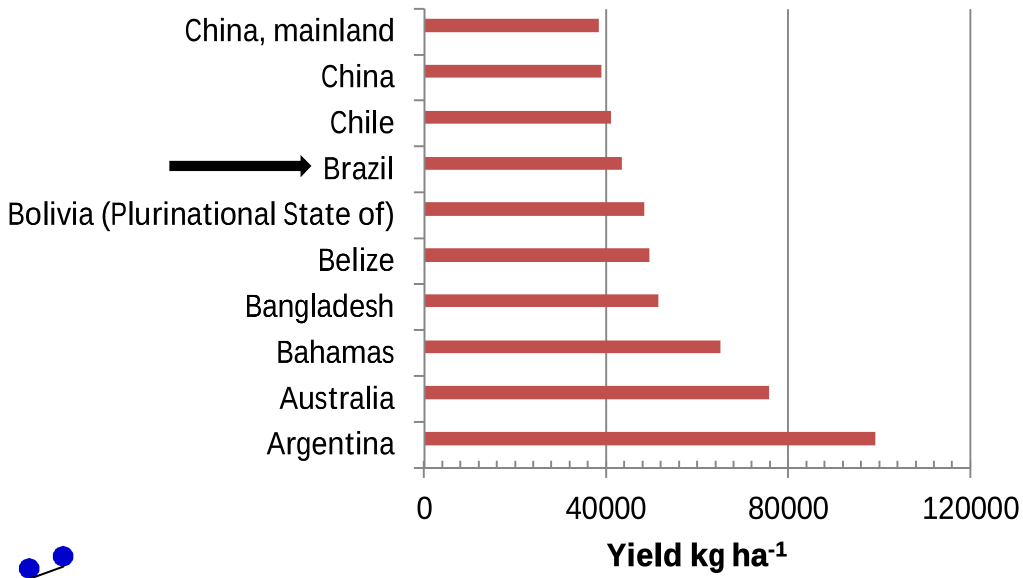


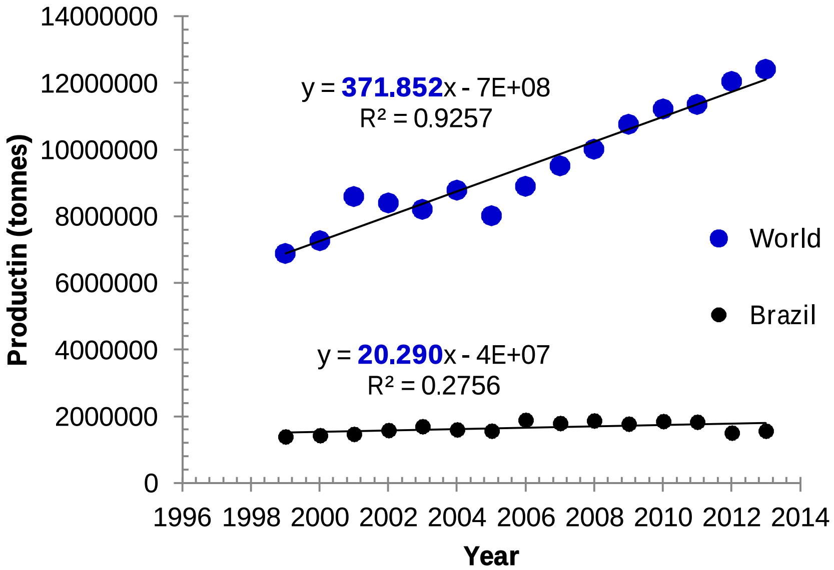
Production in the world: 12,420,584 tonnes
Brazil:1,582, 638 ton (**13%**)

Papaya (*Carica papaya* L.) is a principal horticultural crop of tropical and subtropical regions.

Faostat 2015:

Yield in the world: 28,161 kg ha^{-1}
Brazil: 43,333 kg ha^{-1} (**65% higher!**)





Faostat 2015:

World-wide production of papaya has been increasing approximately 372,000 tonnes year^{-1}(FAOSTAT, 2015)
Brazil has been increasing 20.290 tonnes per year!!

Gaining in popularity worldwide, papaya is now ranked third with 11.22 Mt, or 15.36 percent of the total tropical fruit production, behind mango with 38.6 Mt (52.86%) and pineapple with 19.41 Mt (26.58%)

Total tropical fruit production:

Mango – 52.86%
Pineapple – 26.58%
Papaya – 15.36% (Evans e Ballen, 2012)

Papaya in Europe:

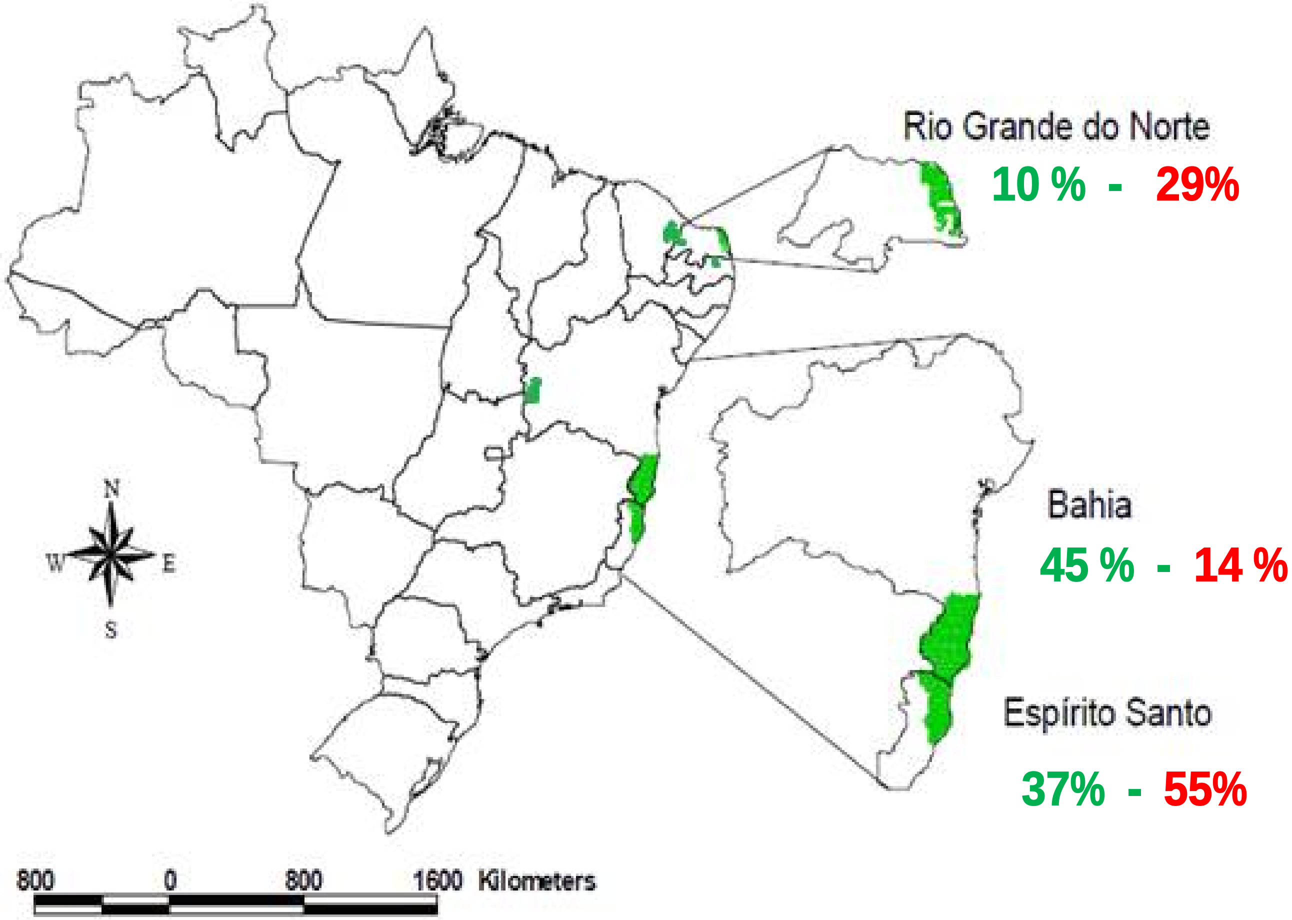
-Tropical fruits are grown in very limited countries in Europe due to the climatic constraints

-However, some of them are grown due to a favorable climate on the Mediterranean coast and Atlantic Islands for local consumption (Voth, 2000)

-Papaya is cultivated under protected cultivation in subtropical country such as the Canary Islands (Spain) (Galan Sauco et al. 2008).

-However, global climate changing should cause an increase in air temperature, and will be expected that cultivation of papaya will be expanded in the subtropical regions in Europe and Asia

Region of Production



Production - Exportation

Brazilian Exportation Company

Espírito Santo state
-Caliman
-Frutasolo
-Frutamel
-Interfruit
-UGBP
-Marin papaya

Bahia state
-Frutas Belo

Rio Grande do Norte state (Formosa group) (Semi-arid)(400 mm per year)
-WG Fruticultura
-Agrícola Famosa

Production cost

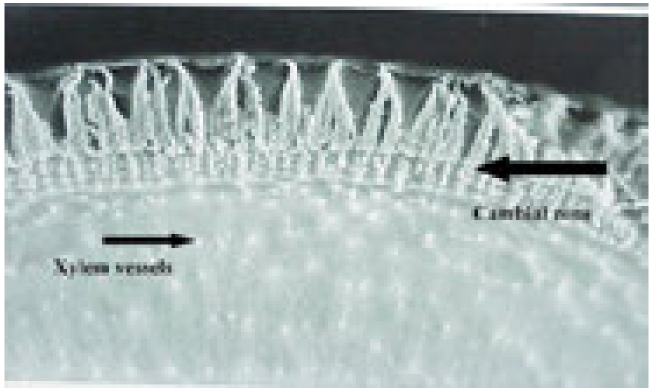
Cultivation		Valor - Euro
month 1		755.2
month2		278.6
month 3		314.1
month 4		234.5
month 5		228.6
month 6		298.8
month 7		221.3
month 8		238.6
TOTAL		2,570.5

	ud	Valores - euro
Starting	Euro ha^{-1}	2,570.5
Production	Euro ha^{-1}	5,133.0
Total	Euro ha^{-1}	7.704.3
Yield	T ha^{-1}	68.58
Production cost	Euro kg^{-1}	0.11
Price average	Euro kg	0.13
Profitability	%	15.31%

water

Consumo de água (litros/planta/dia) nas condições do norte do ES – Caliman (2003 a 2010)								
GOTEJAMENTO								
Idade da planta - dias		l/planta/dia			Consumo de água - l			Total
inicio	fim	dez/fev	mar/abr e out/nov	mai/set				
0	30	6.00	5.00	3.00	549.00	610.00	450.00	1.609.00
30	60	10.00	8.00	5.00	915.00	976.00	750.00	2.641.00
60	90	12.00	9.00	6.00	1.098.00	1.098.00	900.00	3.096.00
90	120	15.00	13.00	8.00	1.372.50	1.586.00	1.200.00	4.158.50
120	360	16.00	14.00	10.00	1.464.00	1.708.00	1.500.00	4.672.00
360	720	16.00	14.00	10.00	1.464.00	1.708.00	1.500.00	4.672.00
				406.01	PEGADA HIDRICA AZUL			20.848.50
chuva - mm	1.200.00			252.39	PEGADA HIDRICA VERDE			12.960.00
l/m2	6.480.00							33.808.50
espaçamento	3.6 x 1.5						l/kg/ciclo	658.39
Produção - kg/planta	51.35							
MICROASPERSÃO								
inicio	fim	dez/fev	mar/abr e out/nov	mai/set				
0	30	8.00	6.00	4.00	732.00	732.00	600.00	2.064.00
30	60	12.00	10.00	6.00	1.098.00	1.220.00	900.00	3.218.00
60	90	12.00	11.00	8.00	1.098.00	1.342.00	1.200.00	3.640.00
90	120	18.00	16.00	10.00	1.647.00	1.952.00	1.500.00	5.099.00
120	360	20.00	17.00	12.00	1.830.00	2.074.00	1.800.00	5.704.00
360	720	20.00	17.00	12.00	1.830.00	2.074.00	1.800.00	5.704.00
				495.21	PEGADA HIDRICA AZUL			25.429.00
chuva - mm	1.200.00			252.39	PEGADA HIDRICA VERDE			12.960.00
l/m2	6.480.00							38.389.00
espaçamento	3.6 x 1.5						l/kg/ciclo	747.59
Produção - kg/planta	51.35						aumento %	11.93%

Papaya plant



-Semi-woody (an intermediate position between herbs and trees)
-Latex-producing

-Usually single-stemmed

-Reproductive precocity (3-4 months)

-High photosynthetic rates **(≈26 μmol m^{-2} s^{-1} - field condition in 2000 μmol m^{-2} s^{-1} PAR)**
-café: 8- 9 μmol m^{-2} s^{-1}
-milho: 40-50 μmol m^{-2} s^{-1}
-feijão: 12 μmol m^{-2} s^{-1}
-arroz: 13 μmol m^{-2} s^{-1}
-cana de açúcar: 40-50 μmol m^{-2} s^{-1}
-banana: 12 μmol m^{-2} s^{-1}
-abacaxi: 7 μmol m^{-2} s^{-1}

-fast growth
-production of many seeds
'Solo' group: **270 seeds per fruit (5g)**
'Formosa' group: **350 seeds per fruit (17g)**

-Low construction cost of hollow stems

-Continuous fruit production
(indeterminate growth)

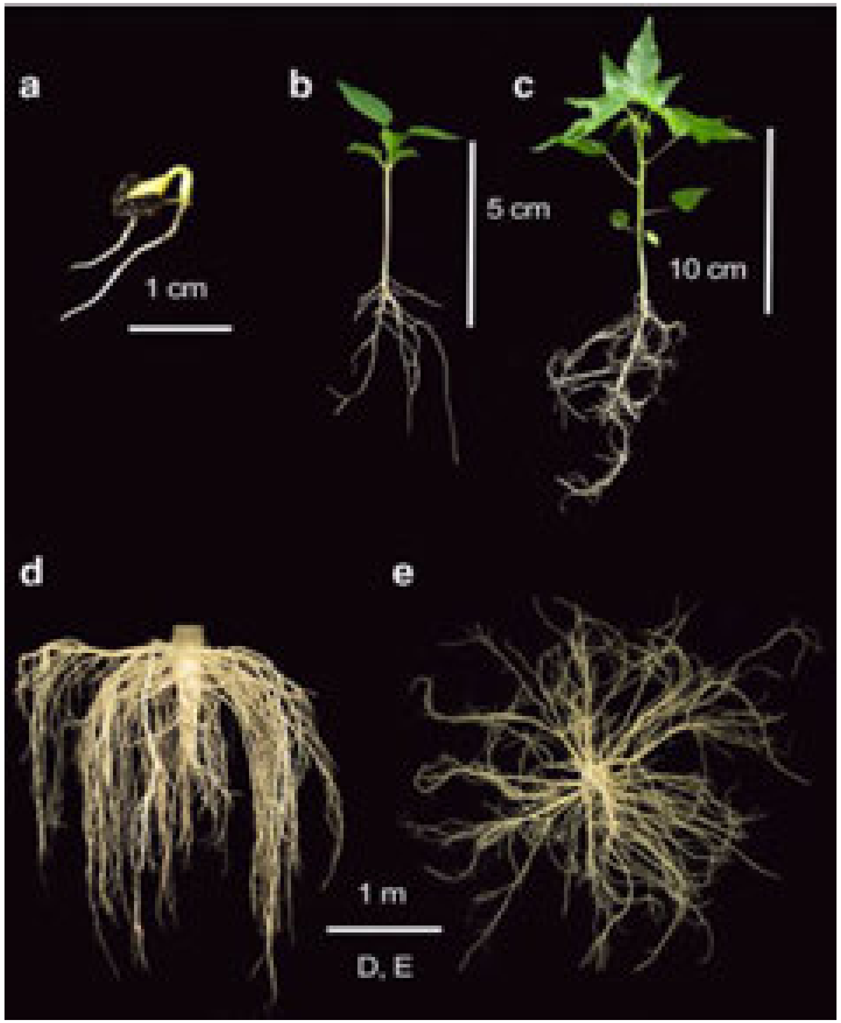
Papaya plant

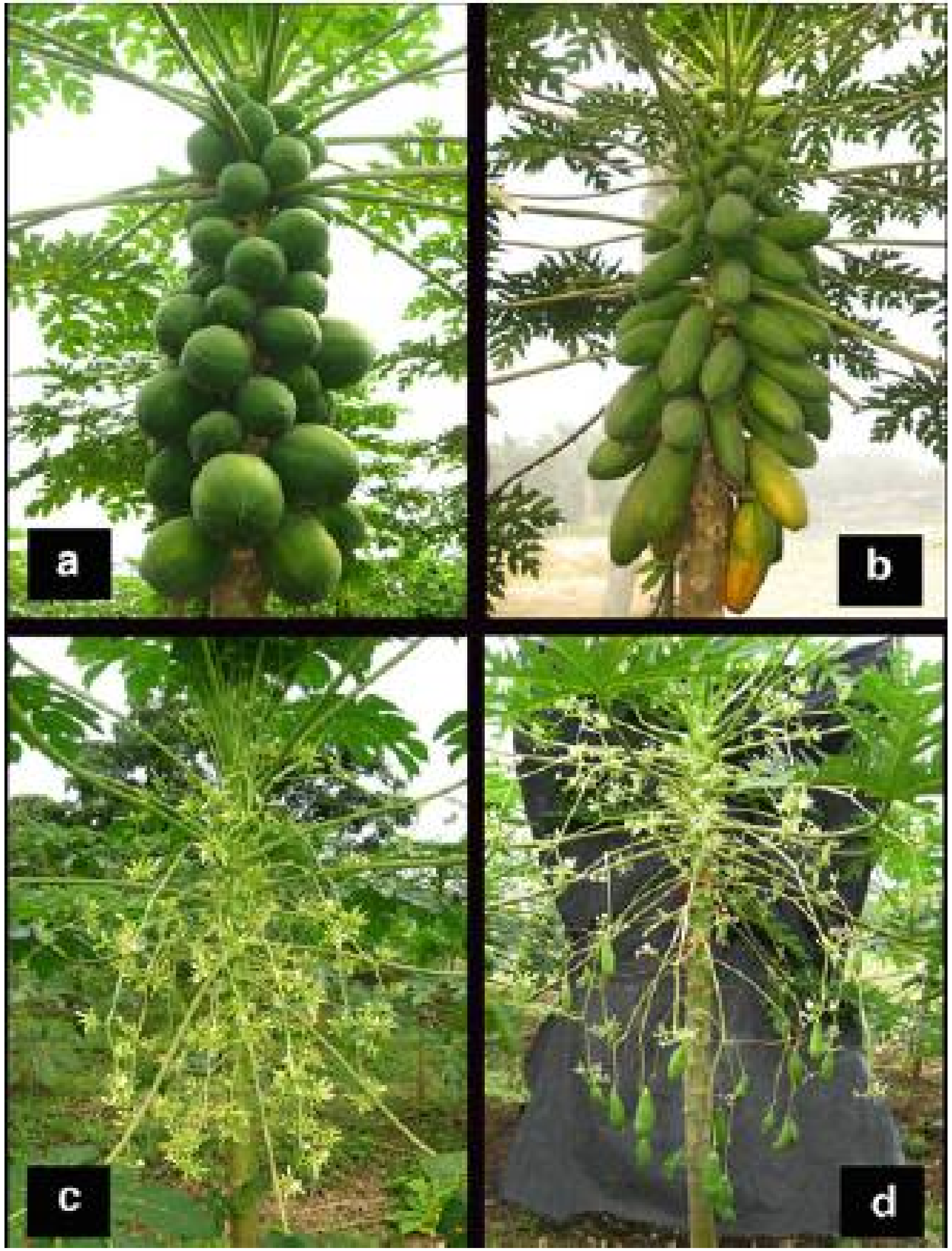
Springer

Genetics and Genomics of Papaya
Ming, R., Moore, P.H. (Eds.)

Chapter 2
Biology of the Papaya Plant

Víctor M. Jiménez, Eric Mora-Newcomer, and Marco V. Gutiérrez-Soto



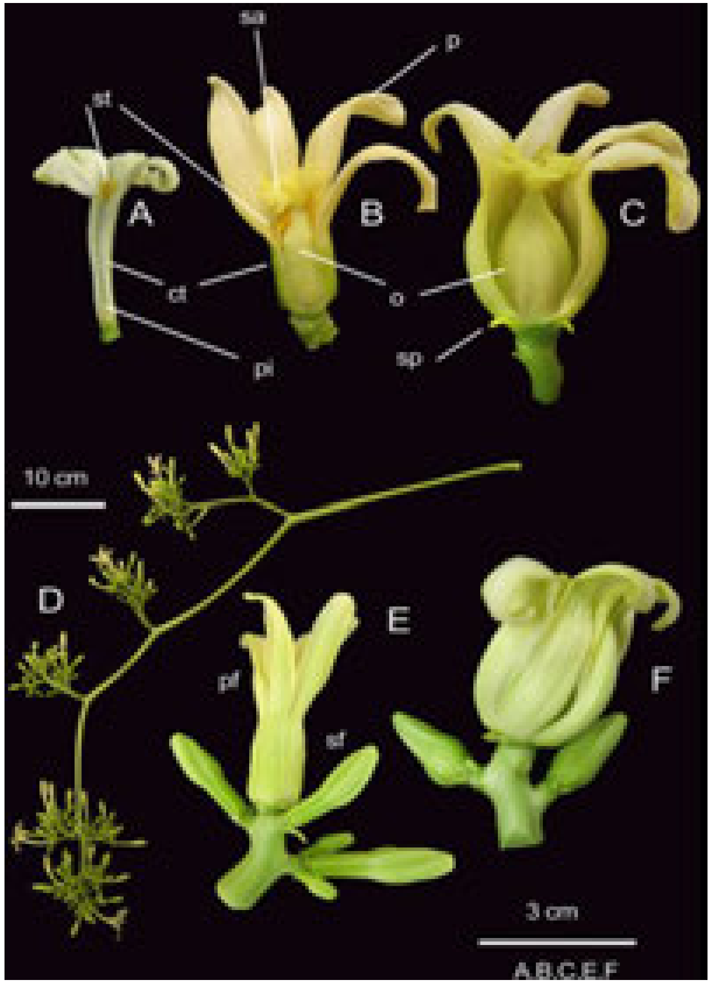


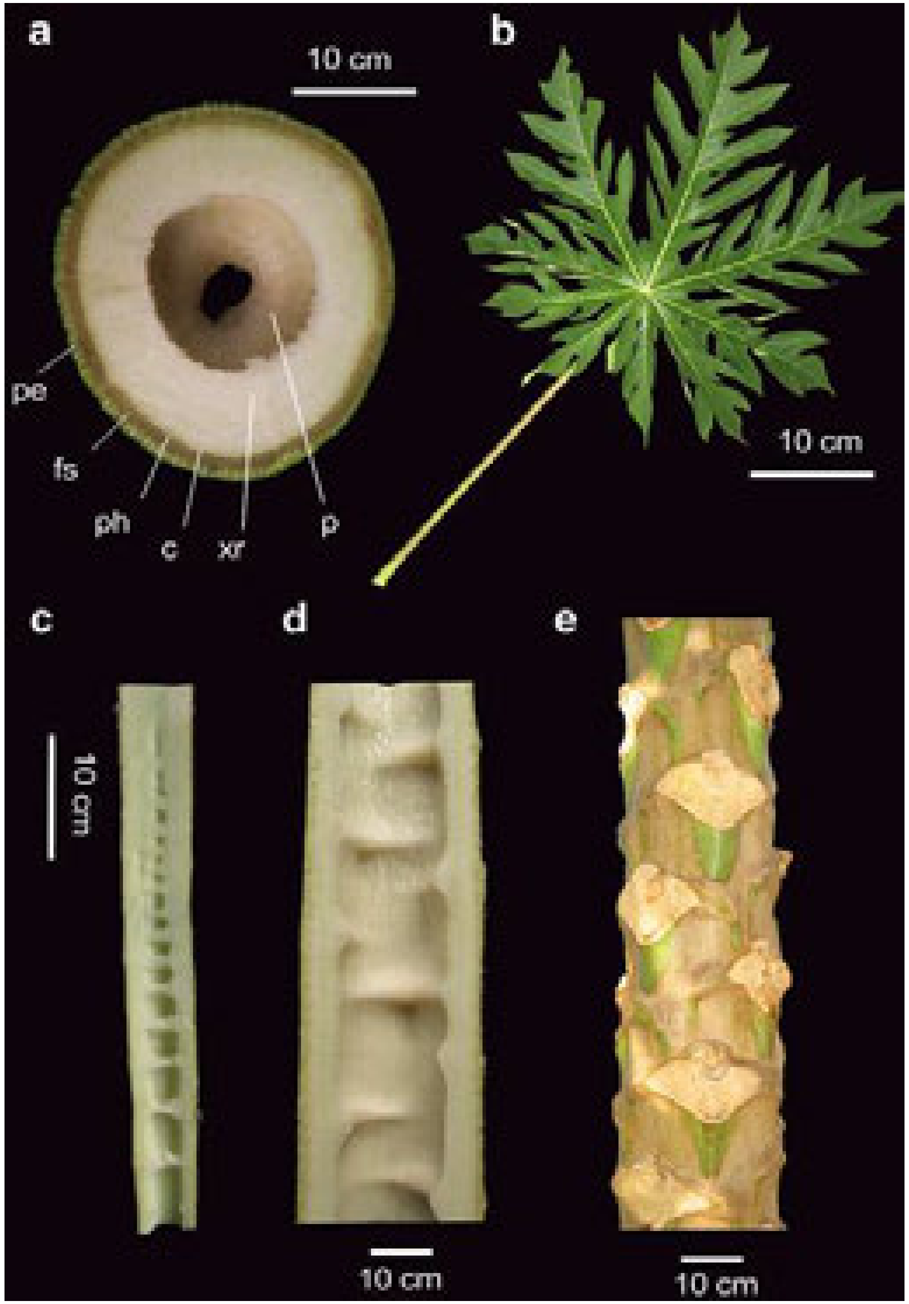
Papaya plant

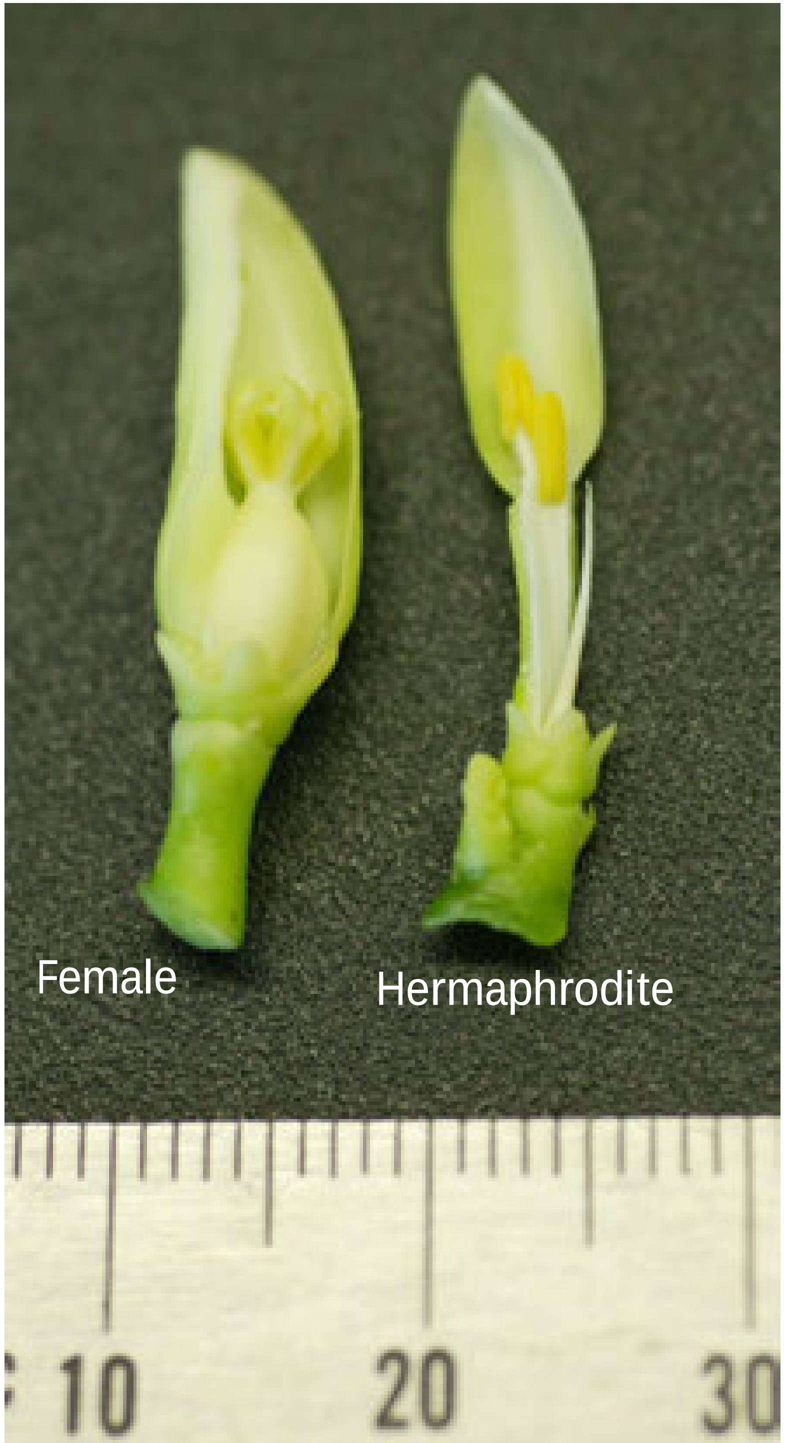
Papaya plant

Chapter 2
Biology of the Papaya Plant

Víctor M. Jiménez, Eric Mora-Newcomer, and Marco V. Gutiérrez-Soto



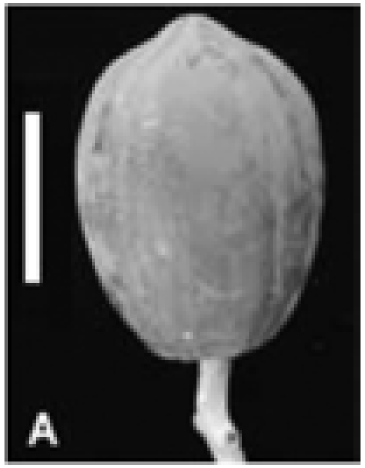


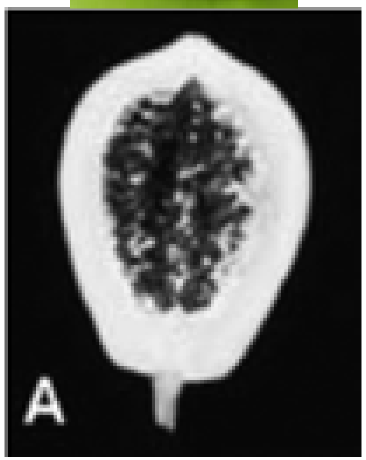

Female
Hermaphrodite
10
20
30

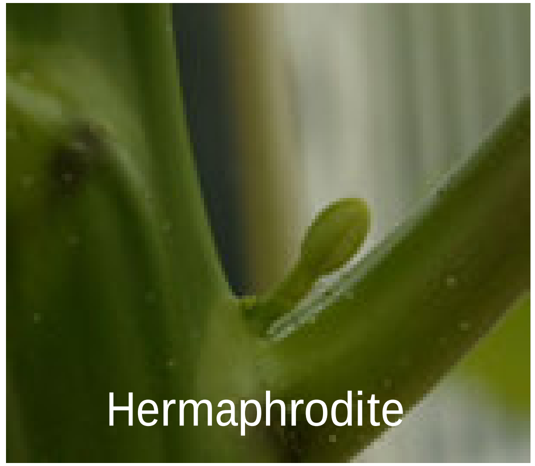

TopTropicals.com
© EleNZ
Male

reduced pulp/volume ratio

high pulp/volume ratio







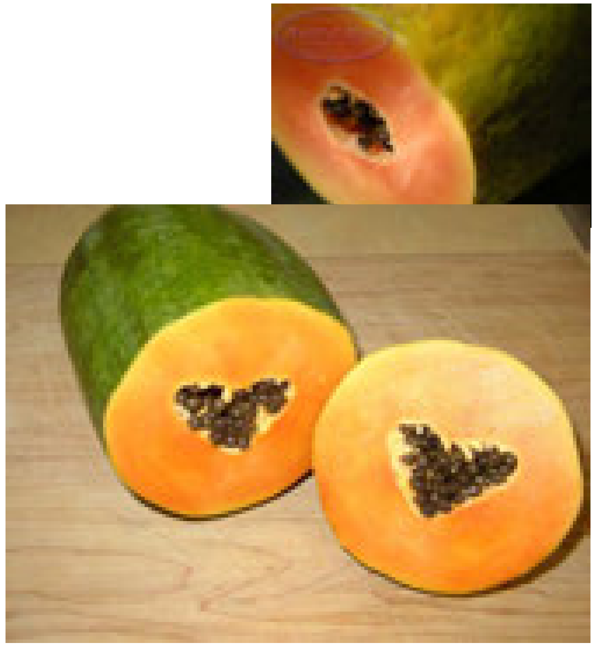
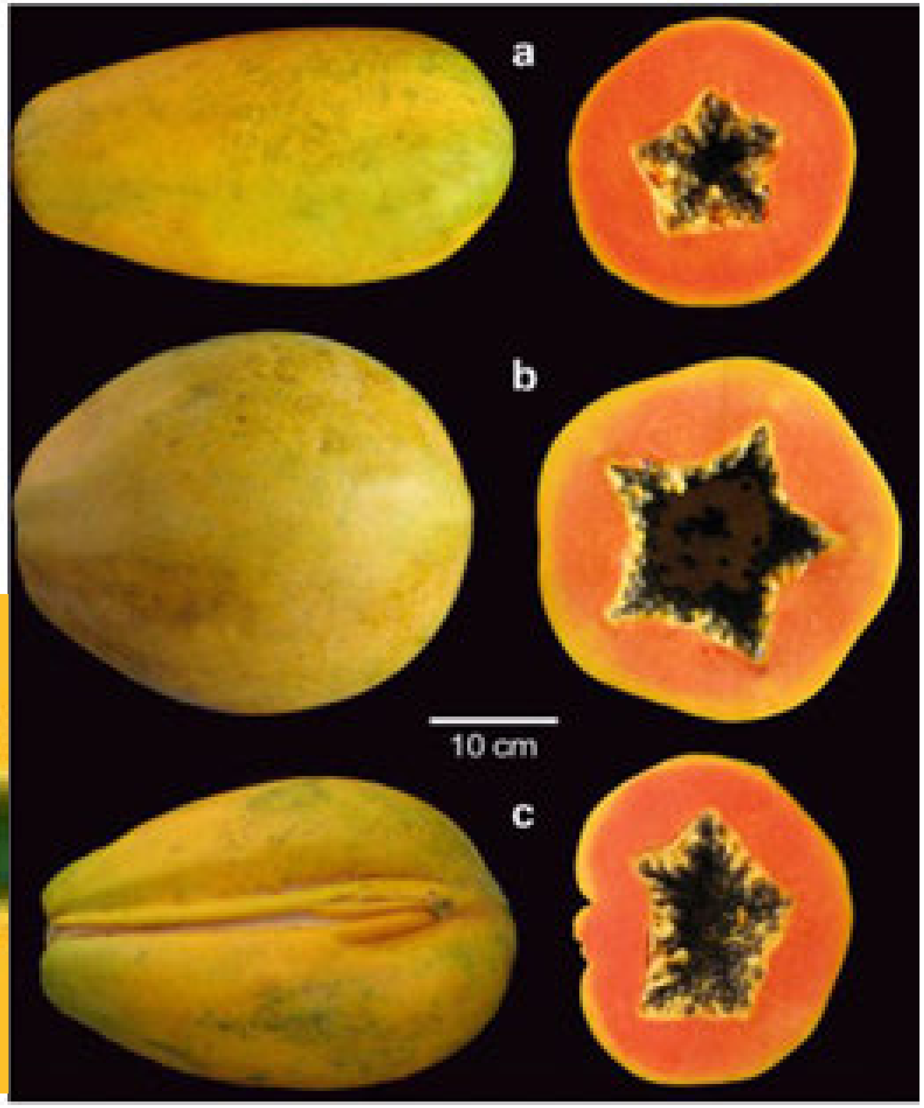
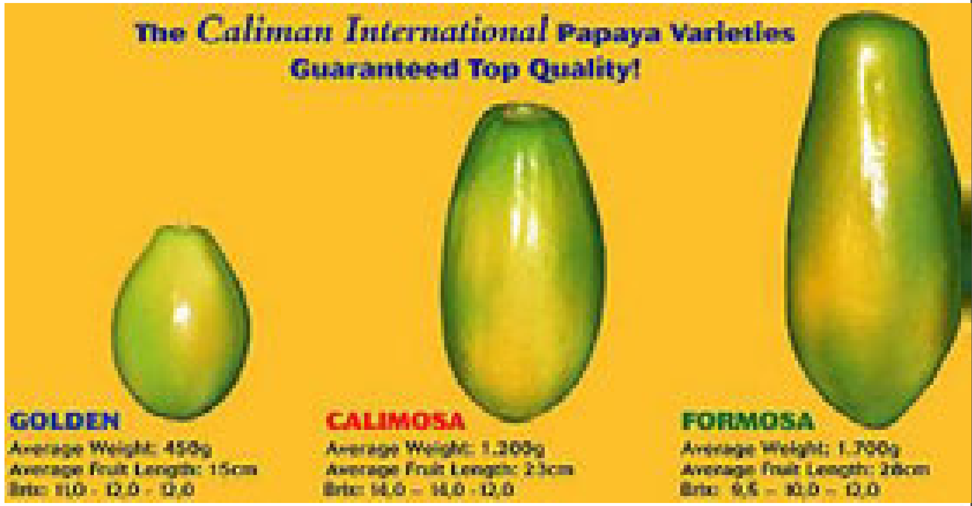


Fig. 2.6 Papaya fruits according to sex type. (**a**) Fruit of a hermaphroditic plant. (**b**) Fruit from a female plant. (**c**) Misshapen fruit from a hermaphroditic plant due to carpellody





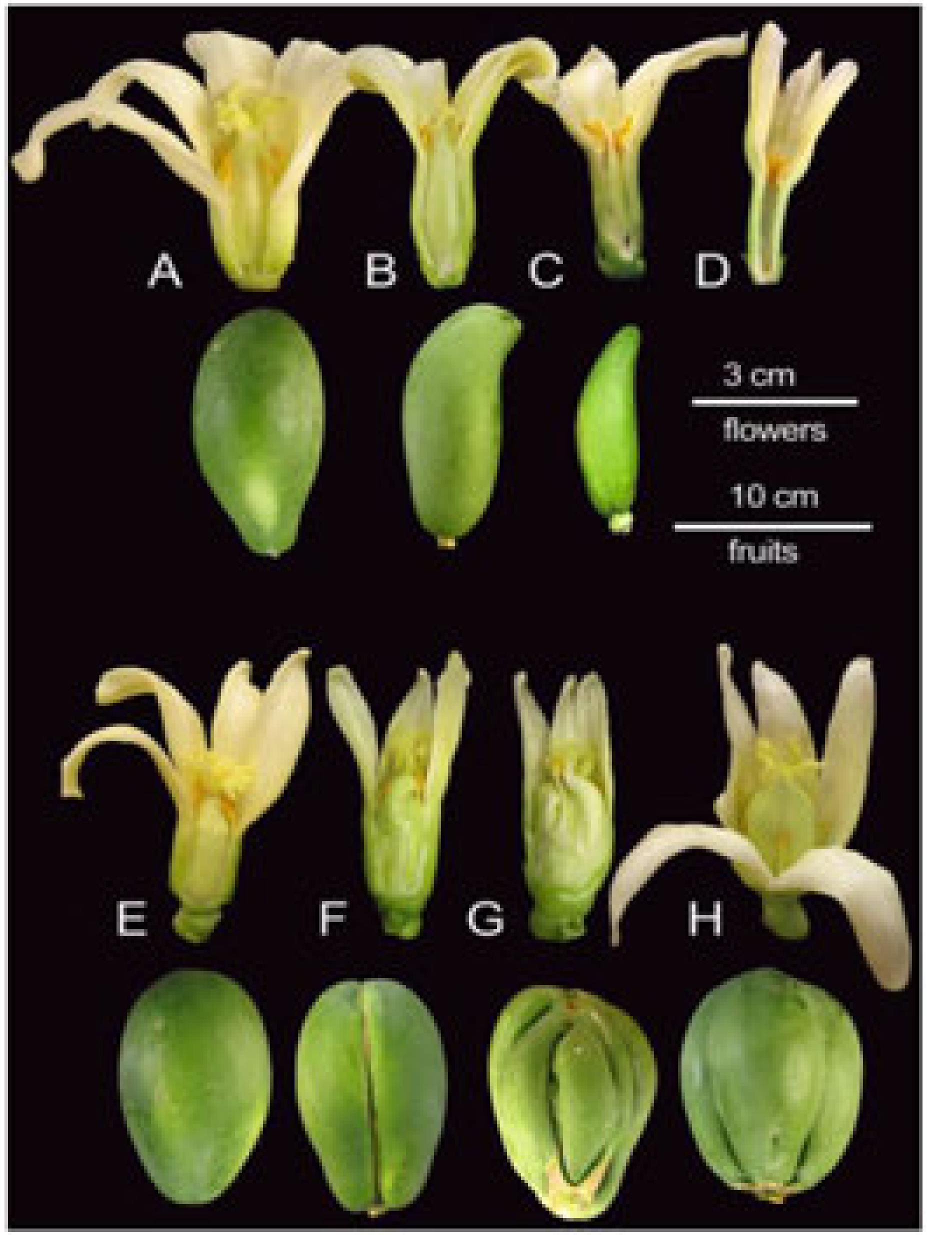


Fig. 2.5 Female sterility and carpellody of papaya. (**a–d**) Gradual reduction in pistil size due to female sterility of flowers and approximate phenotype of the corresponding fruit. (**a**) Normal elongata flower with five carpels. (**b**, **c**). Reduced ovary due to loss of carpels as a result of partial female sterility. (**d**) Completely female sterile flower. (**e**, **f**) Increasing levels of carpellody and approximate phenotype of corresponding fruit. (**e**) Normal elongata flower. (**f–g**) Fusion to the ovary and partial transformation to carpels and of one (**f**) and two (**g**) stamens, leading to misshapen fruits. (**h**) Complete transformation of the five antepetalous whorl of stamens into carpels, leading to the "pentadria" type of flower, with a rounded ovary (and fruit) and almost free petals

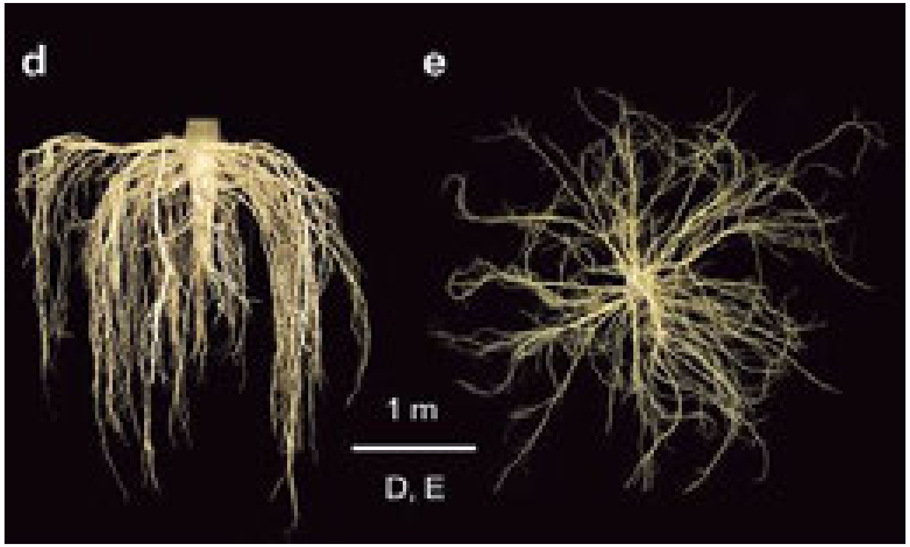
Root

Plant and Soil **195**: 37–42, 1997.

Root development of 'Red Lady' papaya plants grown on a hillside

Thomas E. Marler & Haluk M. Discekici
*College of Agriculture and Life Sciences, 303 University Drive, University of Guam, Mangilao, Guam 96923, USA**

Shape of the root system influences the nutrient and water uptake capabilities of a plant. Therefore, knowledge of the root distribution of papaya plants is useful for determining suitable placement of cultural inputs such as fertilizer or sensors for monitoring soil moisture depletion. Substrate aeration is highly controlling of papaya plant physiology and growth (Marler et al., 1994). Thus, we hypothesized that lateral roots on the uphill side of papaya plants growing on a hillside would ascend into the more favorably aerated surface soil, rather than maintain a 90° inclination angle or cease growing altogether. In non-saturated soil conditions negatively gravitropic roots ensure root proliferation in the better aerated soil surface (Jackson, 1985).



Root ⇒ 70 a 75% in 30cm ⇒ 1 year old ≈ 3.5 m

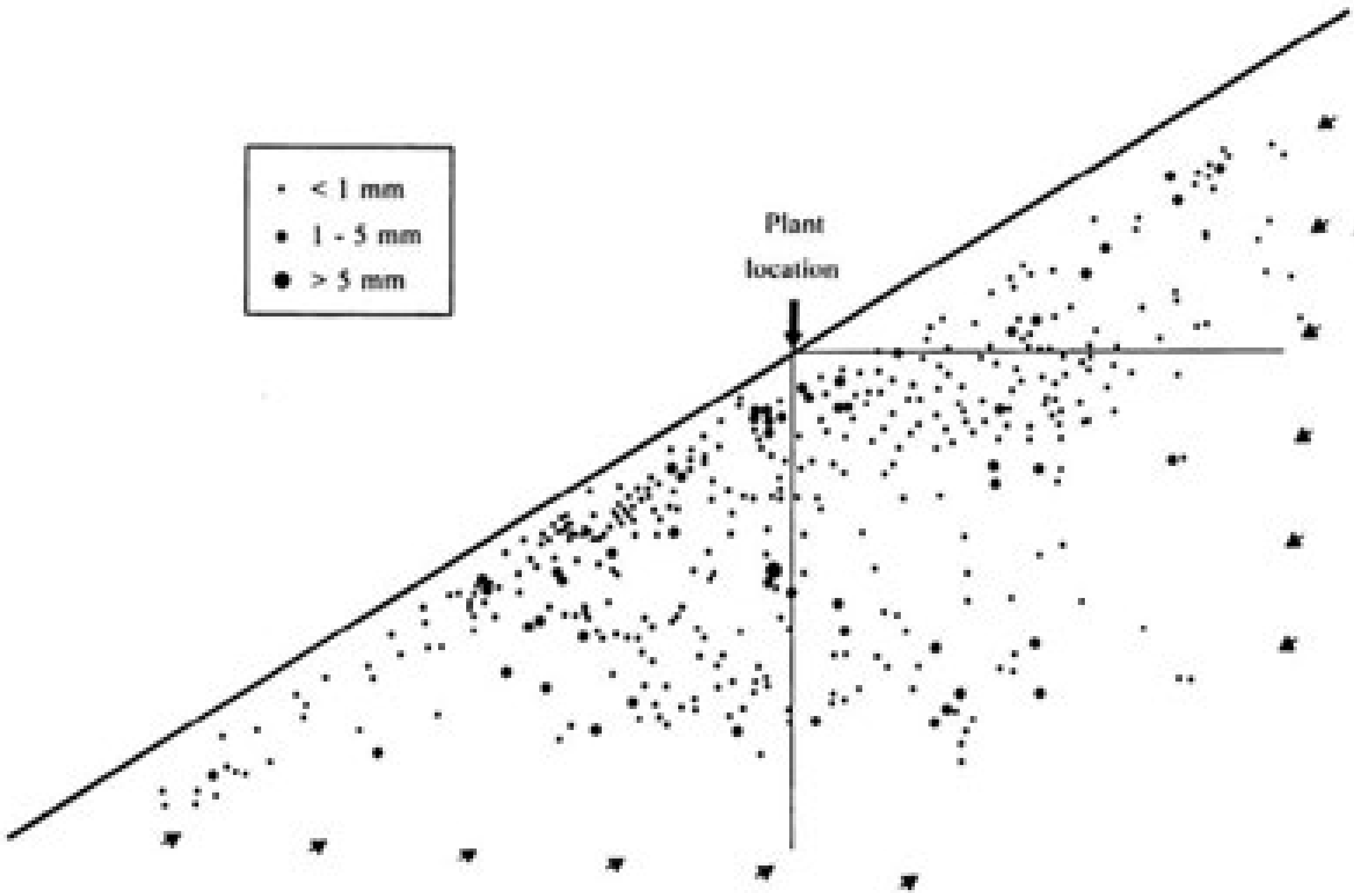


Figure 2. Scaled root map of a 'Red Lady' papaya plant 17 weeks after transplanting to a hillside with a 62% slope. The heavy line indicates the hillside surface. The vertical arrow indicates plant location. The arrows below the hillside surface indicate 15-cm depth increments which are parallel to the surface. The vertical line indicates position of the taproot system. The horizontal line depicts the horizontal plane positioned at the stem base.

Table 2. Root characteristics of 'Red Lady' papaya plants growing on a hillside with a 60% to 70% slope following 17 weeks of growth. Root concentration data were obtained from trench profiles, and root length and mass data were obtained from excavations ($n = 4$)

Root characteristic	Zone		
	Downhill	Uphill	Significance
Root concentration (< 1 mm, roots per m^2)	435	262	$p = 0.05^z$
Root concentration (total, roots per m^2)	508	312	$p = 0.05^z$
Length (cm)	9287	3737	$p = 0.01^y$
Dry mass (g)	25.96	11.92	$p = 0.01^y$

[z]Significance of F values.
[y]Significance according to t test.

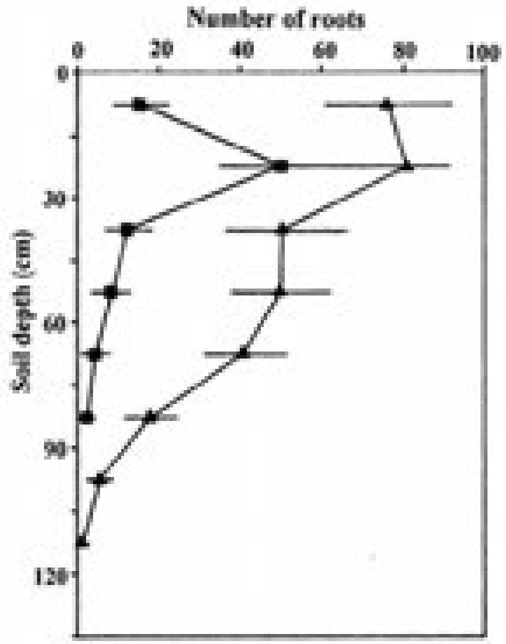


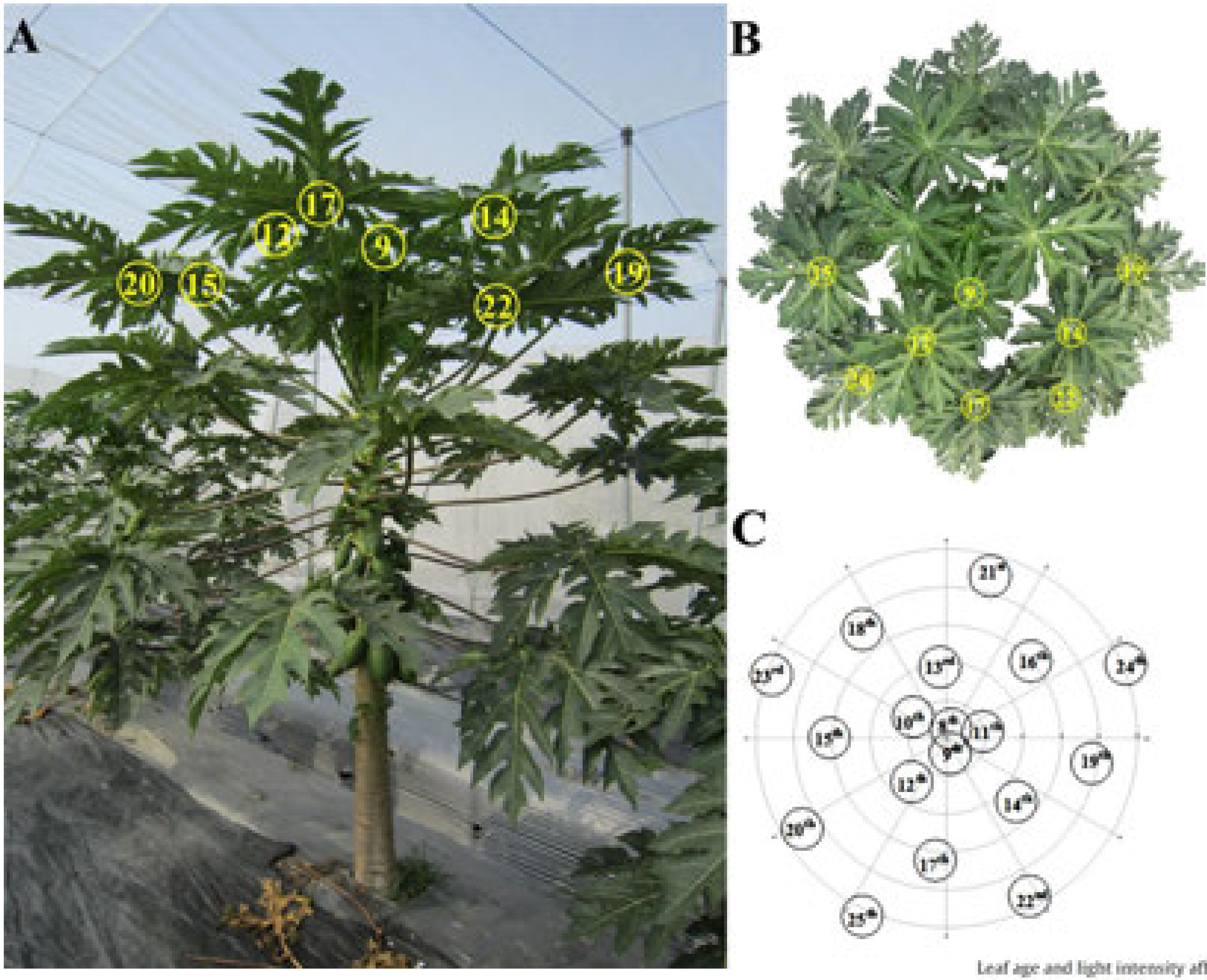
Figure 1. Depth distribution of 'Red Lady' papaya plant roots seven weeks (Experiment 1, $n = 3$, ■) or 17 weeks (Experiment 2, $n = 4$, ▲) after transplanting to a 60% to 70% sloped hillside. Symbols and lateral bars indicate mean ± standard error.

Table 1. Root characteristics of 'Red Lady' papaya plants growing on a hillside with a 60% to 70% slope following 7 weeks of growth. Root number data were obtained from trench profiles ($n = 3$). Root length and mass data were obtained from excavations ($n = 4$)

Root characteristic	Zone		
	Downhill	Uphill	Significance
Root number (<1 mm)	61	26	$p = 0.05^z$
Root number (total)	65	29	$p = 0.05^z$
Length (cm)	1038	811	$p = 0.05^y$
Dry mass (g)	2.53	1.44	$p = 0.05^y$

[z]Significance of F values.
[y]Significance according to t test.

Leaves arranged in a spiral pattern

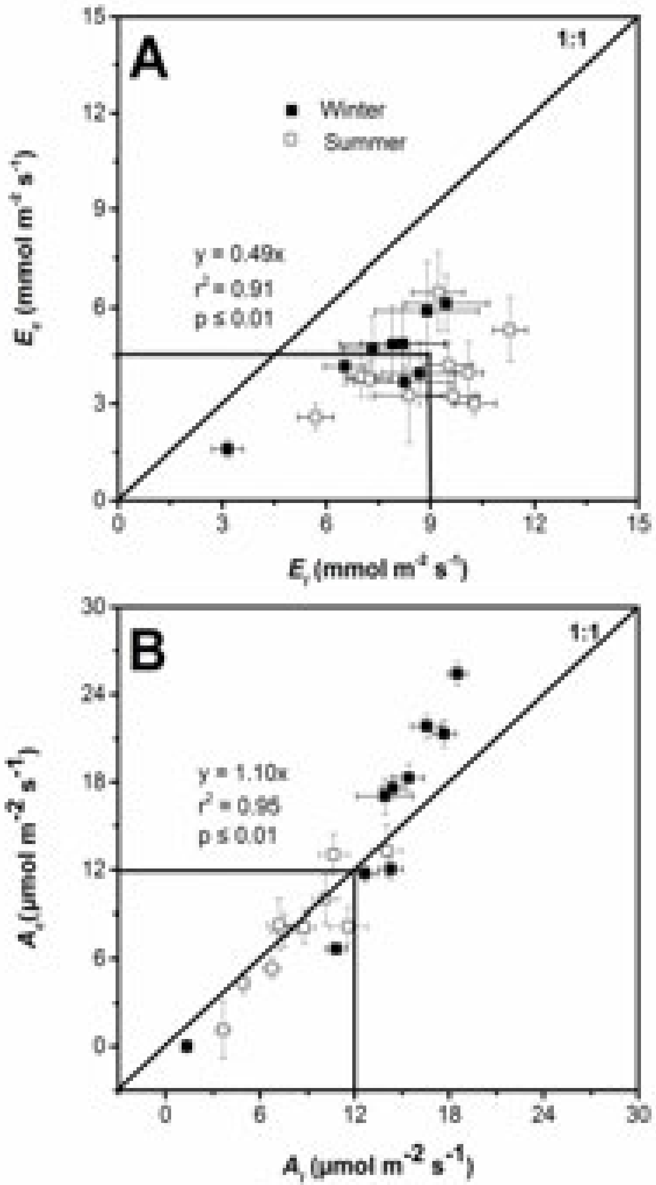


> light interception
> Number of sun leaves

Scientia Horticulturae 165 (2014) 365–373

Leaf age and light intensity affect gas exchange parameters and photosynthesis within the developing canopy of field net-house-grown papaya trees

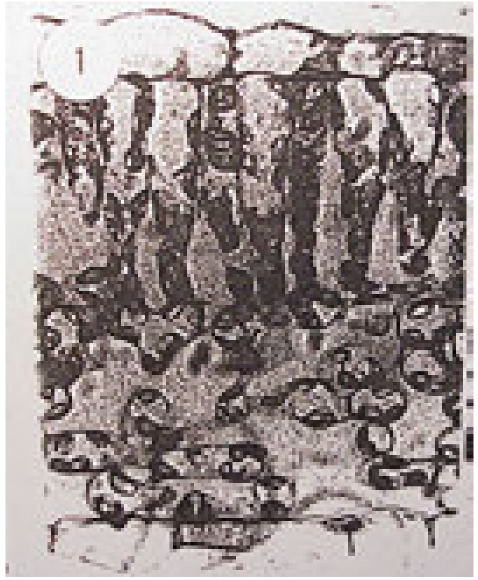
Ren-Huang Wang, Jer-Chia Chang, Kuo-Tan Li, Tzong-Shyan Lin, Loong-Sheng Chang

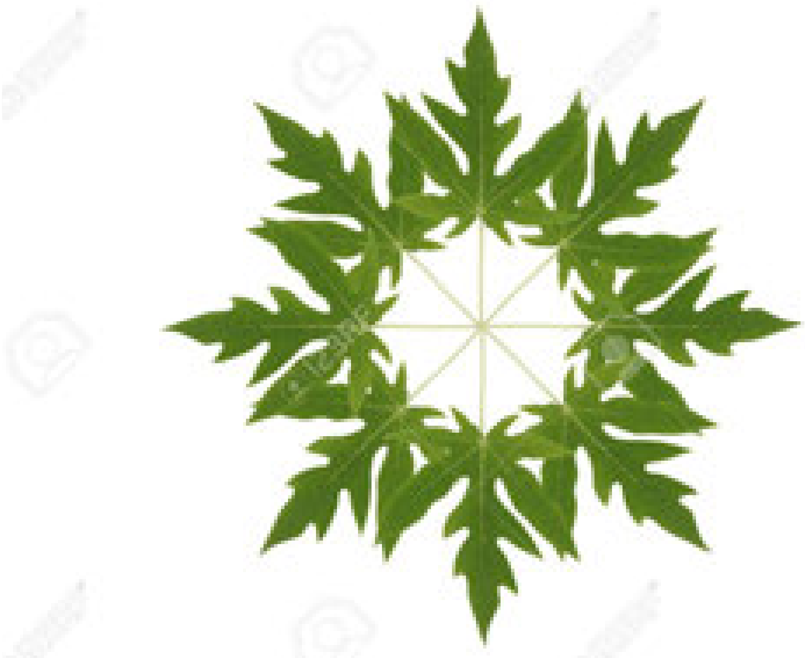


A
1:1
Winter
Summer
y = 0.49x
r² = 0.91
p ≤ 0.01
E_c (mmol m⁻² s⁻¹)
E_l (mmol m⁻² s⁻¹)
0
3
6
9
12
15
B
1:1
y = 1.10x
r² = 0.95
p ≤ 0.01
A_c (µmol m⁻² s⁻¹)
A_l (µmol m⁻² s⁻¹)
0
6
12
18
24
30

Leaf

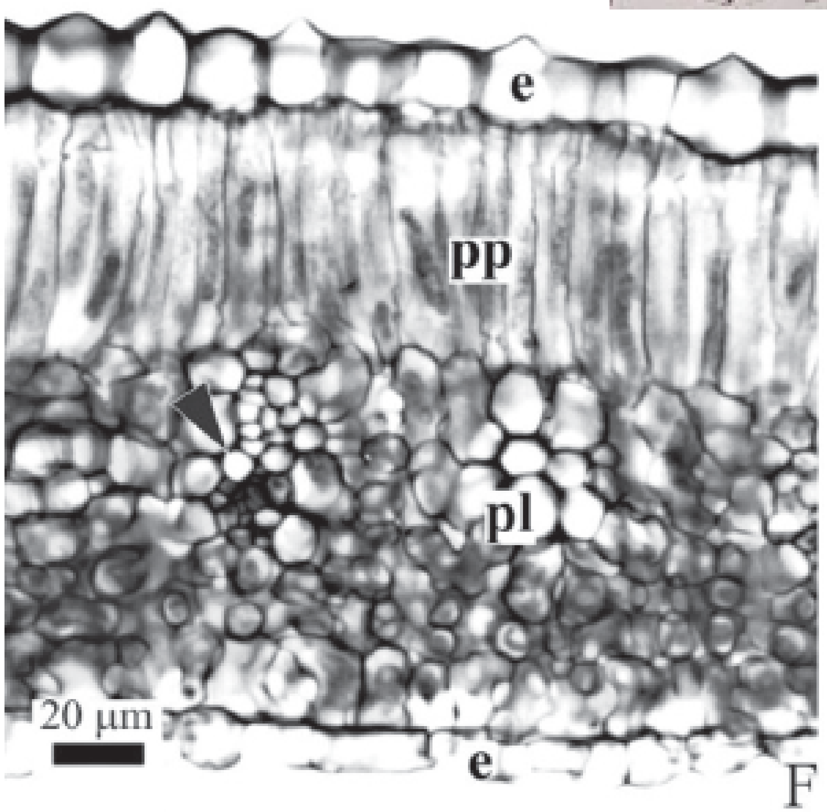
-plant produce large palmate leaves ($\approx 0{,}6 m^2$)
-Five to nine pinnate lobes of various widths (40-60 cm)
-Leaf epidermis and the palisade parenchyma are composed of a single cell layer, while spongy mesophyll consists of four to six layers of tissue





Anatomia foliar de plantas transgênicas e não transgênicas de *Carica papaya* L. (Caricaceae)

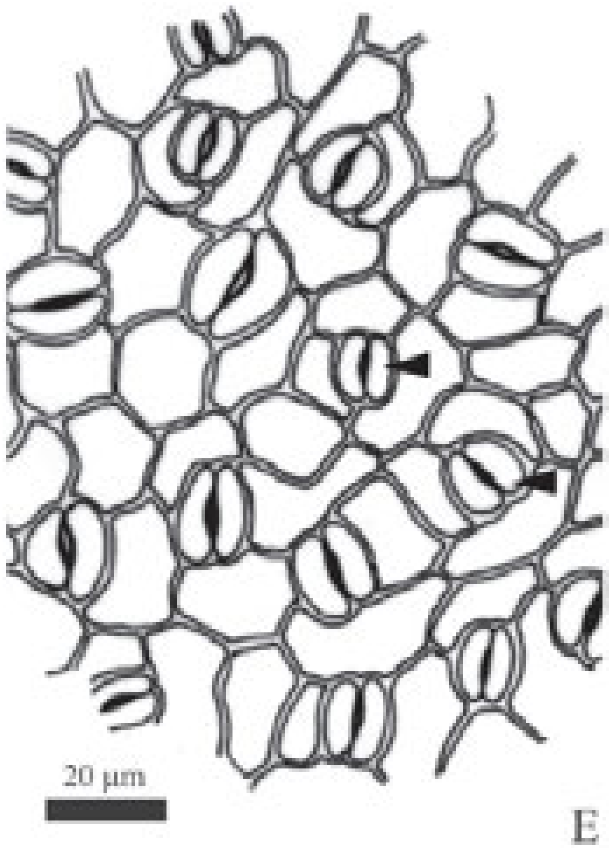
Acta bot. bras. 24(2): 595-597. 2010.

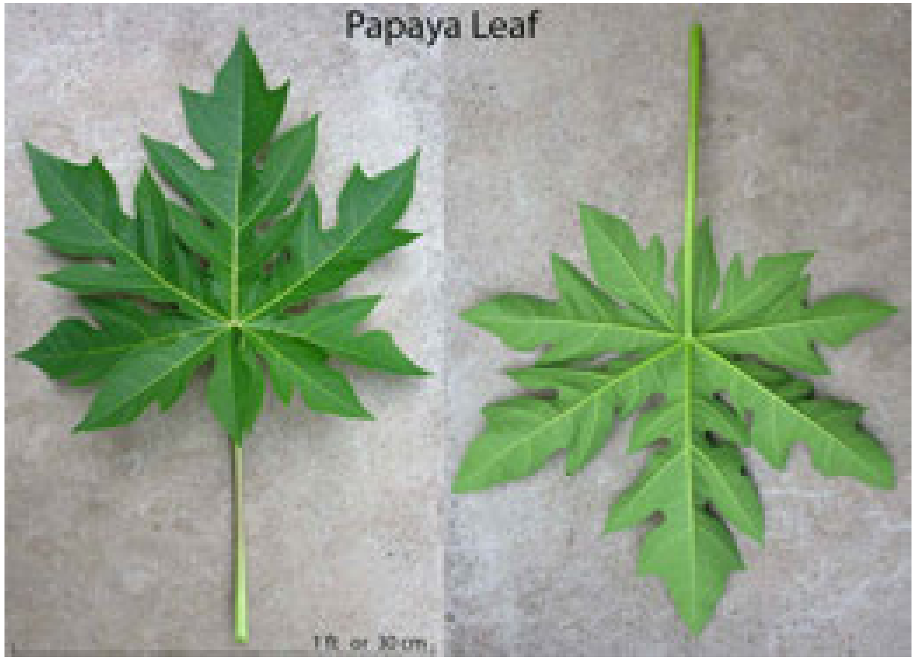


Stomata

-Papaya leaves are hypostomatics

-stomatal density of sunlight leaves is 400 to 800 stomata mm^{-2}






1.60m

Stem (trunk)

-The single stem provides structural support
-Stem diameters of adult plants vary from 10 to 30 cm at base to 5 -10 cm at the crown.

Stem (trunk)

- C. papaya exhibits a very unusual functional anatomy
-Stem density is only **0.13 g cm³**
-Carica papaya L. does not contain wood, according to the botanical definition of wood as lignified secondary xylem

-Despite its parenchymatous secondary xylem, these plants are able to grow up to 10 m high, and each plant can produce 50 fruits with 0.5kg each fruit (**25kg**) ('Solo' group) and 25 fruits with 1.5kg each fruit (**45kg**)('Formosa').

This is surprising, as wooden structural elements are the ubiquitous strategy for supporting height growth and high fruit weight in papaya plants!

Proposed possible alternative principles to explain the compensation for lack of wood in *C. papaya* are **turgor pressure of the parenchyma**, **lignified phloem fibres in the bark**, or **a combination of the two**

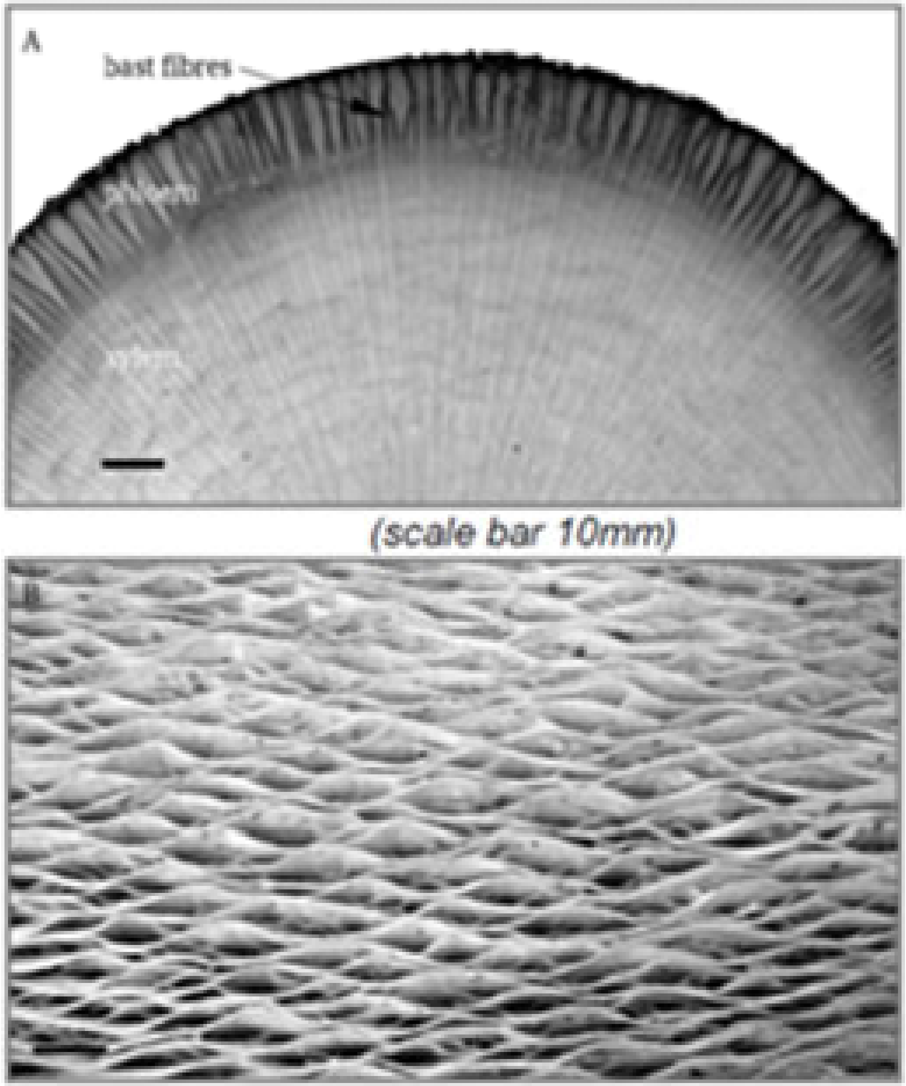


Fig. 1. Detail of papaya stem's cross section (A) and fibres after removal of parenchyma in longitudinal view (B)

Kempe, Lautenschläger, Lange & Neinhuis

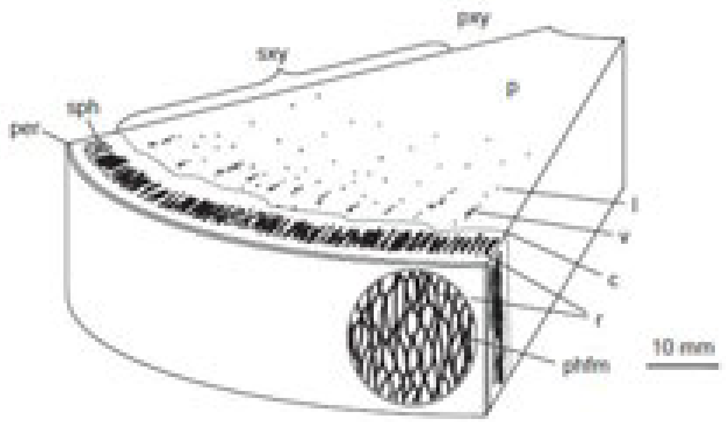
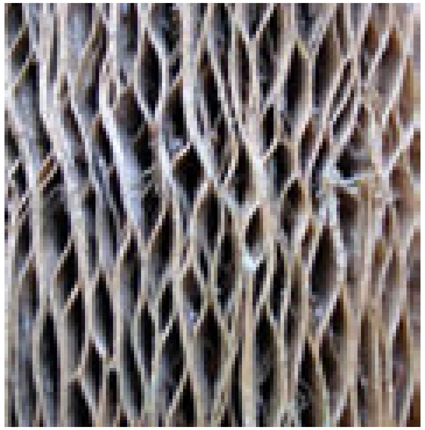


Fig. 1. Segment of Carica stem cross-section. c, cambium; l, laticifers; p, parenchyma; phfm, phloem fibre mesh; per, periderm; pxy, primary xylem; r, rays; sph, secondary phloem; sxy, secondary xylem; v, vessels.



The construction of fibers and high-pressure matrix parenchyma is unique in tree-like plants, and guarantees adequate flexural rigidity with a minimum fibre content!!

plant biology

RESEARCH PAPER

How to become a tree without wood – biomechanical analysis of the stem of *Carica papaya* L.

A. Kempe, T. Lautenschläger, A. Lange & C. Neinhuis

Each plant with 20cm diameter!!
'Solo' group can support 25kg
"Formosa' group can suppor t 45kg

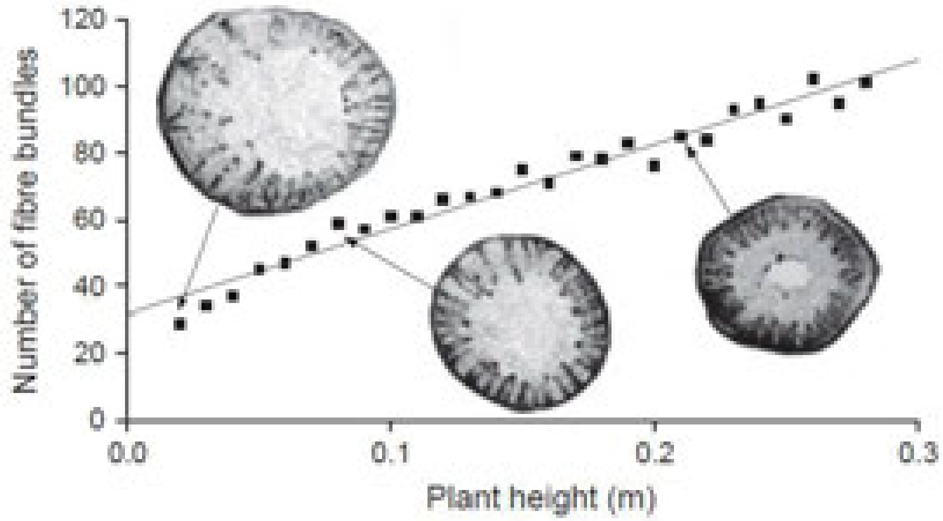


Fig. 5. Representative number of fibre bundles from the stem of a young plant 300-mm high.

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Sap flow in papaya plants: Laboratory calibrations and relationships with gas exchanges under field conditions

Fabrício de Oliveira Reis [a,*], Eliemar Campostrini [a], Elias Fernandes de Sousa [b], Marcelo Gabetto e Silva [b]

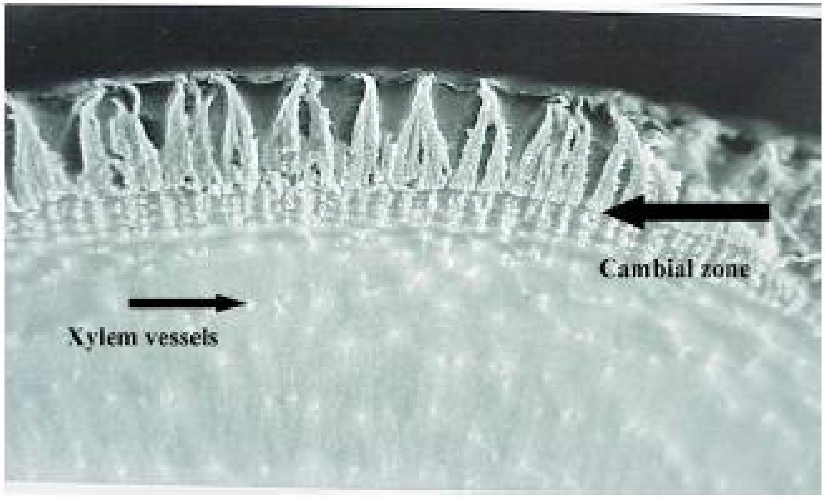


Fig. 3. Standardized xylem vessel distribution in papaya trunk. Picture obtained from a 6-month papaya plant. Notice that the vessel distribution concentrates near the cambial zone of the trunk.

Turgor pressure was between 0.82 and 1.25 MPa, indicating that turgor is essential for flexural rigidity of the entire stem!!!!
Kempe et al (2014)

A car tire is typically inflated to about 0.2 MPa
The water pressure in home plumbing is typically 0.2-0.3 MPa


Store No.: 412865

Stem (trunk)

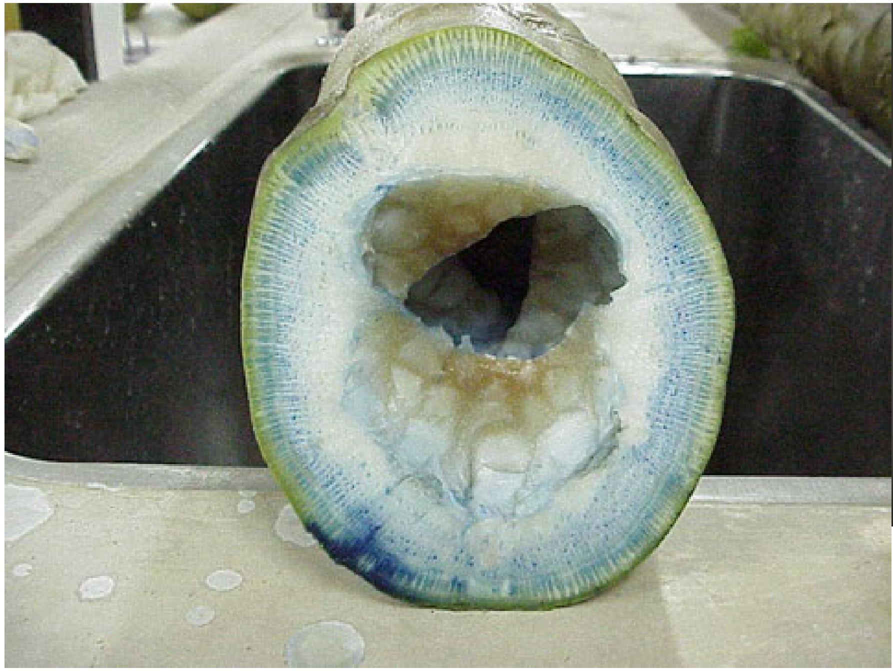
-The lower internodes are compact and wider and seem to mechanically support the entire weight of the plant (Morton 1987).

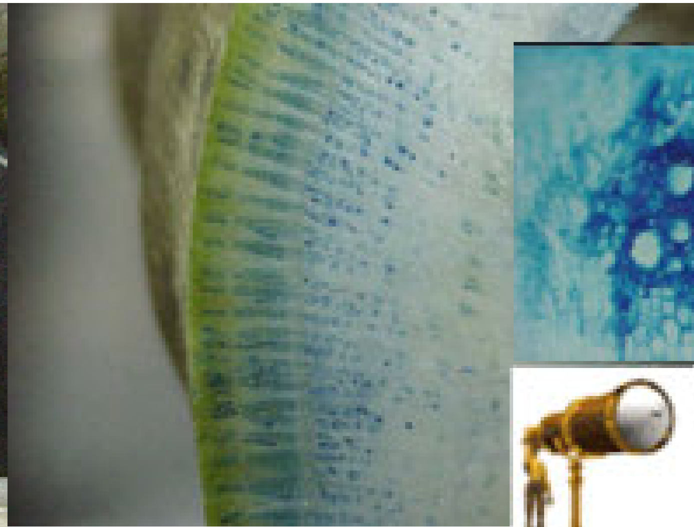
Stem (trunk)

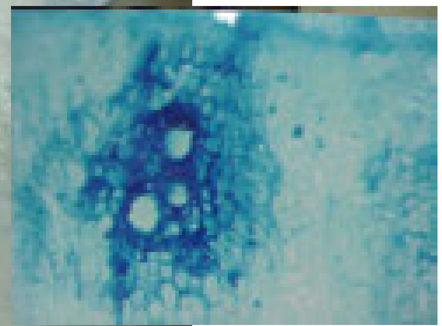
-The lower internodes are compact and wider and seem to mechanically support the entire weight of the plant (Morton 1987).

-The xylem is poorly lignified and aids in storage of water and starch (Fisher 1980)

-The xylem is composed of wide vessels that can be seen with the naked eye, imbibed in non-lignified parenchyma tissues and rays







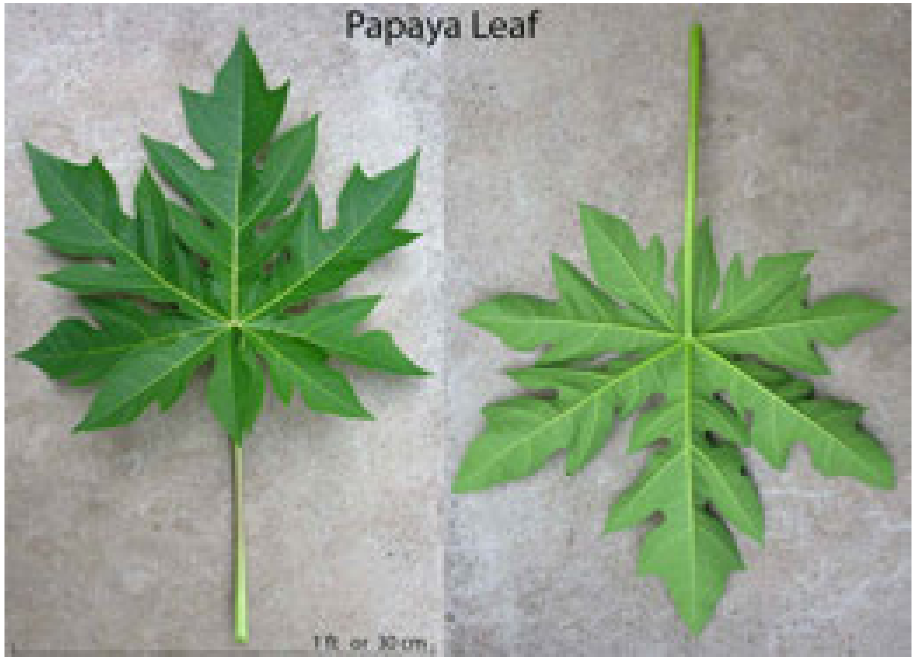
Xylem vessel

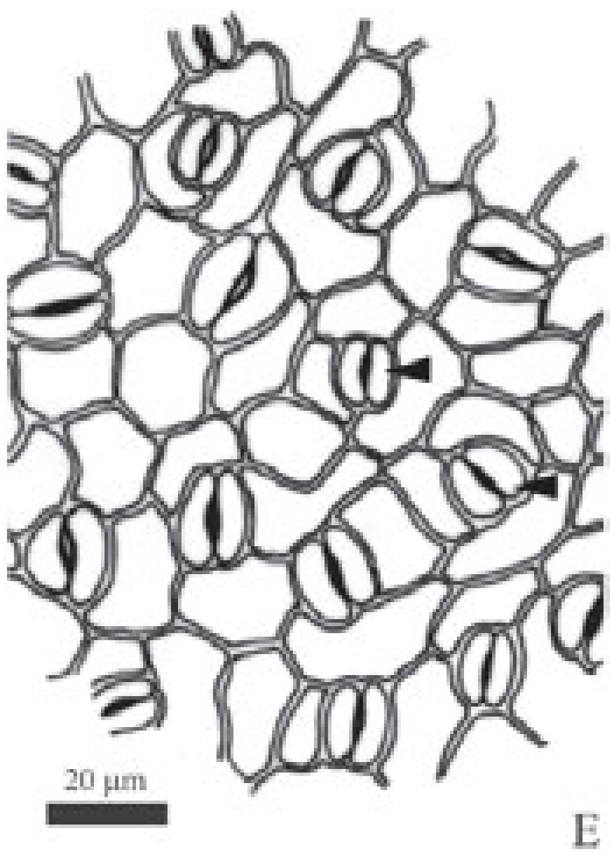
Single-leaf photosynthesis

Stomata

-Papaya leaves are hypostomatics

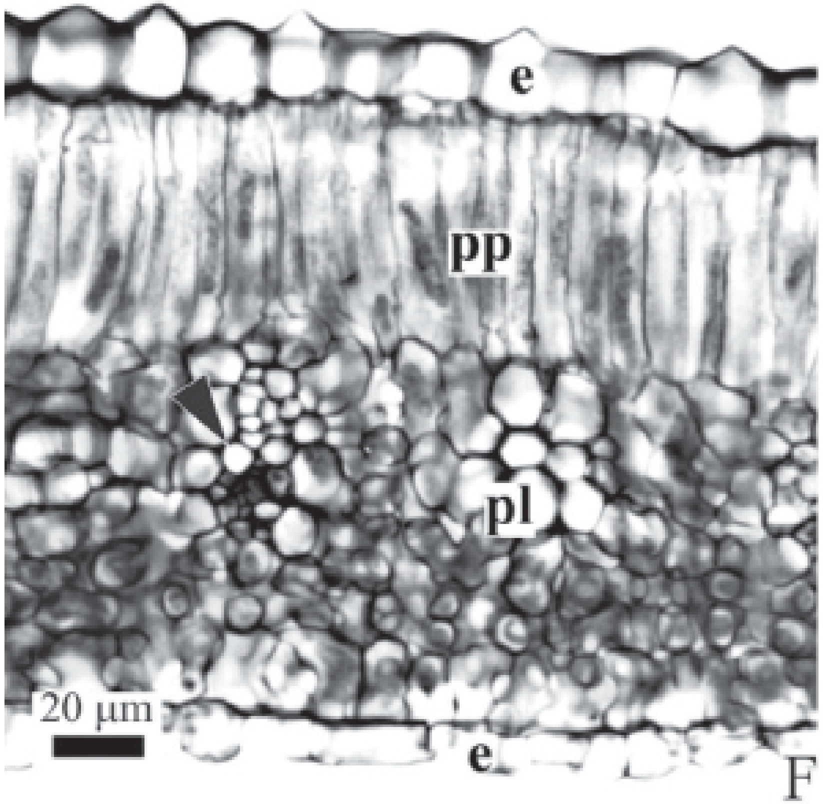
-stomatal density of sunlight leaves is 400 to 800 stomata mm^{-2}



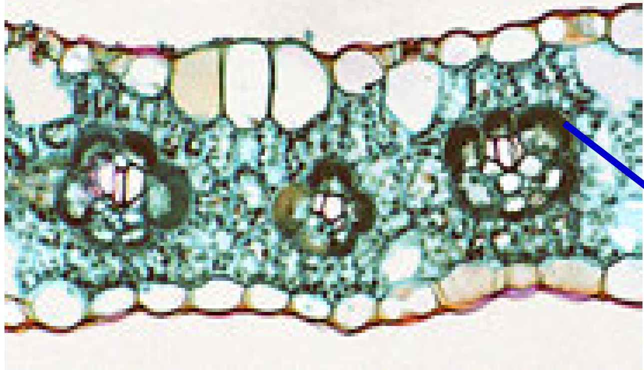


Single-leaf photosynthesis

Papaya is classified as a plant with C3 metabolism (Imai et al., 1982; Marler et al., 1994; Campostrini, 1997; Marler and Mickelbart, 1998; Jeyakumar et al., 2007) The absence of margin cell formation in the vascular bundles of papaya leaves (Buisson and Lee, 1993) is a characteristic associated with C3 metabolism



C4 leaf

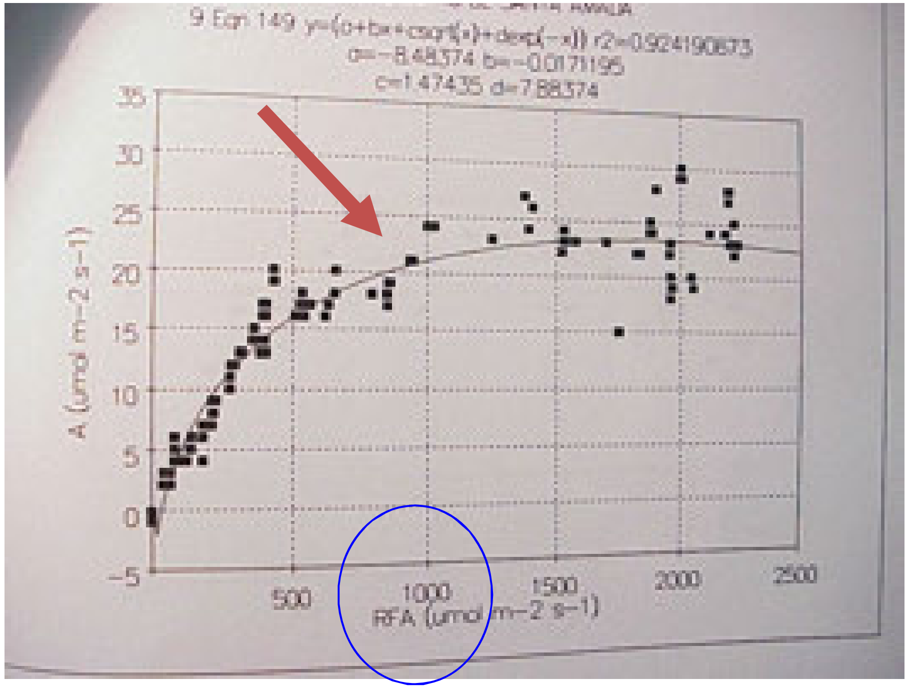


Bundle sheath

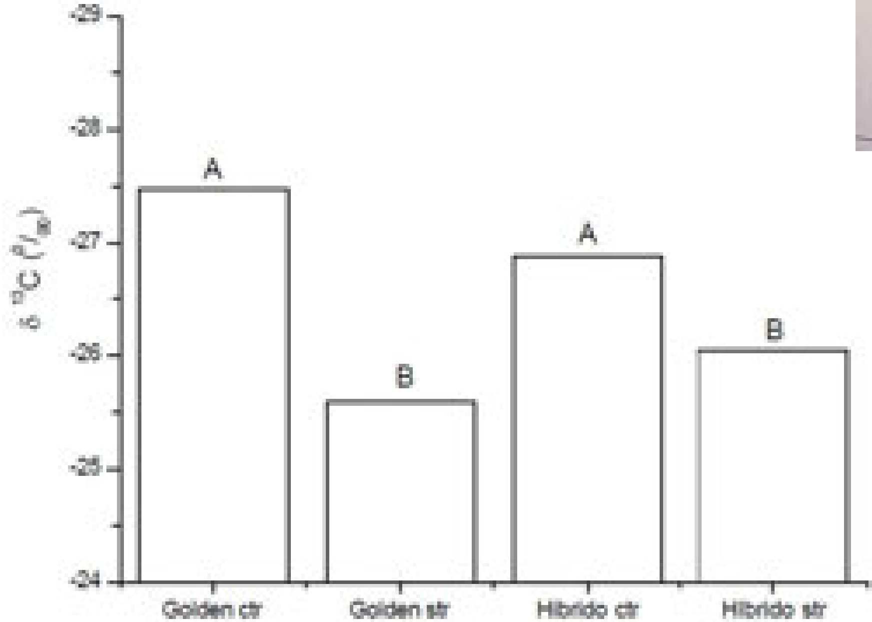
Single-leaf photosynthesis

The average C^{13} value of C4 plants is **-14‰**

C3 plants is **-23 to -36 ‰**

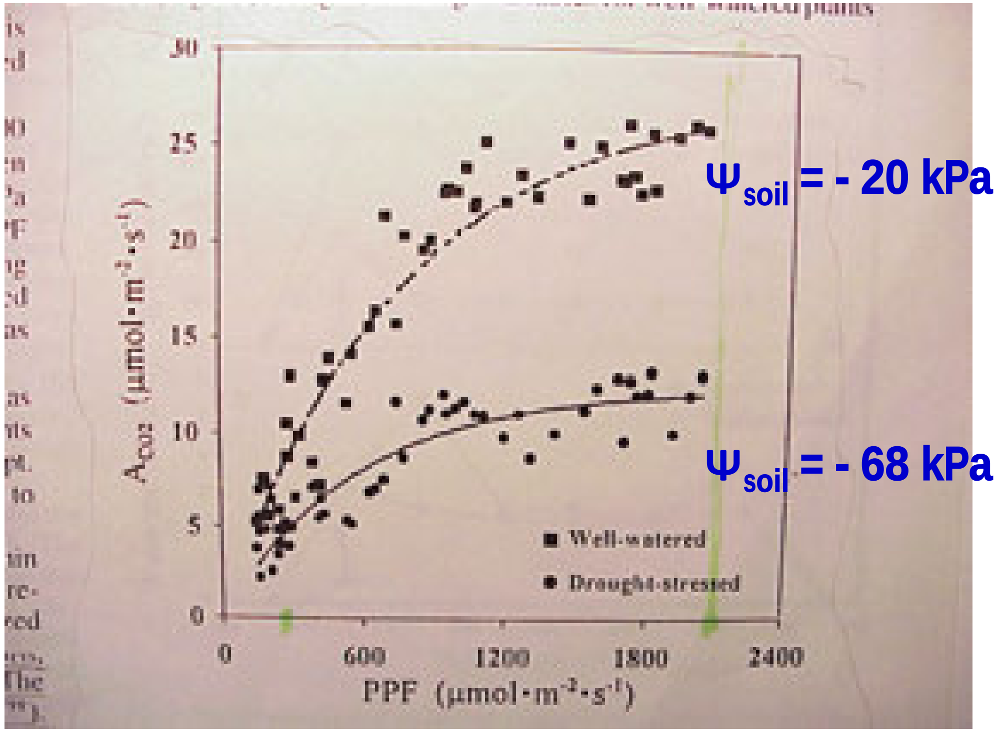


Campostrini, 1997



Torres-Netto 2005

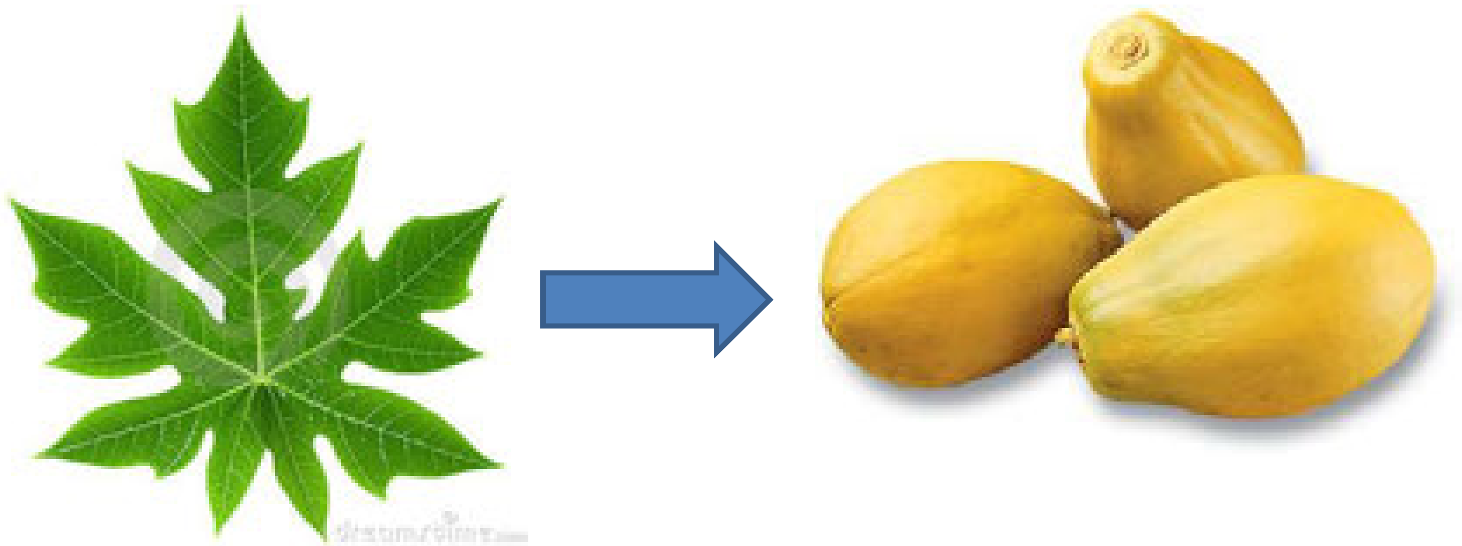
Single-leaf photosynthesis



Marler e Mickelbart, 1998

Maximum net carbon assimilation (*A*) rates of 25 to 30 μmol m^{-2} s^{-1} are achieved at 2000 μmol m^{-2} s^{-1} photosynthetic photo flux (PPF) in soil field capacity (Marler and Mickelbart, 1998; Campostrini and Yamanishi, 2001; Reis, 2007)

In general, each mature leaf can provide photoassimilate for about three fruits (Zhou et al., 2000)



The photosynthetic capacity also influences papaya fruit quality (Salazar, 1978).

Defoliation by *75%* significantly reduced new flower production and fruit set, decreased ripe fruit total soluble solids (TSS)

50% defoliation did not reduce new fruit set or ripe fruit TSS (Zhou et al, 2000)

In general: (Brazil)

Solo group: **< leaf area**

High yield:

95 t ha^{-1}

95 fruits 1 leaf support 4 fruits

24 leaves

Average yield :

61 t ha^{-1}

62 fruits 1 leaf support 3 fruits

19 leaves

Formosa group: **> leaf area**

High yield:

150 t ha^{-1}

73 fruits 1 leaf support 3 fruits

25 leaves

Average yield :

85 t ha^{-1}

42 fruits 1 leaf support 2 fruits

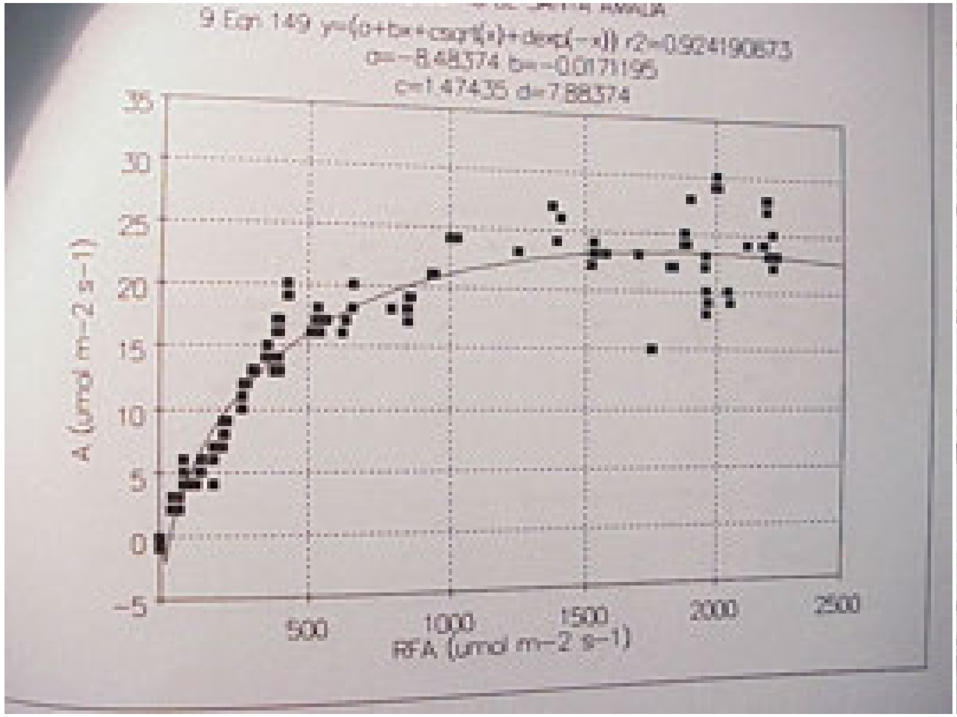
21 leaves

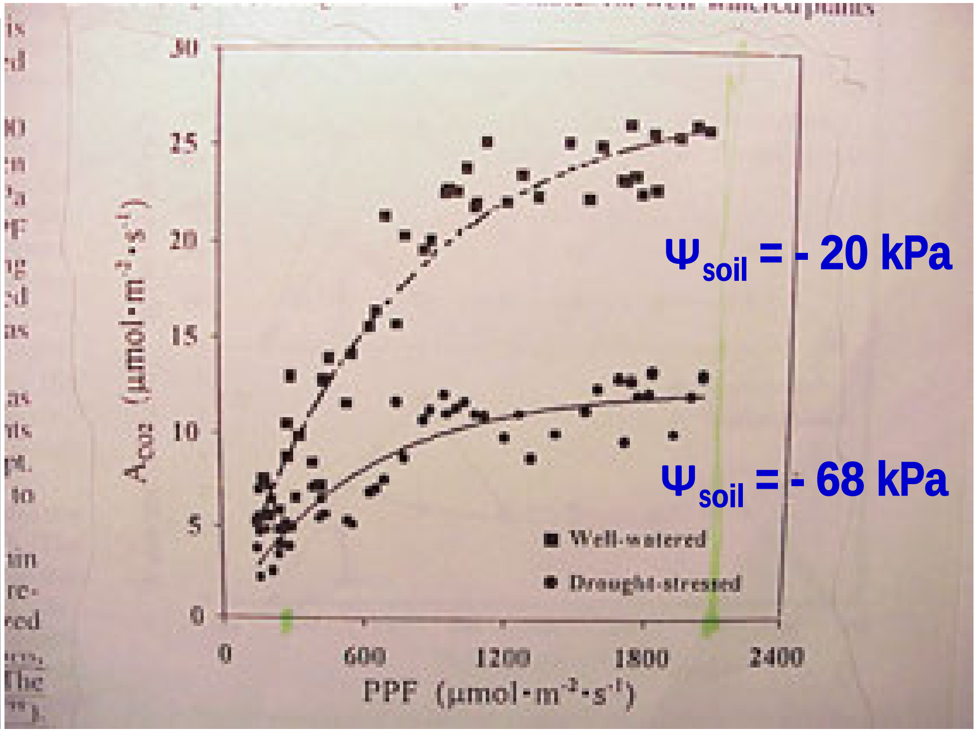
Increase net photosynthetic rate (A) is very important to high papaya production

While high *A* rates are possible in papaya, environmental factors as PPF (light), water (soil and air), soil compaction, wind, VPD, temperature, soil oxygen, often limit *A.*

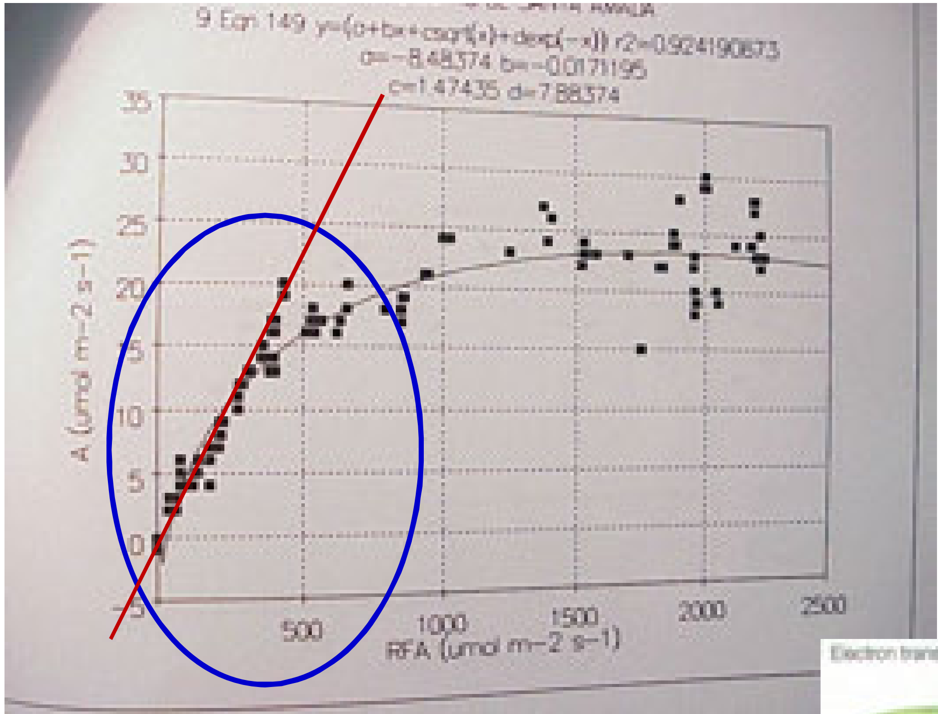
1) Light (PPF)

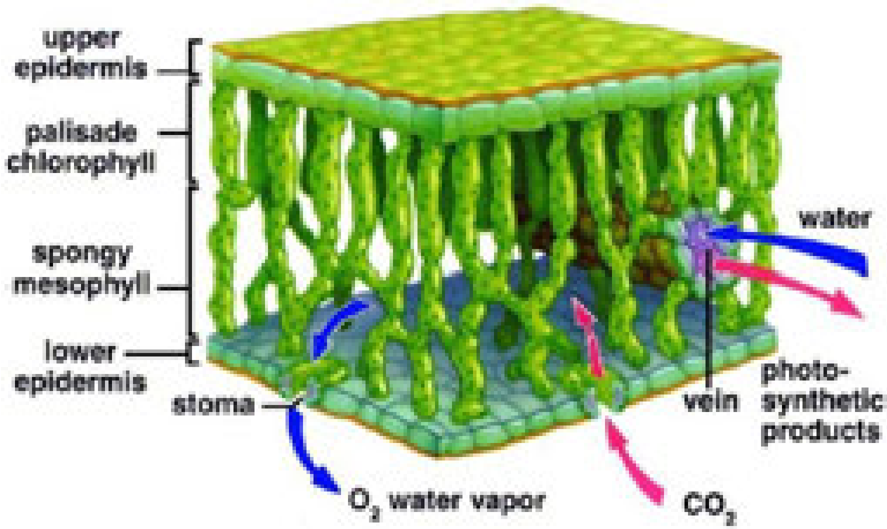
Sun leaf

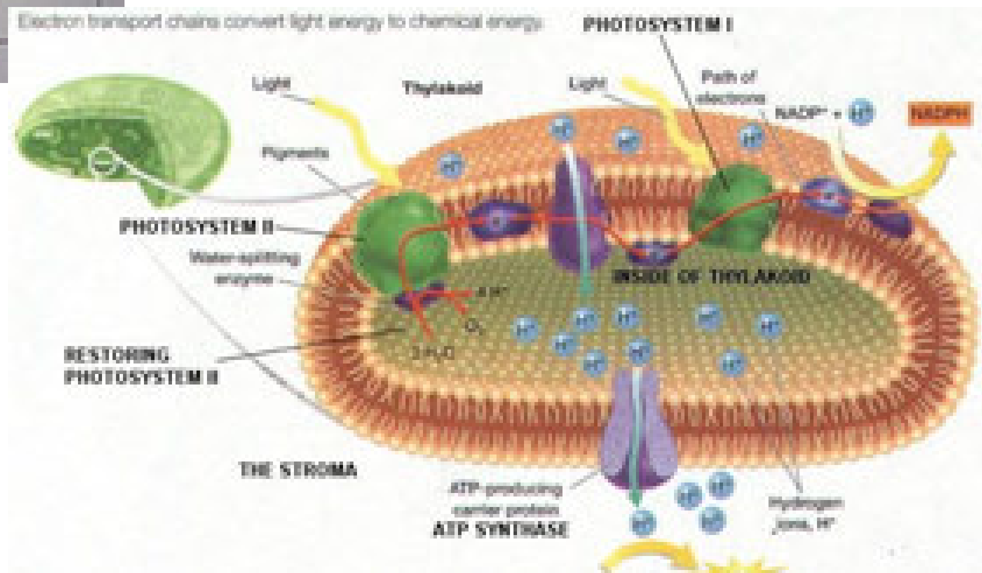




With rapid reductions in irradiance, photosynthesis declines due to rapid biochemical adjustments. With the return to high irradiance, and in the absence of any stomatal Imitation, photosynthesis quickly increase





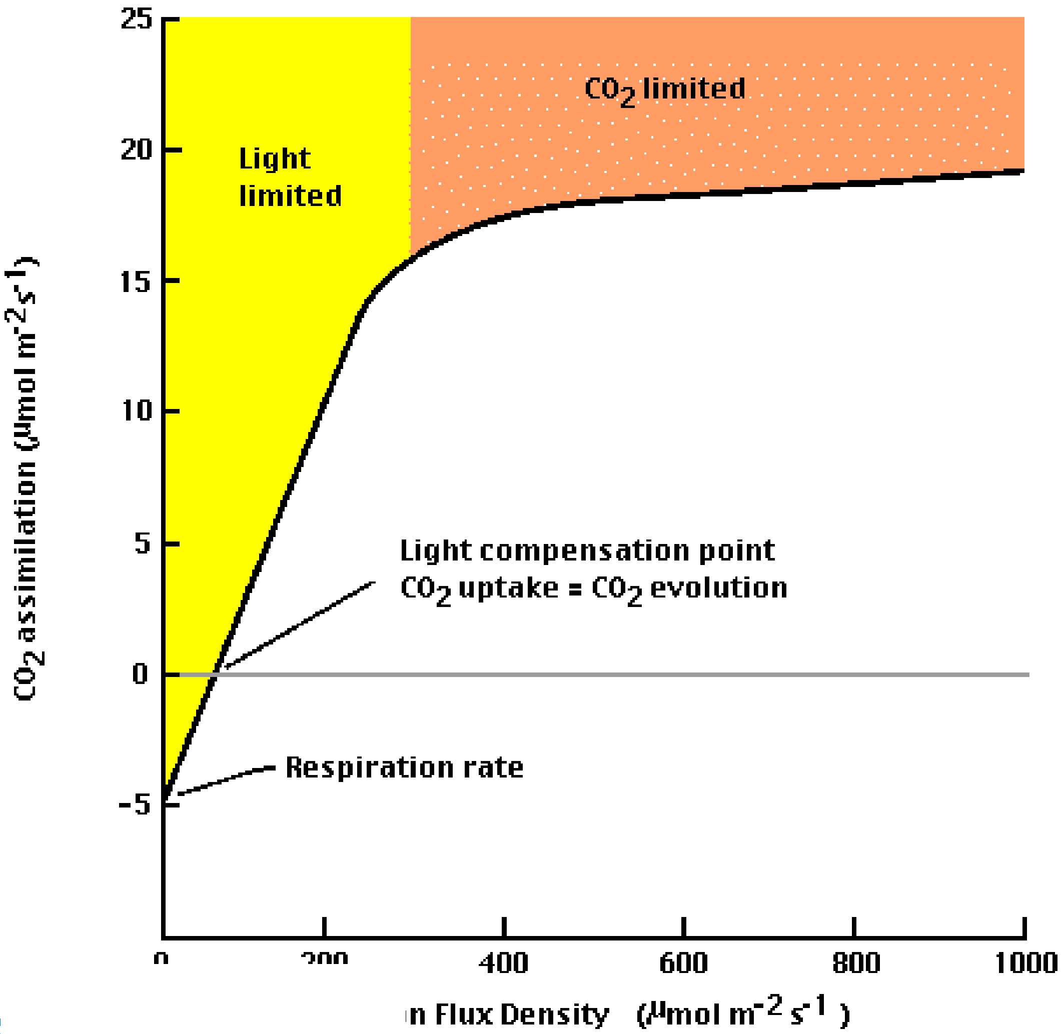


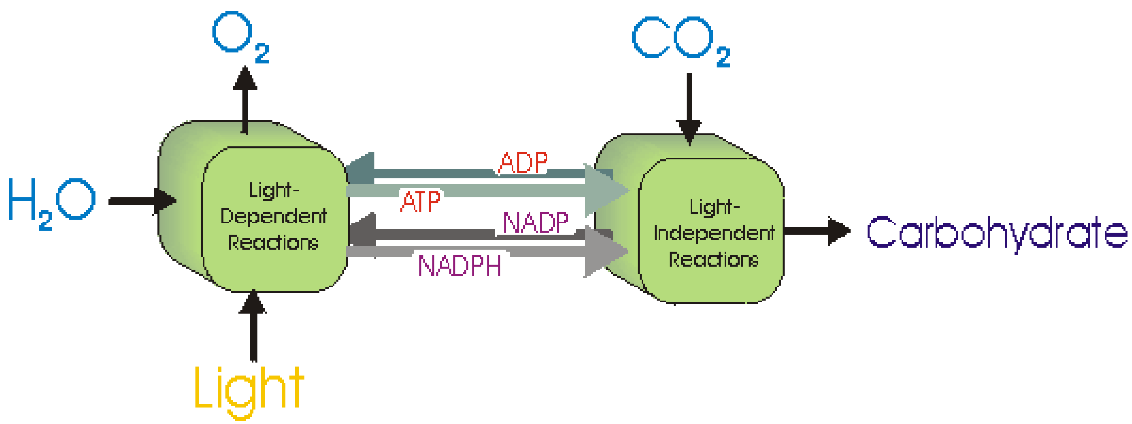
Ligh compensation point in papay single leaf. Field condition

60 μmol m^{-2} s^{-1}

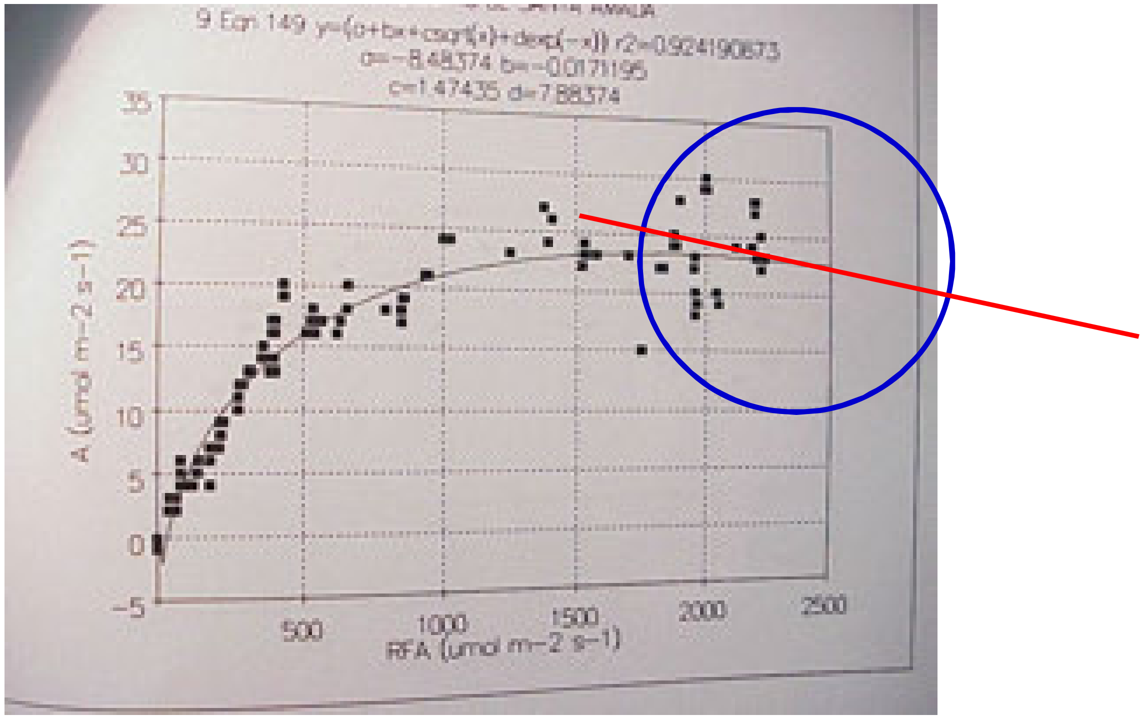
Dark respiration

1.75 to 2.5 μmol $CO_2 m^{-2}$ s^{-1}

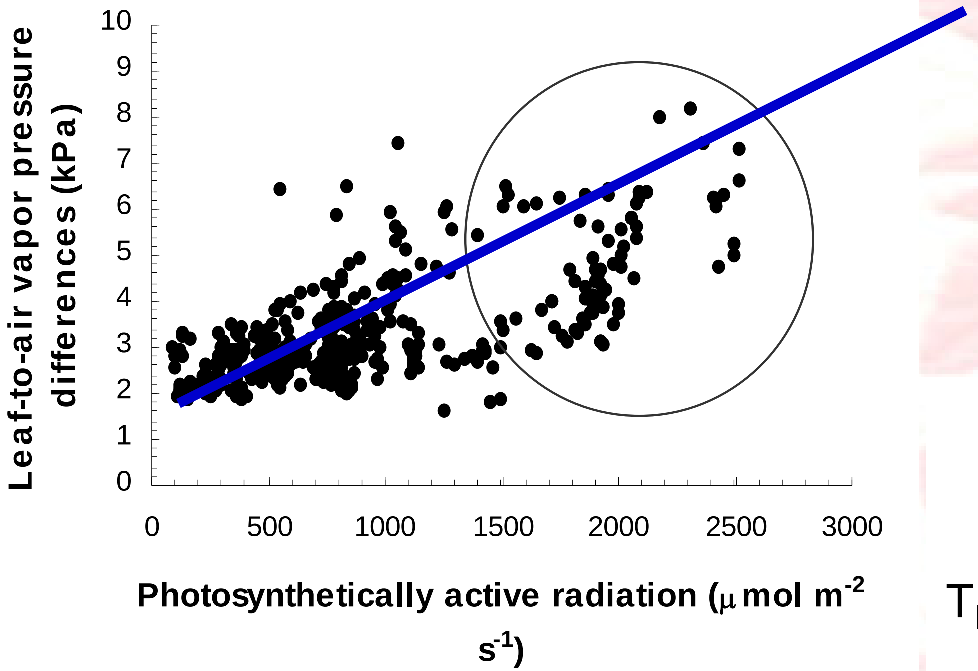


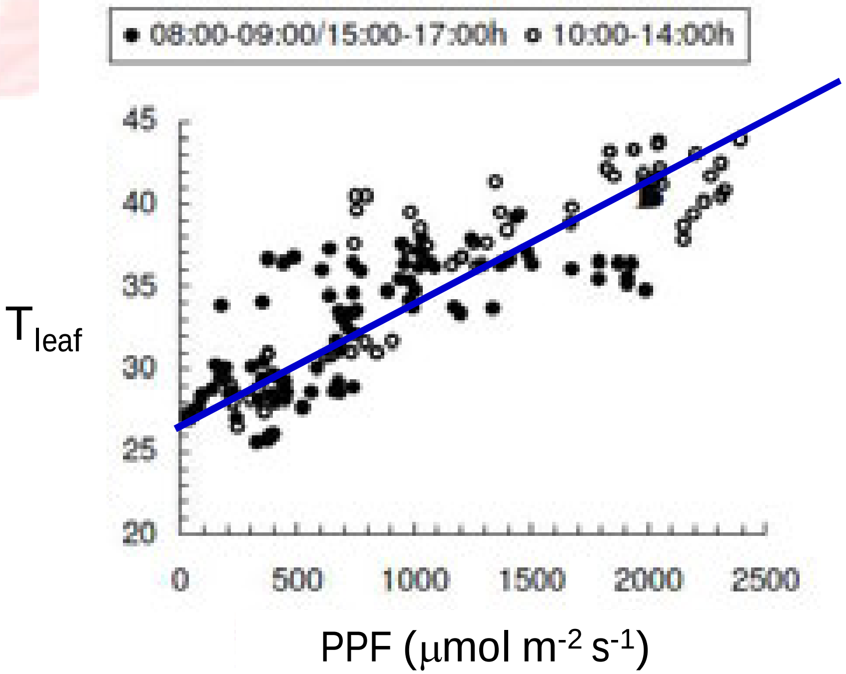


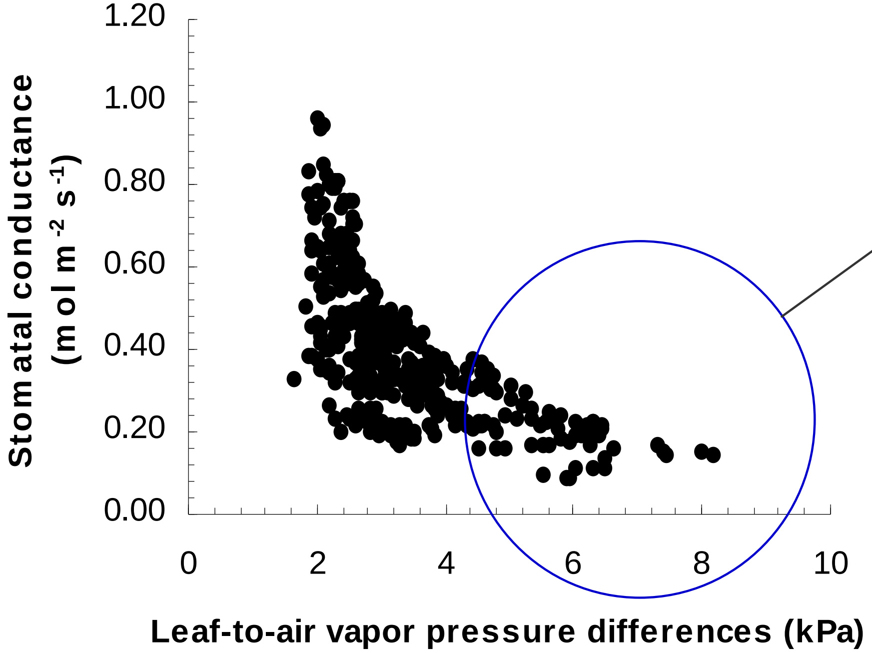
The PPF response of papaya may also decline with PPF above saturating levels



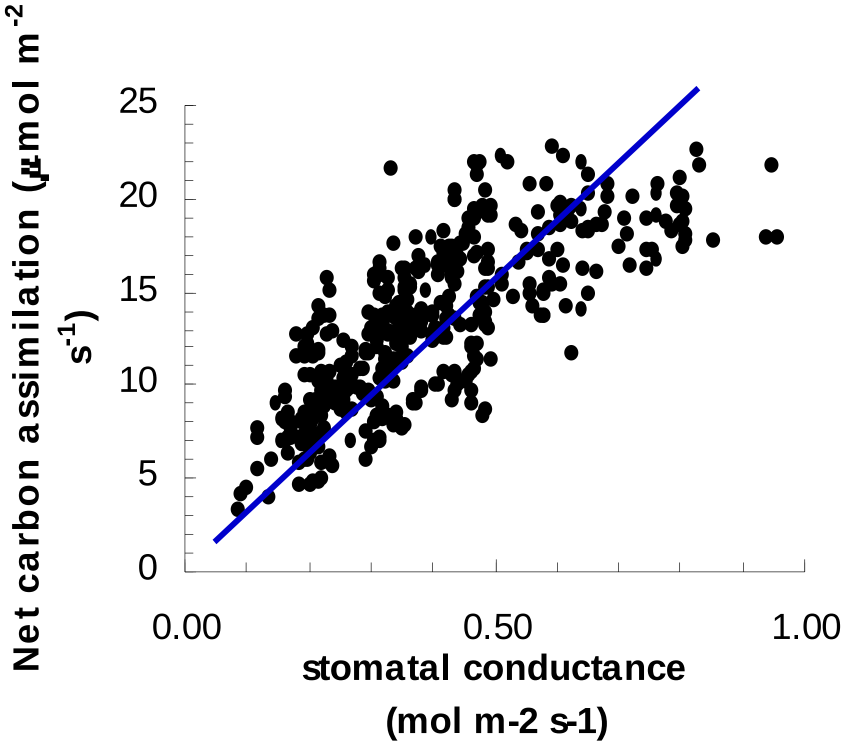
The decrease in A that begins at light saturation is due, in part, to the decrease in stomatal conductance (gs) through the direct action of radiant energy on leaf heating (**stomatal limitation**)



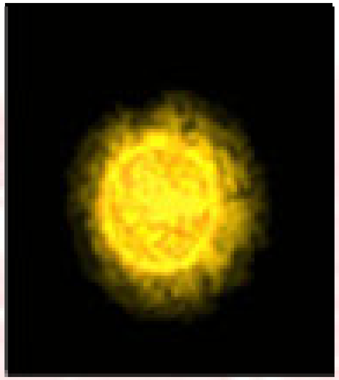




11:00 to 14:00 hours



Tainung genotype



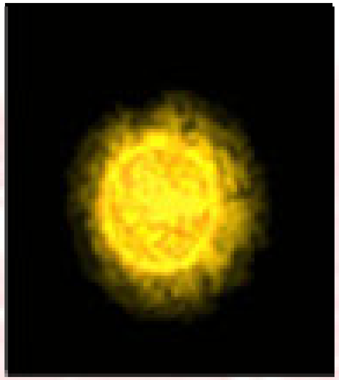
The photosynthetic response of papaya is strongly linked to environmental conditions through stomatal behavior

13:00 **soil field capacity**

High light (2200 µmol m^{-2} s^{-1})
High leaf temperature (40ºC)
High VPD (≈ 6 kPa)
Low g_s (0.20 mol m^{-2} s^{-1})
Low A (5 µmol m^{-2} s^{-1})

Midday depression of photosynthesis
can reduce yield

Tainung genotype



13:00 **soil field capacity**

Papaya leaves showed paraheliotropic movement associated with reduced leaf turgor (Reis 2008).

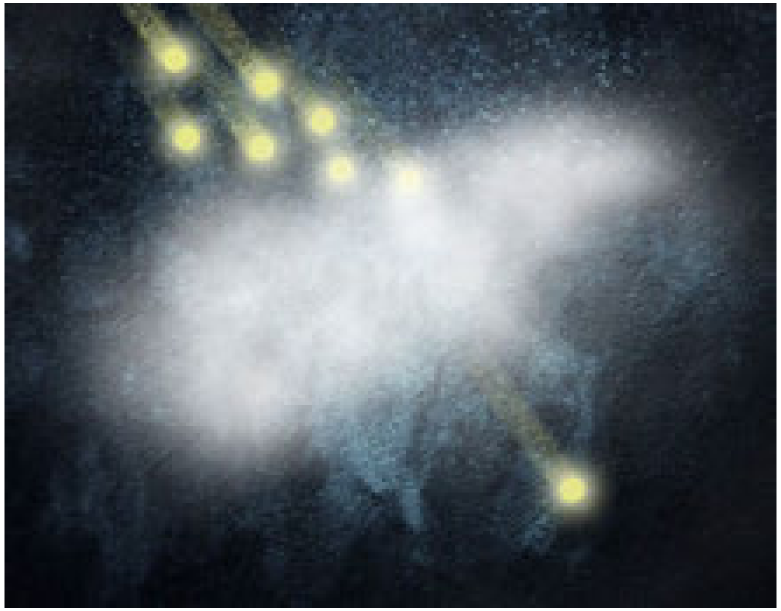
Paraheliotropic movement can be translated into decreased radiation load per unit leaf area which, in turn, could prevent the photoinhibition

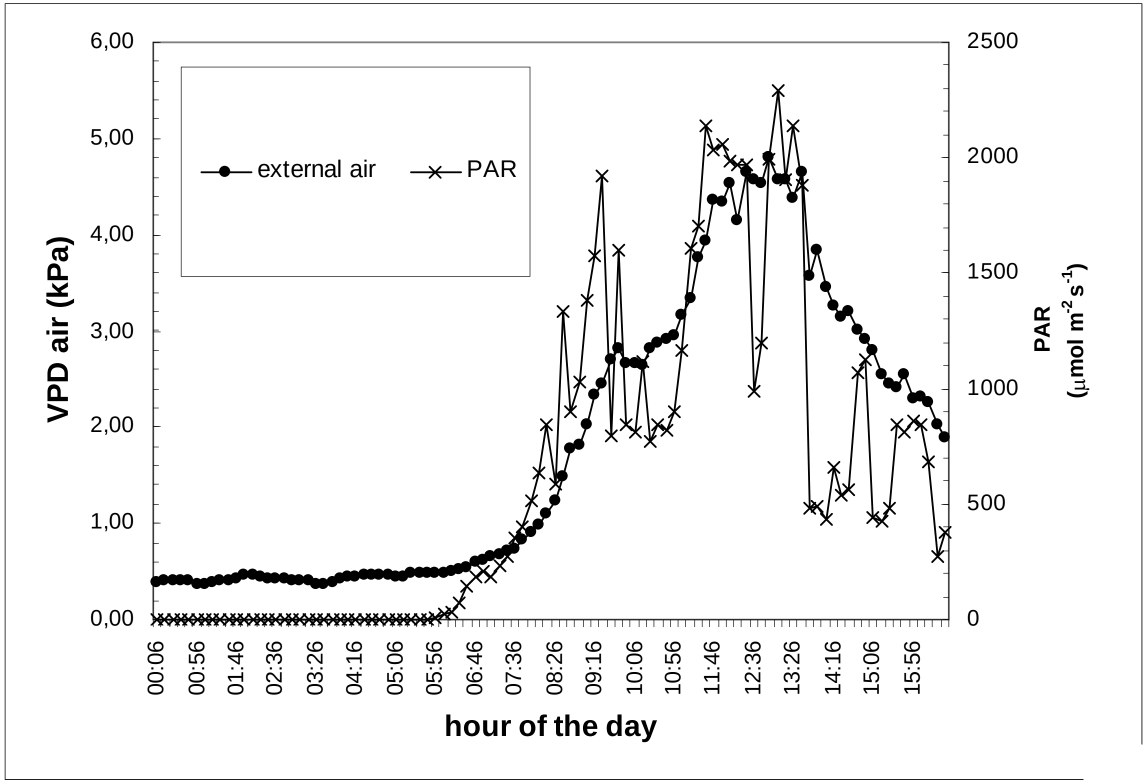
Irradiance can control stomatal conductance and can reduce photosynthesis

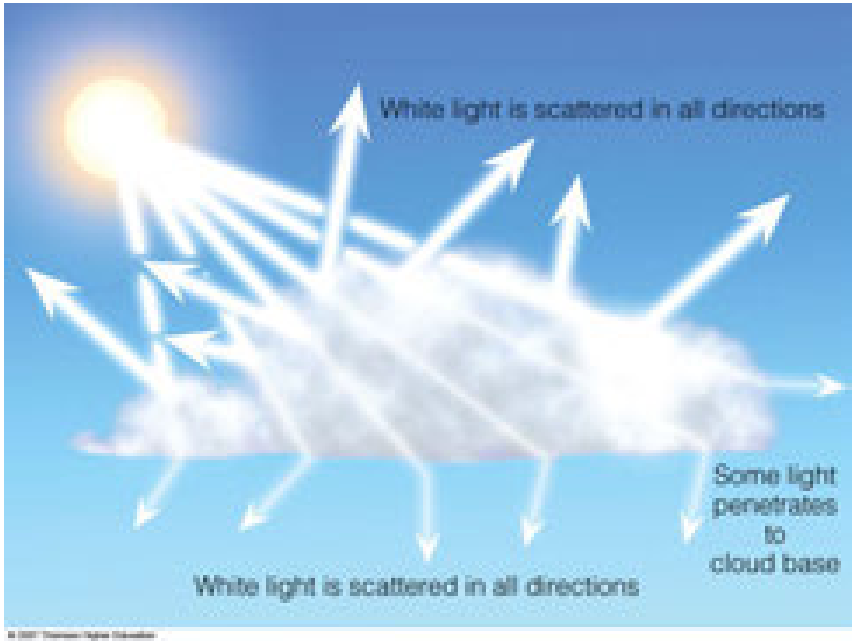
Papaya stomata are able to track rapid changes in irradiance!! (Clemente and Marler, 1996)

Most plants experience continuous fluctuations in light under natural conditions rather that long periods of uniform irradiance!!

Even individuals of pioneer and other species growing in open habitats experience high and low light periods in the order of several minutes each due to broken cumulus cloud cover (Knapp and smith, 1990).







Light Diffraction Through Clouds

Figure 1

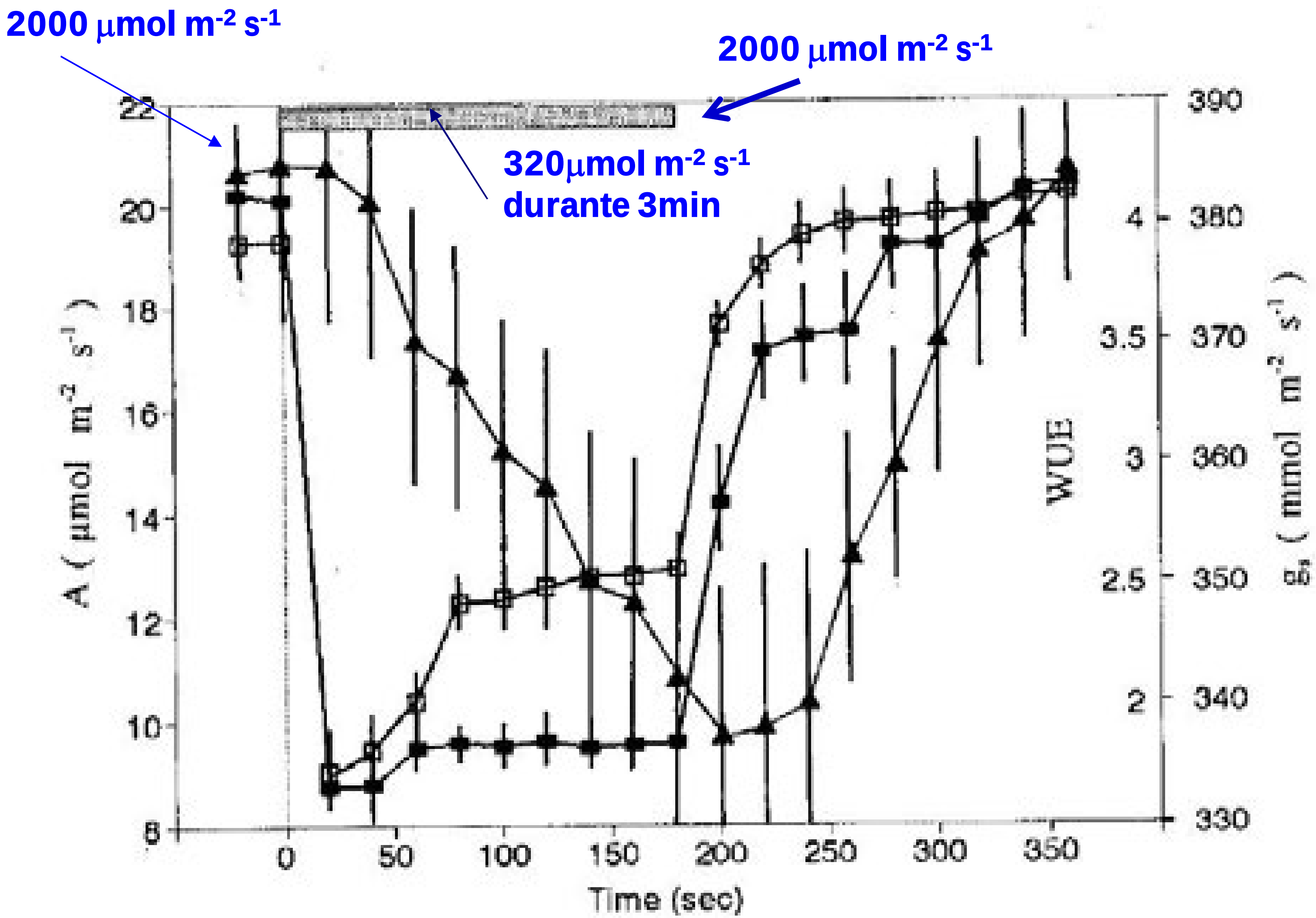


Fig. 1. Response of net CO_2 assimilation (A, ■), stomatal conductance (g_s, ▲),

1600 μmol m^{-2} s^{-1}

250 μmol m^{-2} s^{-1} durante 2.5 min

1600 μmol m^{-2} s^{-1}

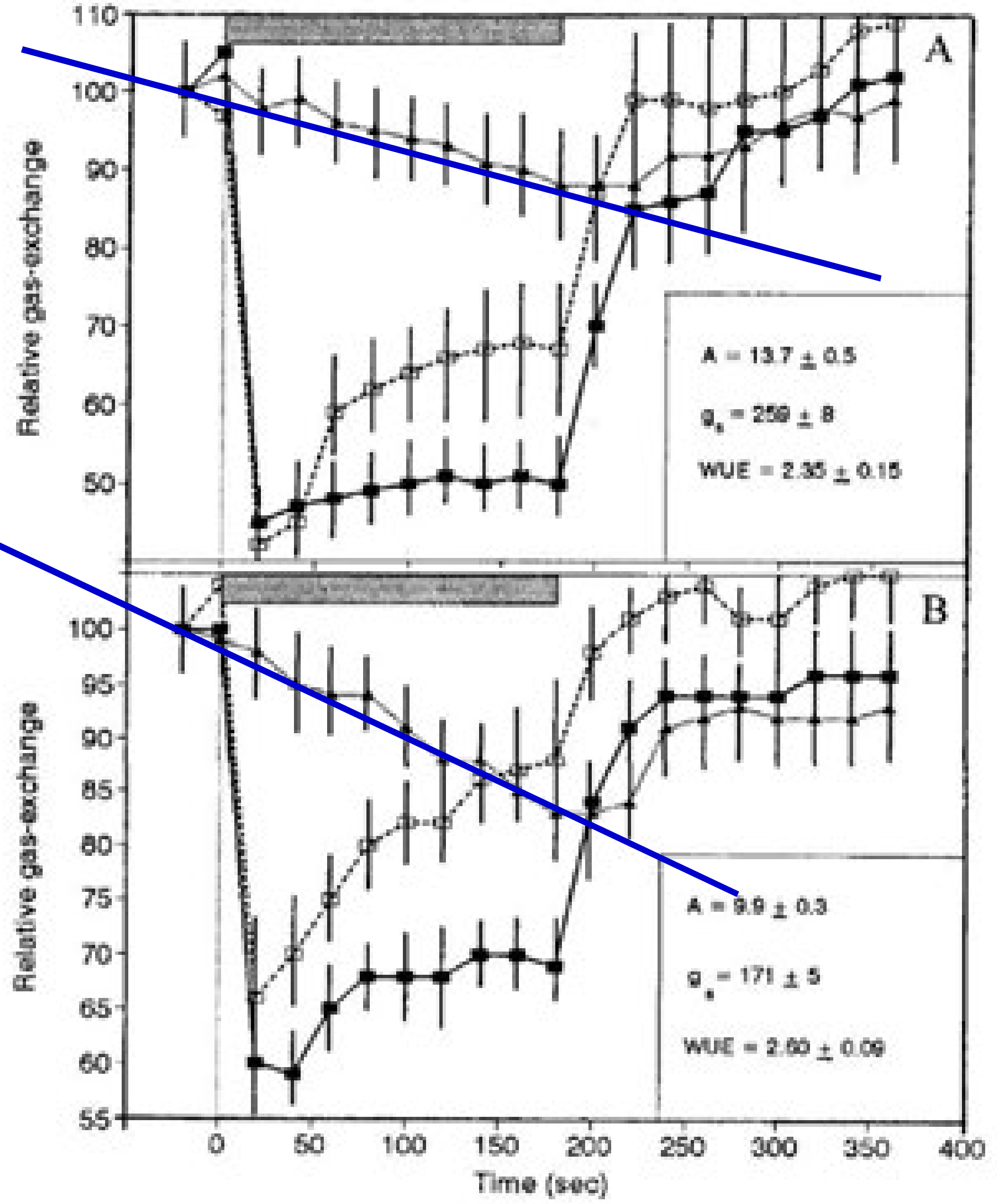


Fig. 2. Relative response of net CO_2 assimilation (A, ■), stomatal conductance


Leaf age and light intensity affect gas exchange parameters and photosynthesis within the developing canopy of field net-house-grown papaya trees

Scientia Horticulturae 165 (2014) 365–373

Ren-Huang Wang[a,b], Jer-Chia Chang[c], Kuo-Tan Li[b], Tzong-Shyan Lin[b], Loong-Sheng Chang[b,*]

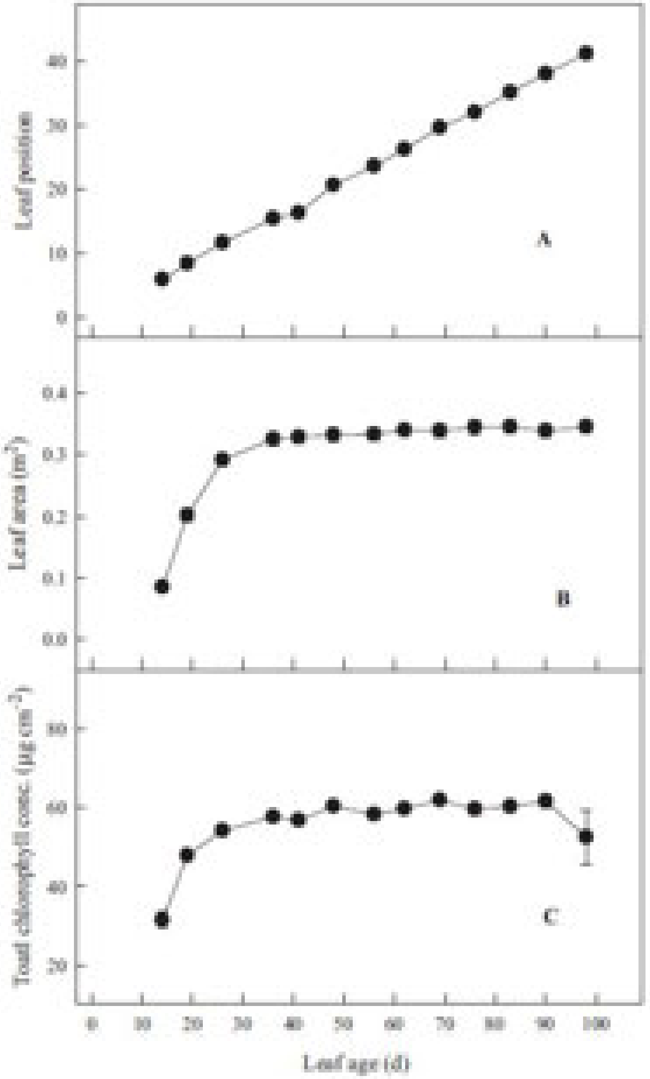
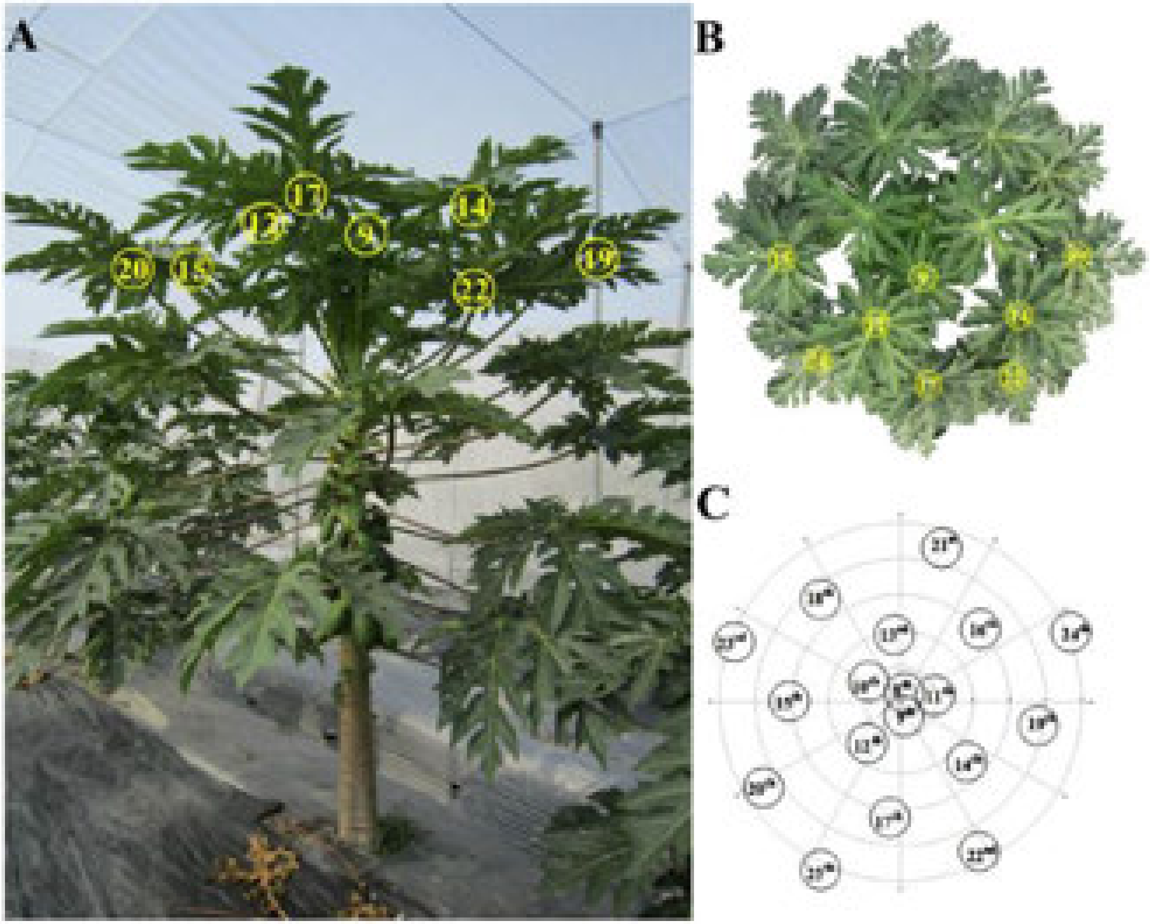


Fig. 2. Effects of leaf age on leaf position (A), leaf area (B) and total chlorophyll concentration (C) of the tagged leaves in 'Tainung No. 2' papaya in 2009–2010 cropping season. Bars indicate standard errors of the mean (n = 8).



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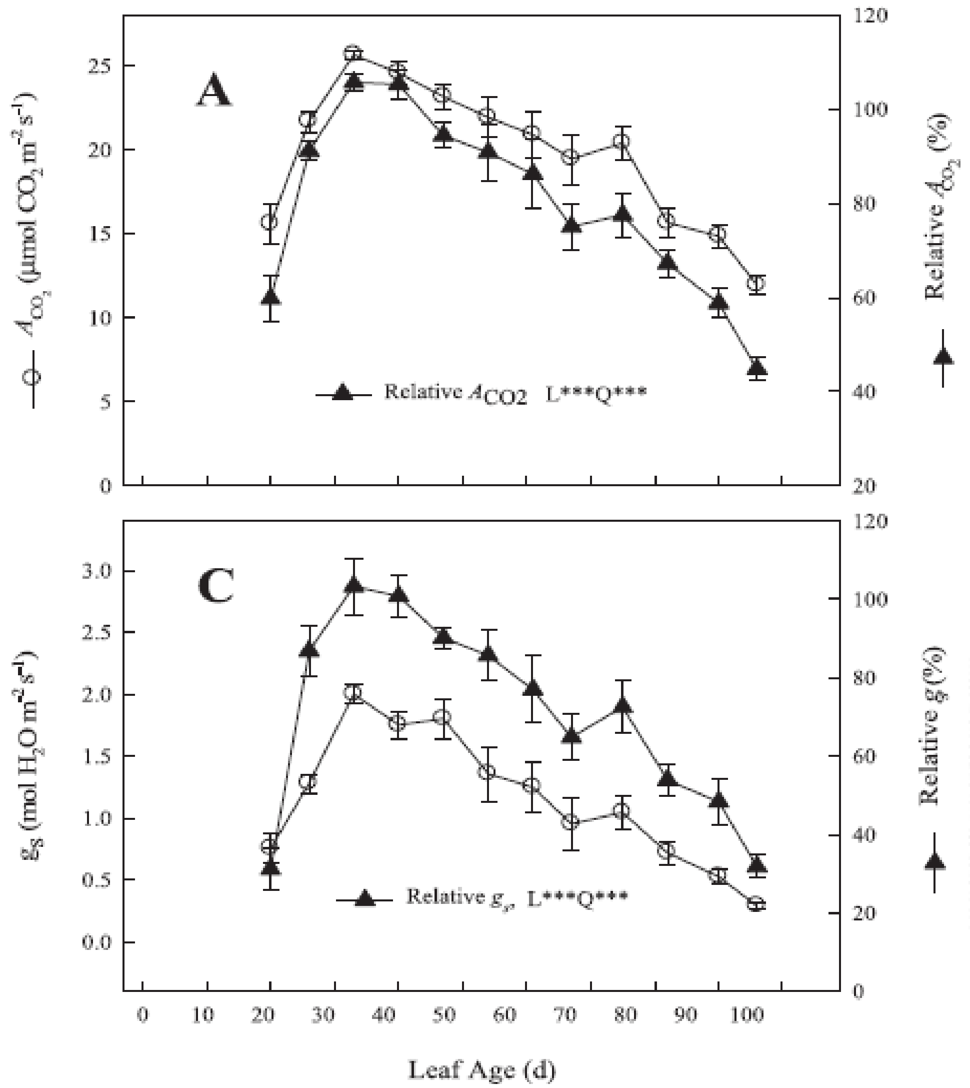


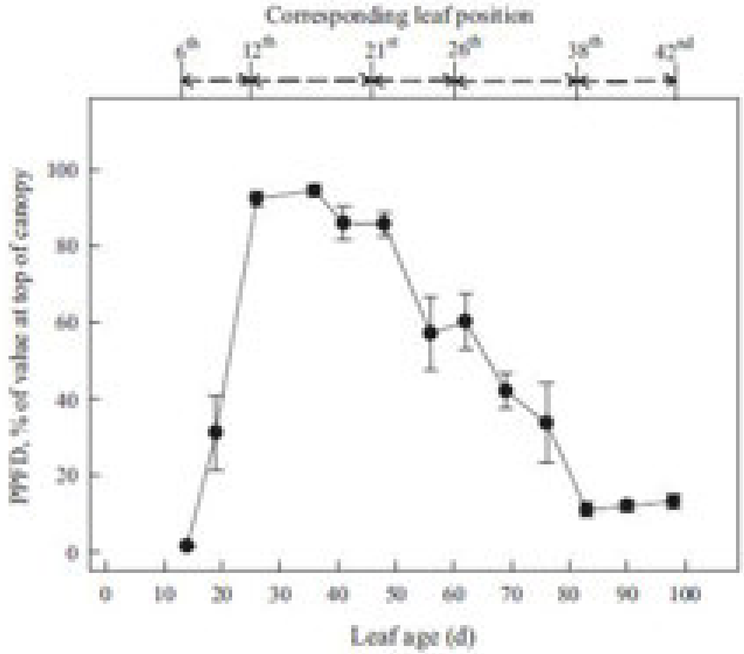
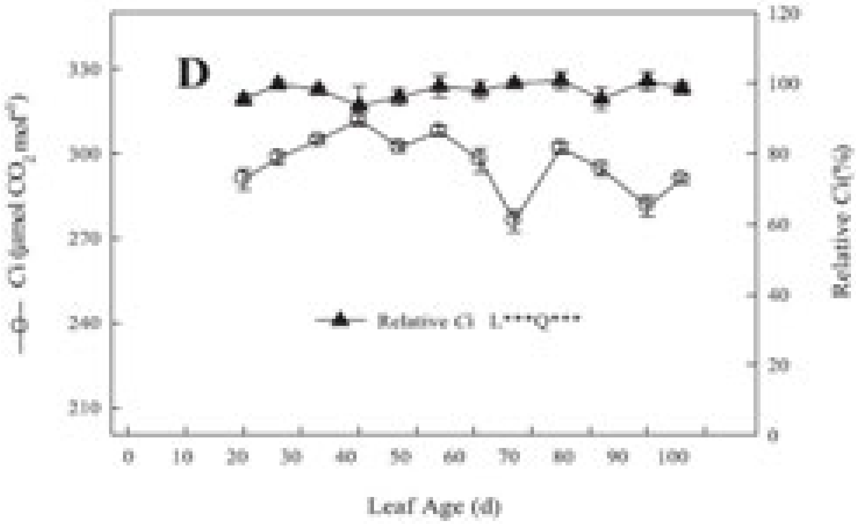
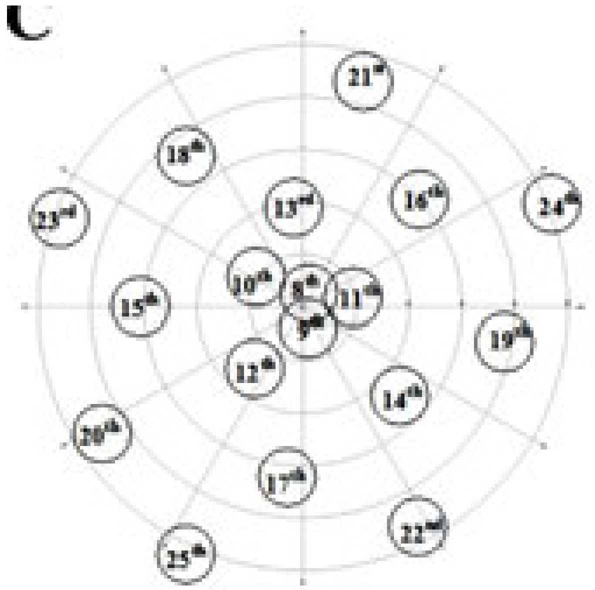
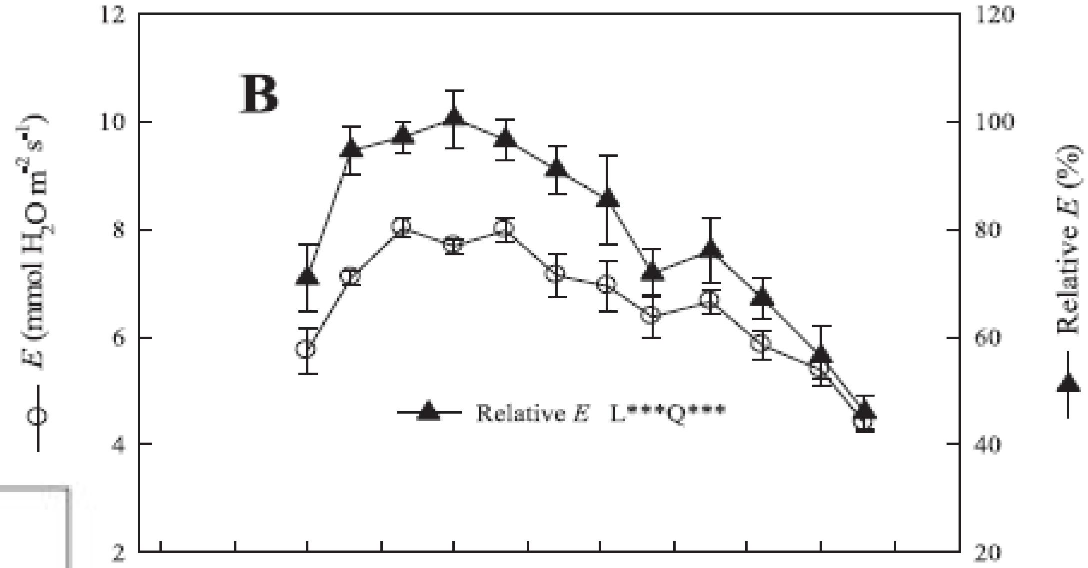


Fig. 3. Changes in PPFD, % of value at top of canopy, on the tagged leaves in 'Tainung No. 2' papaya in 2009–2010 cropping season. Bars indicate standard errors of the mean (n = 8).







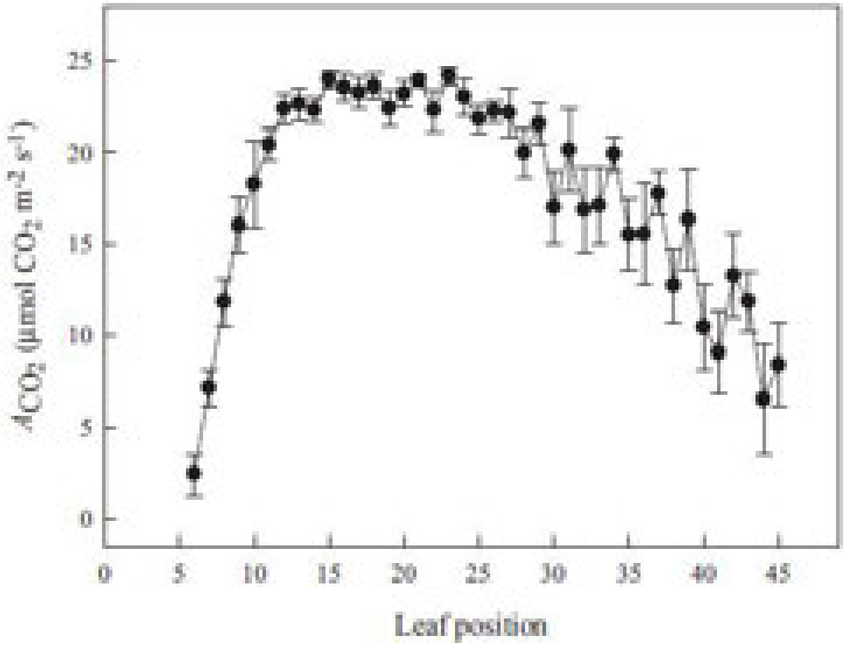


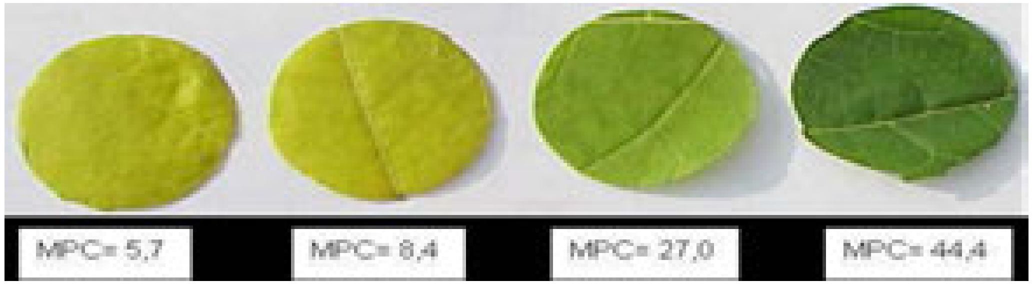
Fig. 6. Effects of leaf positions on the maximum net CO_2 assimilation (A_{CO_2}) of the leaves in 'Tainung No. 2' papaya in 2009–2010 cropping season. Bars indicate standard errors of the mean ($n = 5$).

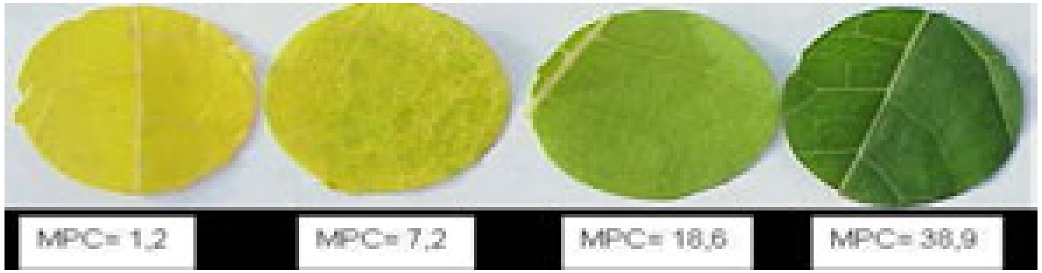
3.6m x 1.5m = 5.4m2 field condition in Brazil   Almeria greenhouse: 3.0m x 1.6m = 4.8 m2

The papaya photosynthetic capacity can be linked to non stomatal limitation in soil field capacity condition.

As exemple:
-Nitrogen leaf concentration

15 g kg^{-1}DM **35 g kg^{-1}DM**





18 g kg^{-1}DM **37 g kg^{-1}DM**

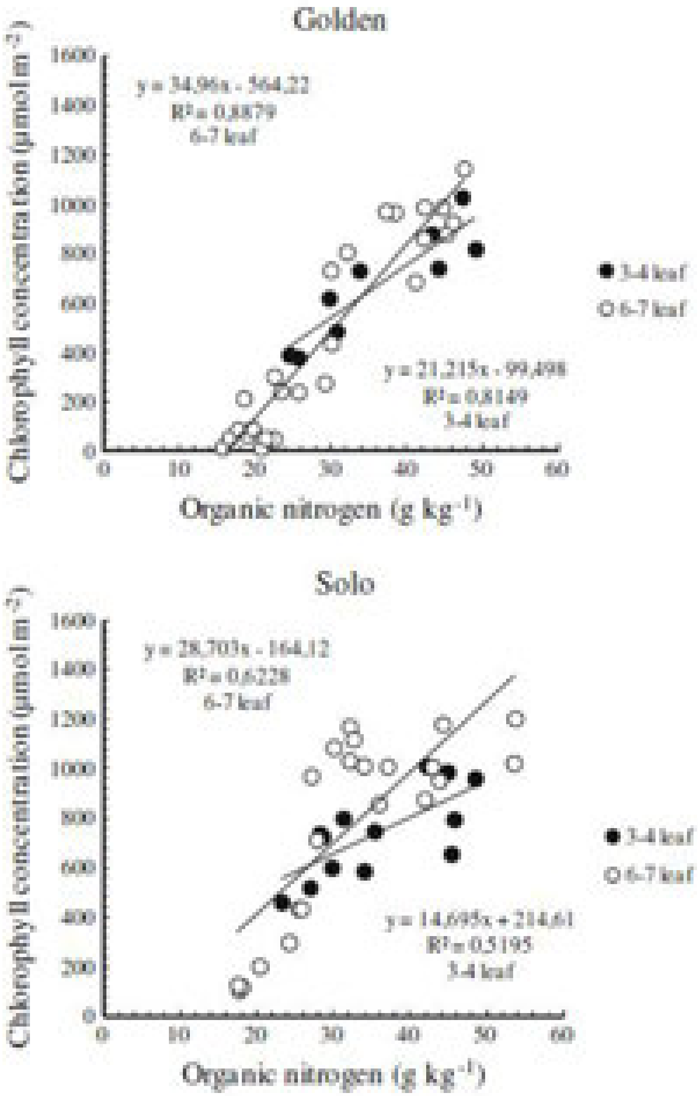


Fig. 2 Relationship between chlorophyll concentration (a+b) (µmol m^{-2}) and leaf N_{org} (g kg^{-1} DW) in 'Solo' and 'Golden' papaya plants cultivated in greenhouse conditions. The R^2 indicated significant correlation at the 0.1 % level

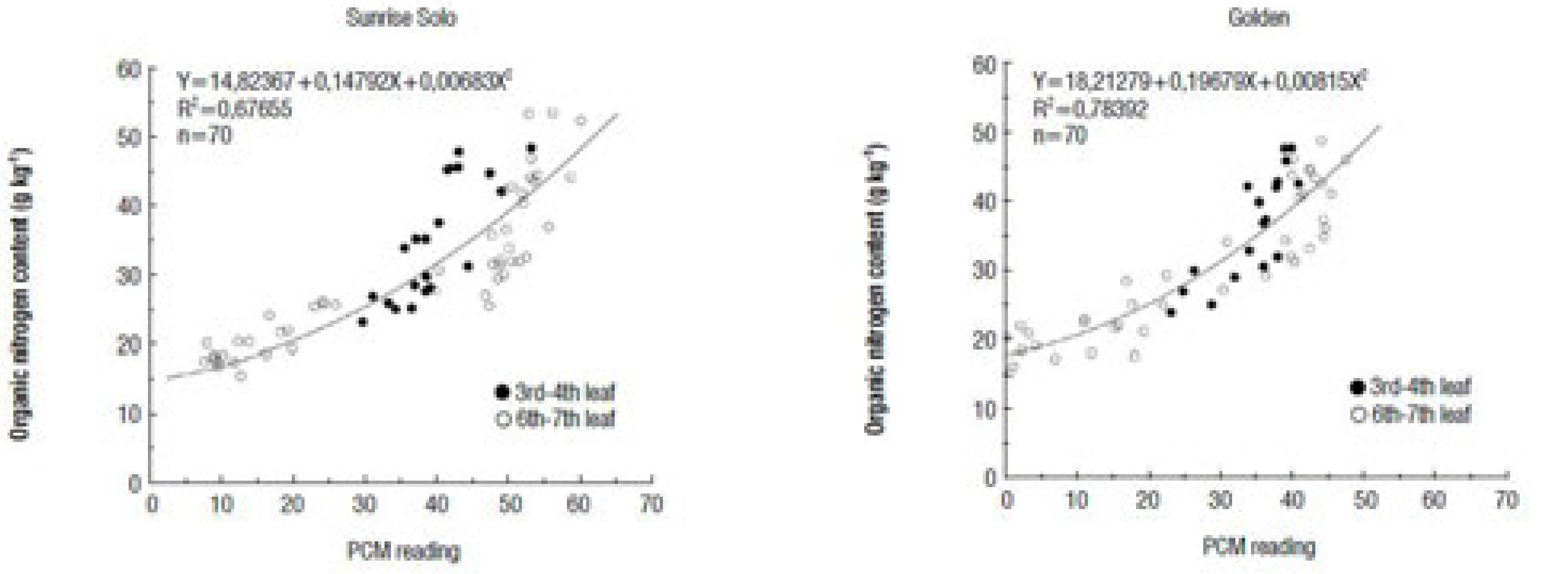
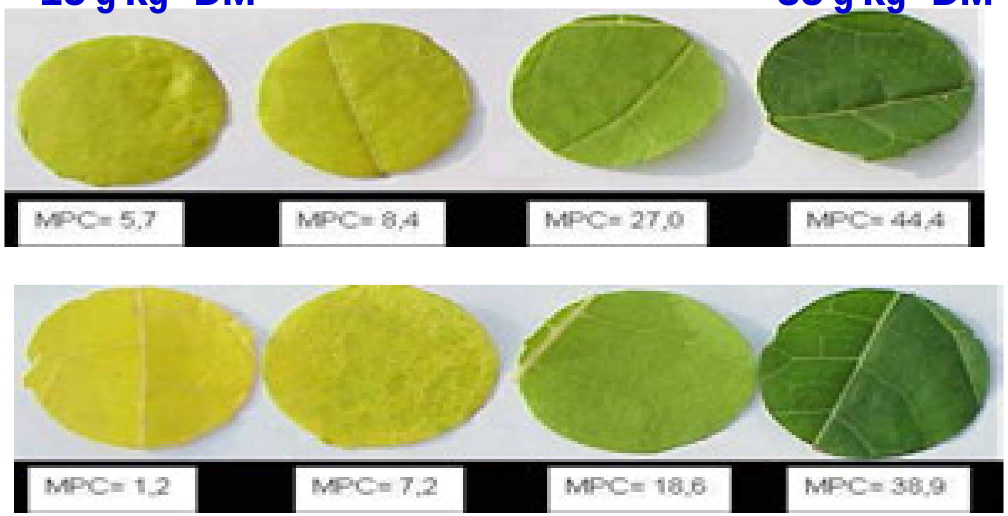


Figure 4. The relation between the organic nitrogen content and the PCM reading, in Sunrise Solo and Golden papaya plants, cultivated in a greenhouse. The open circles with reduced PCM readings (<30) refer the senescent 6th – 7th leaves.

15 g kg^{-1}DM **35 g kg^{-1}DM**



18 g kg^{-1}DM **37 g kg^{-1}DM**

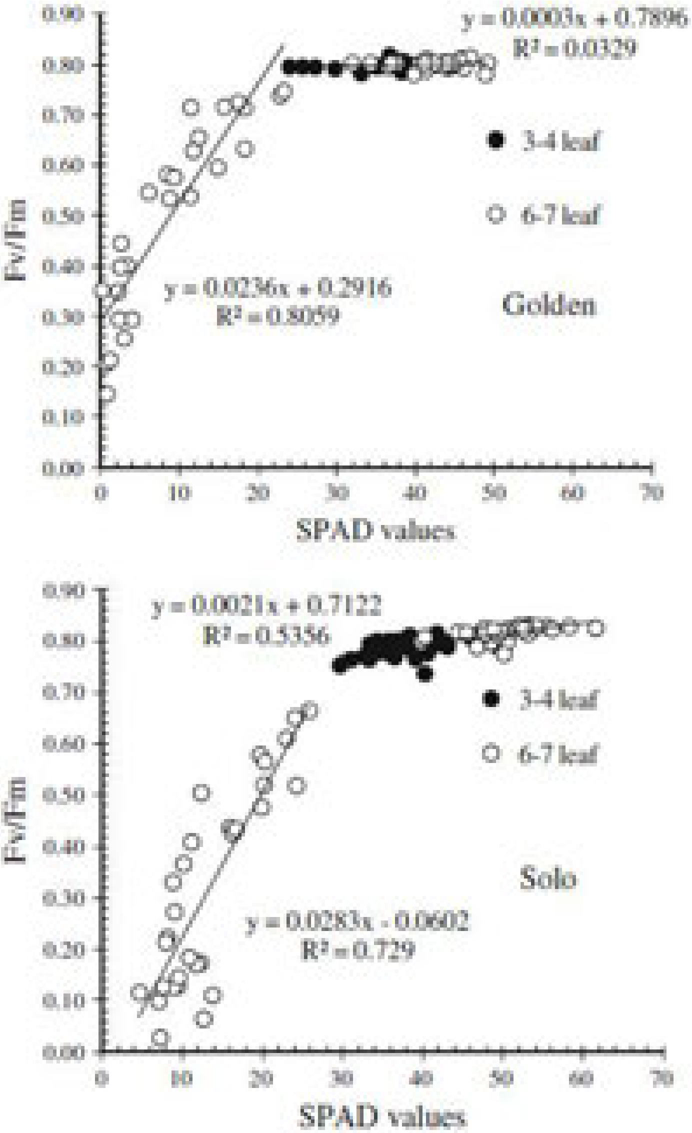


Fig. 6 Relationship between total maximum quantum efficiency (F_v/F_m) and SPAD values in 'Solo' and 'Golden' papaya plants cultivated in greenhouse conditions. R^2 indicate significant correlation at 0.1 % level

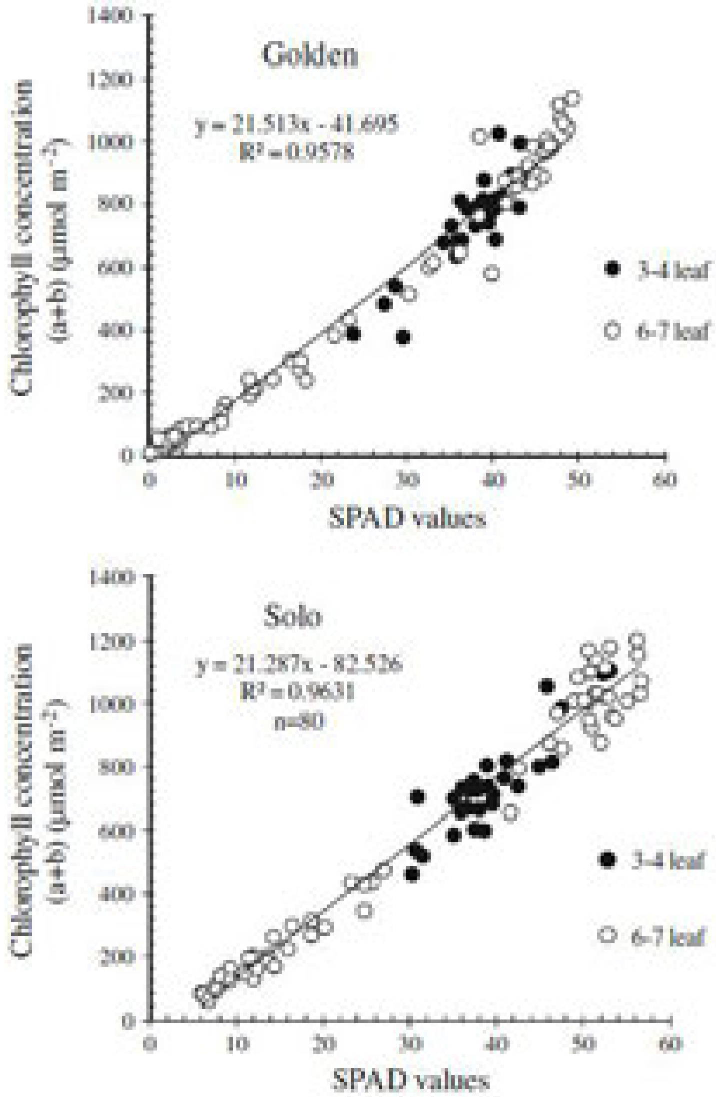


Fig. 4 Relationship between chlorophyll concentration (a + b) (μmol m^{-2}) and SPAD values in 'Solo' and 'Golden' papaya plants cultivated in greenhouse conditions. R^2 indicate significant correlation at the 0.1 % level

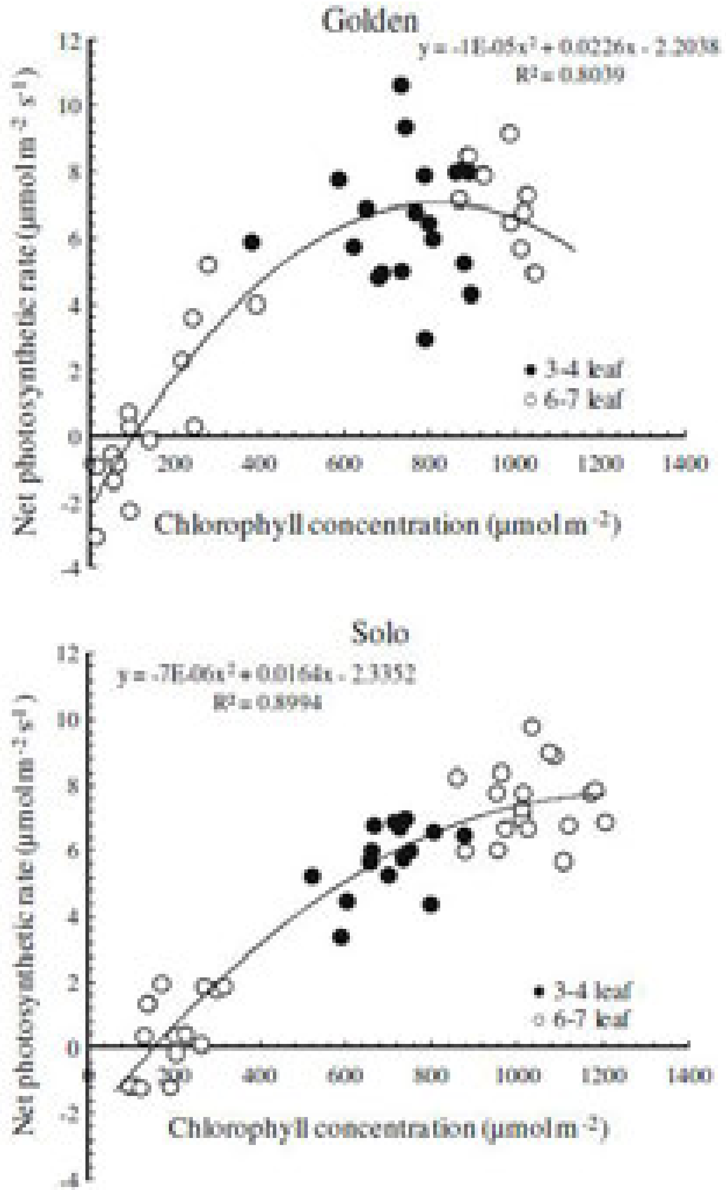


Fig. 3 Relationship between net photosynthetic rate (A) (μmol m^{-2} s^{-1}) and chlorophyll concentration (a + b) (μmol m^{-2}) in 'Solo' and 'Golden' papaya plants cultivated in greenhouse conditions. R^2 indicate significant correlation at the 0.1 % level

Theor. Exp. Plant Physiol.
DOI 10.1007/s40626-014-0018-y

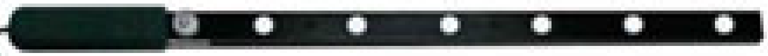
Portable chlorophyll meter (PCM-502) values are related to total chlorophyll concentration and photosynthetic capacity in papaya (*Carica papaya* L.)

Fernanda Assumpção De Castro · Eliemar Campostrini · Alena Torres Netto · Mara De Menezes De Assis Gomes · Tiago Massi Ferraz · David Michael Glenn

http://www.specmeters.com/weather-monitoring/weather-stations/2000-mini-stations/watchdog-2475-plant-growth-station/

Model 2475 Mini Station shown

EXAMPLE RED TO FAR-RED RATIOS	
Sunlight	1.2
Under a canopy of leaves	0.13
Under 5mm of soil	0.88



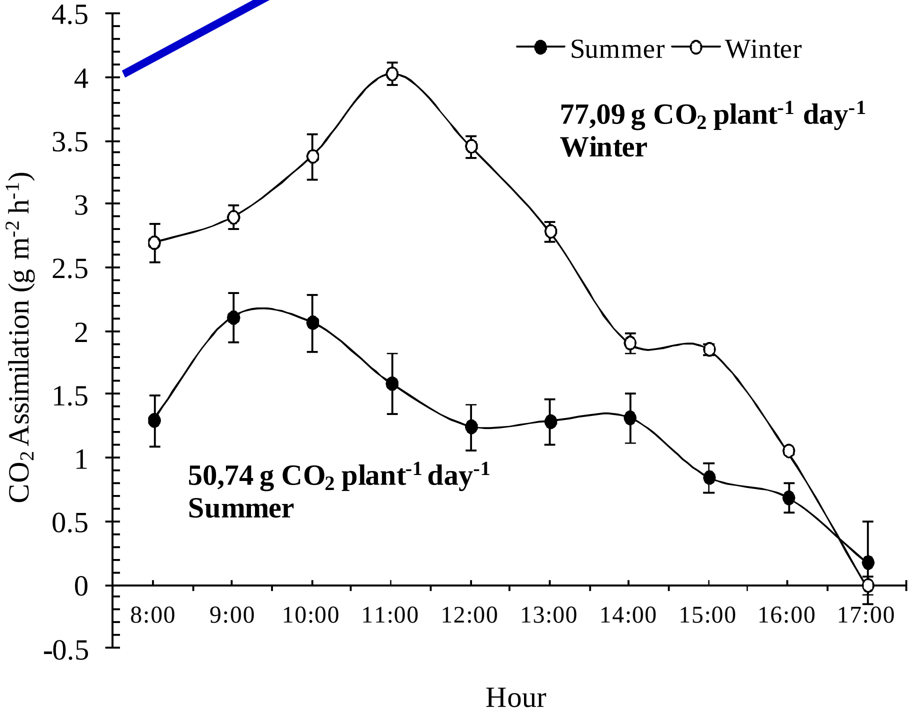
Individual light sensors, available individually or as
or 6 sensors, allow you to measure site-specific are
hand-held sensors feature cosine correction, built-ir
mounting brackets for stationary measurements. Li
frequently used when measuring across a greenhou

3415FX	**Field Scout External Light Sensor Meter**
3668I	**Quantum Light Sensor**
3668I3	**Quantum Light 3 Sensor Bar**
3668I6	**Quantum Light 6 Sensor Bar**
3676I	**UV Light Sensor**
3670I	**Silicon Pyranometer Sensor**

3686WD
with 3668I

Whole-canopy photosynthesis

25.2 μmol m^{-2} s^{-1}



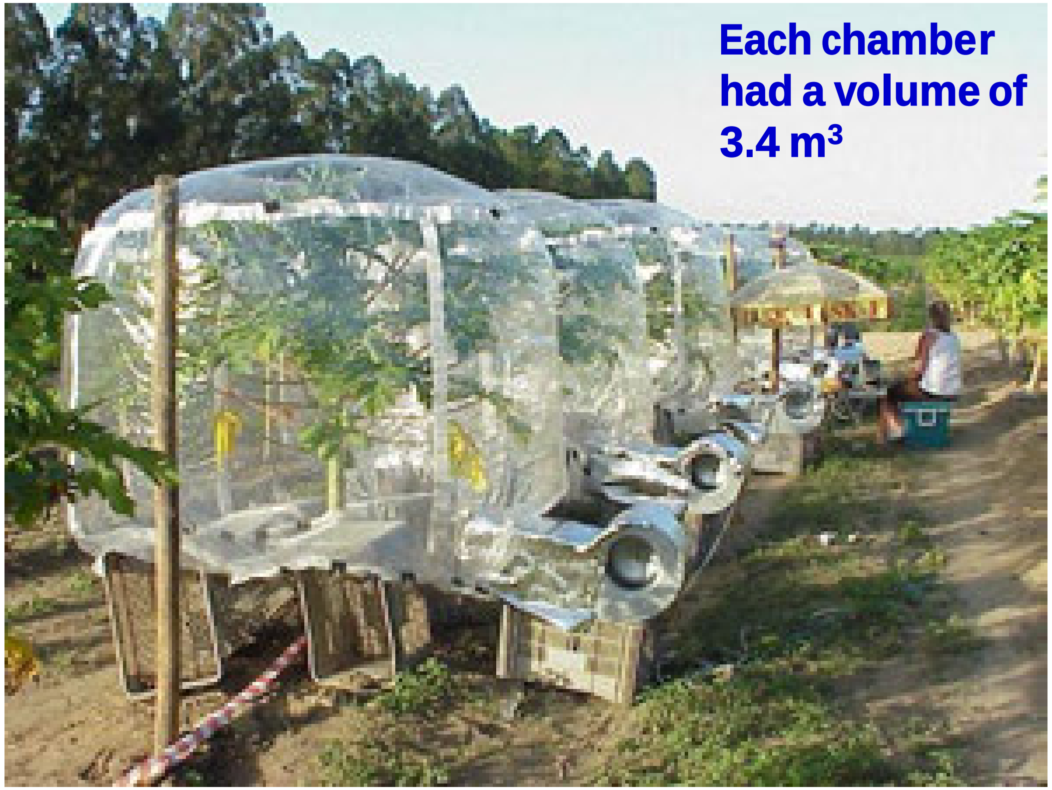
g CO_2 m^{-2} h^{-1} to μmol m^{-2} s^{-1}

conversion factor is **6.30**

The crop was irrigated with a drip/fertigation system providing supplemental irrigation of **10** (winter) and **16 L per plant per day** (summer)

Summer: (clear sky, during 4 days)
PPF_{max}: 2400 μmol m^{-2} s^{-1}
T_{max}: 38ºC
VPD_{max}: 4 kPa

Winter: (clear sky during 4 days)
PPF_{max}: 1400 μmol m^{-2} s^{-1}
T_{max}: 33ºC
VPD_{max}: 3.5 kPa



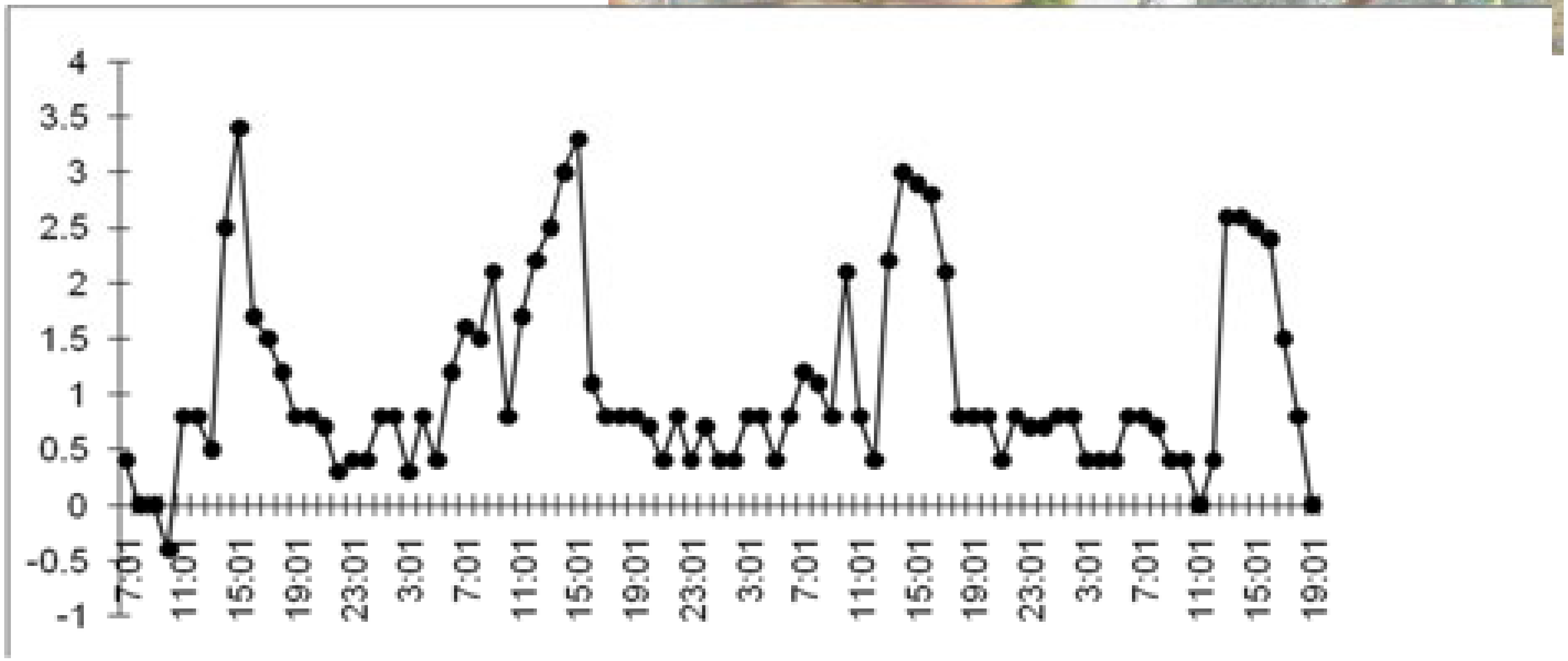
Under the environmental conditions evaluated :
(4 sunny days)

Winter:
Maximum vapor pressure deficit (VPD_{air})=3.5 kPa
Air maximum temperature of 33°C
Maximum PPF: 1400 μmol m^{-2} s^{-1}

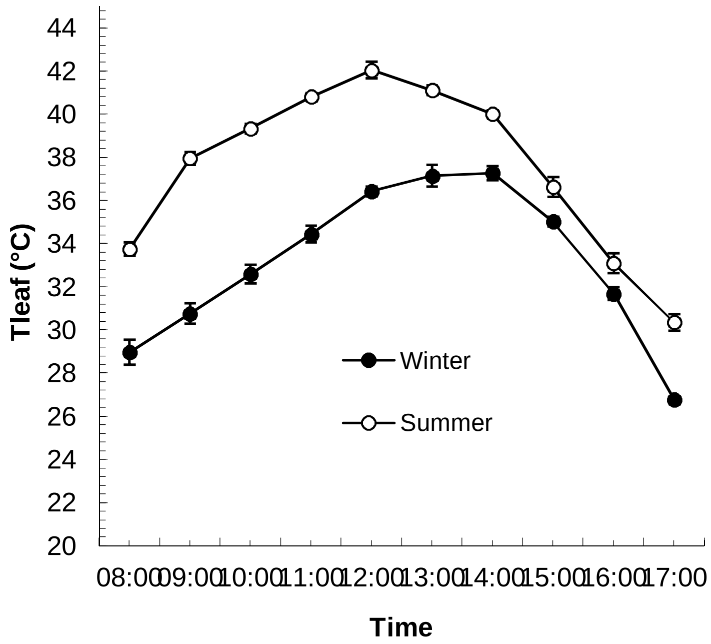
Summer
Maximum VPD_{air}=4.0 kPa
Air maximum temperature of 38°C
Maximum PPF : 2400 μmol m^{-2} s^{-1}

Leaf area each plant
5 months old
Winter :3.5m²
Summer: 4 m²

$T_{air\ inside\ ballon} - T_{air\ outside}$ ºC



Luz



44
42
40
38
36
34
32
30
28
26
24
22
20
Tleaf (°C)
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
17:00
Time
Winter
Summer

Air temperature

Optimal temperature:

21 a 33ºC (Knight, 1980)
22 A 26ºC (Lassoudiere, 1968)
30ºC (Allan, 1978)

Allan and Jager (1978) reported that A increased when air temperature rose from 16 to 30°C, and then A decreased linearly at temperatures above 30°C, the value at 41°C being half that at 30°C

However, air temperature acts indirectly on papaya photosynthesis via increases in leaf-to-air VPD! (stomatal limitation)

When air temperature increased from 20° to 40°C for 'Sunrise Solo' papaya growing in Linhares, southeastern Brazil, the $VPD_{leaf\ air}$ increased from 2 to 6 kPa and *A* decreased from 20 to 5 $\mu mol\ m^{-2}\ s^{-1}$ (Torres-Netto, 2000)

Air temperature

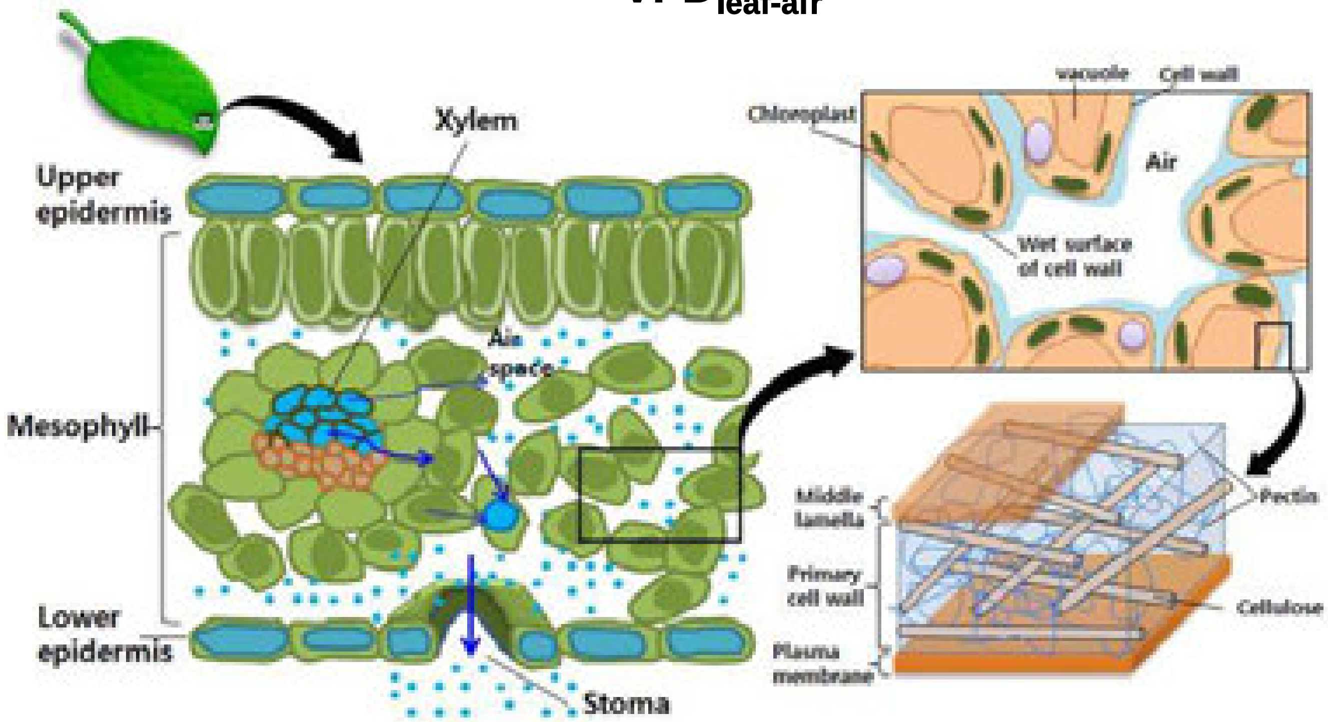
High air temperature and low Relative Humidity increase VPD_{air}

$$VPD_{air} = 0{,}61137 * \exp\left(17{,}502 * T° \,/\, 240{,}97 + T°\right) * \left(1{,}0 - \left(UR\% \,/\, 100\right)\right)$$

Threshold VPD values to papaya:
VPD_{air} = < 1kPa $(e_{sair} - e_{air})$
$VPD_{leaf\text{-}air}$ = < 2kPa $(e_{sleaf} - e_{air})$

High VPD_{air} and $VPD_{leaf\text{-}air}$ reduce g_s

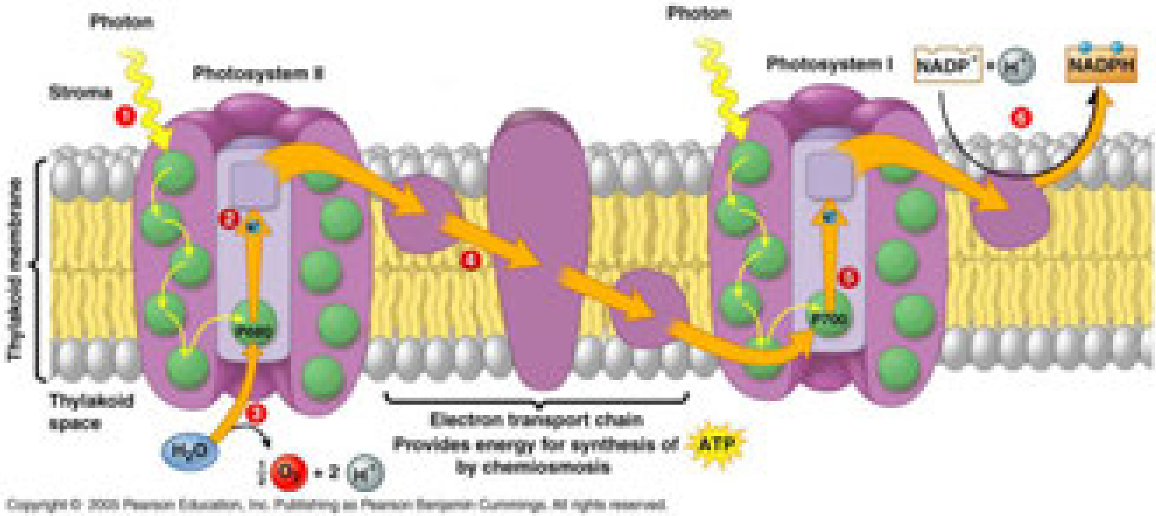
$VPD_{leaf\text{-}air}$



In addition, air temperature acts directly on papaya leaves photosynthesis via increases in leaf temperature
(non stomatal limitation)

Nonstomatal limitation:
-inhibition of Rubisco,
-heat stress results in a loss of the oxygen evolving complex activity ([Enami et al., 1994]; [Yamane et al., 1998]),
-**dissociation of the peripheral antenna complex of PSII from its core complex ([Gounaris et al., 1984]; [Srivastava et al., 1997])**
-**inhibition of electron transfer from primary / secondary electron-accepting plastoquinone of PSII at the acceptor side ([Bukhov et al., 1990]; [Cao and Govindjee, 1990]),**

High temperature increases the membrane fluidity and electron transport is blocked!!
Than F_o increase



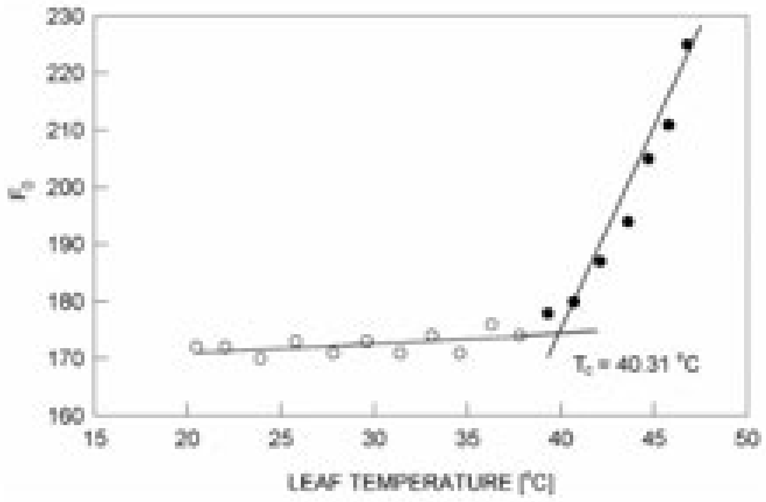


Fig. 1. Determination of the critical temperature (T_c, the temperature at which basic fluorescence F_0 increased sharply when leaf was exposed to high temperature treatment at about 1 °C min^{-1} graduation in darkness) as the intersection point of two regression lines extrapolated from the slow and the fast rising portions of the temperature-dependent F_0 response.

Family	Scientific name (common name, type)	T_c [°C] Jan.-Feb.
Bromeliaceae	*Ananas comosus* (pineapple, CAM)	47.19±0.99
Gramineae	*Zea mays* (maize, C_4)	42.67±0.07
Gramineae	*Saccharum officinarum* (sugarcane, C_4)	41.31±0.51
Gramineae	*Miscanthus transmorrisonensis* (C_4)	43.52±1.54
Gramineae	*Miscanthus floridulus* (C_4)	44.39±0.86
Gramineae	*Oryza sativa* (rice, cv. Taiken 14, C_3)	27.02±1.03 45.59±0.76[#]
Convolvulaceae	*Ipomoea batatas* (sweet potato, C_3)	29.39±0.60 33.59±0.28[#]
Convolvulaceae	*Ipomoea aquatica* (C_3)	30.42±0.90 36.91±0.84[#]
Caricaceae	*Carica papaya* (papaya, C_3)	43.85±0.51
Myrtaceae	*Psidium guafava* (guava, C_3)	37.74±0.71
Bombacaceae	*Pachira marrocarpa* (C_3)	29.14±1.18
Anacardiaceae	*Mangifera indica* (mango, C_3)	24.78±0.05
Lauraceae	*Persea americana* (avocado, C_3)	32.00±0.37
Sapindaceae	*Euphoria longana* (longan, C_3)	25.85±0.58
Leguminosae	*Acacia confusa* (C_3)	43.25±0.09
Moraceae	*Ficus retusa* (C_3)	29.46±0.61
Moraceae	*Ficus wightiana* (C_3)	32.18±0.82
Rutaceae	*Citrus sinensis* (orange, C_3)[##]	36.71±0.38

Carica papaya is heat tolerant!

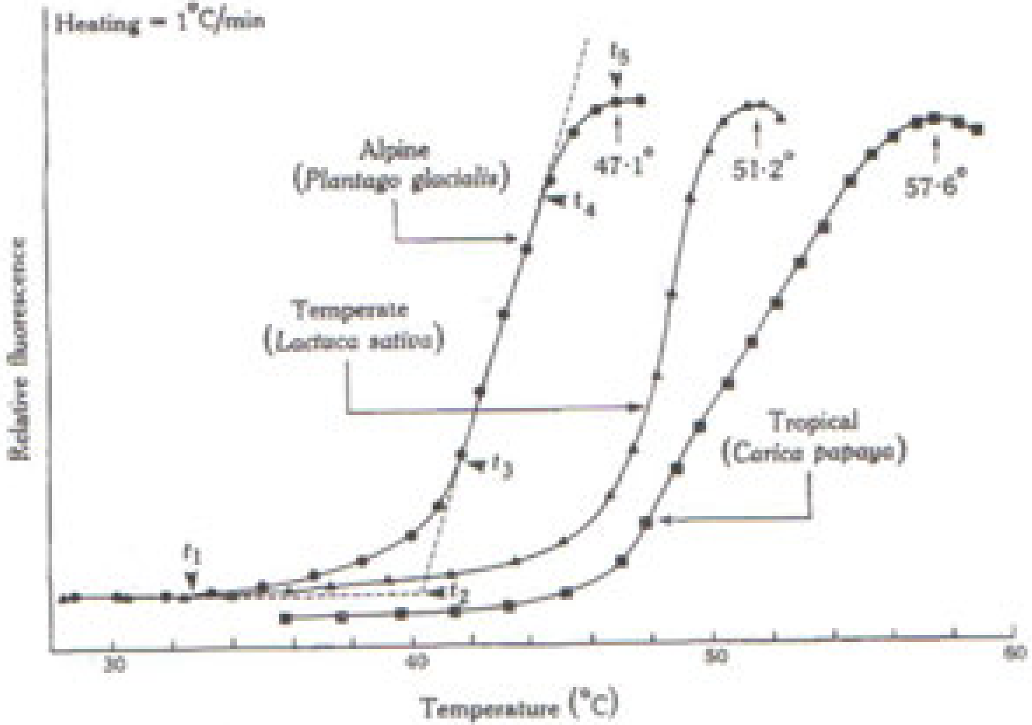
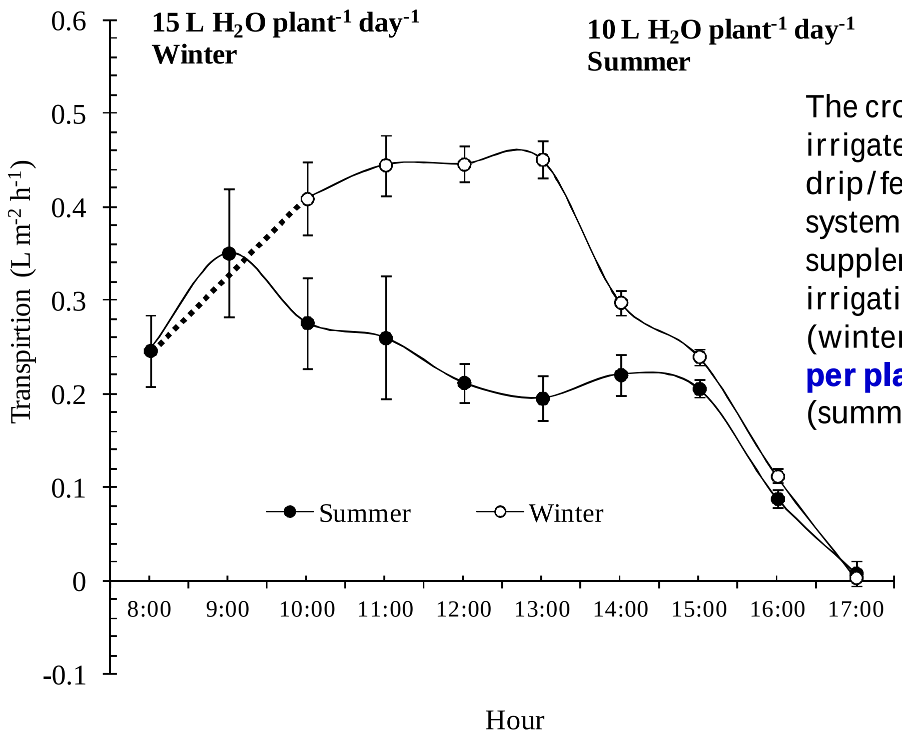
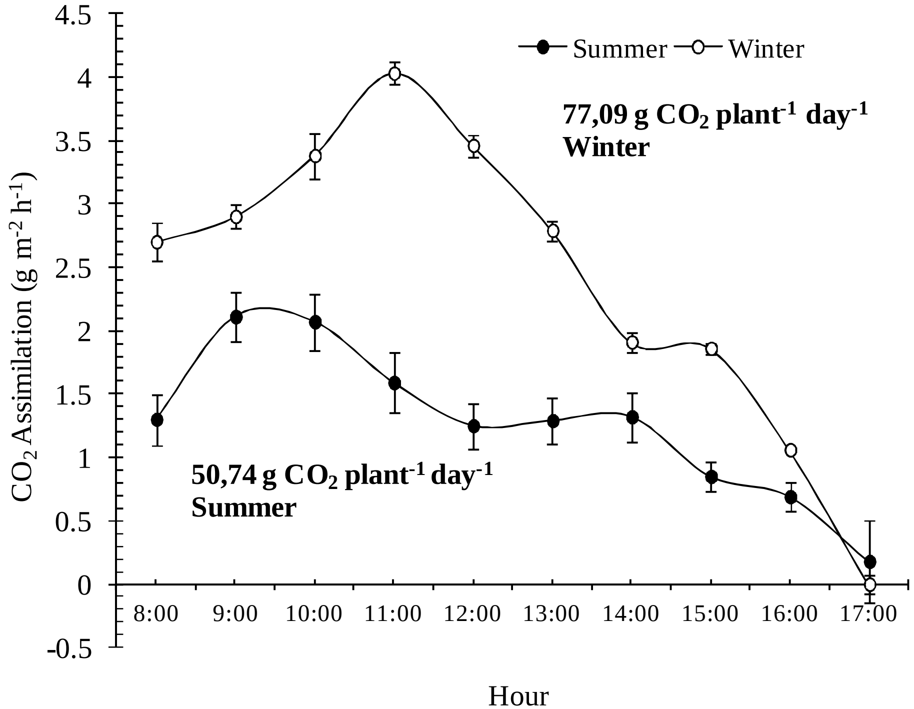


Fig. 1. Changes in chlorophyll fluorescence in leaves of three plants heated continuously at a rate of 1°C per minute. The temperature values (t_1 to t_5) used to compare the fluorescence-heating curves for different plants are shown on the curve for *P. glacialis* (see also text).



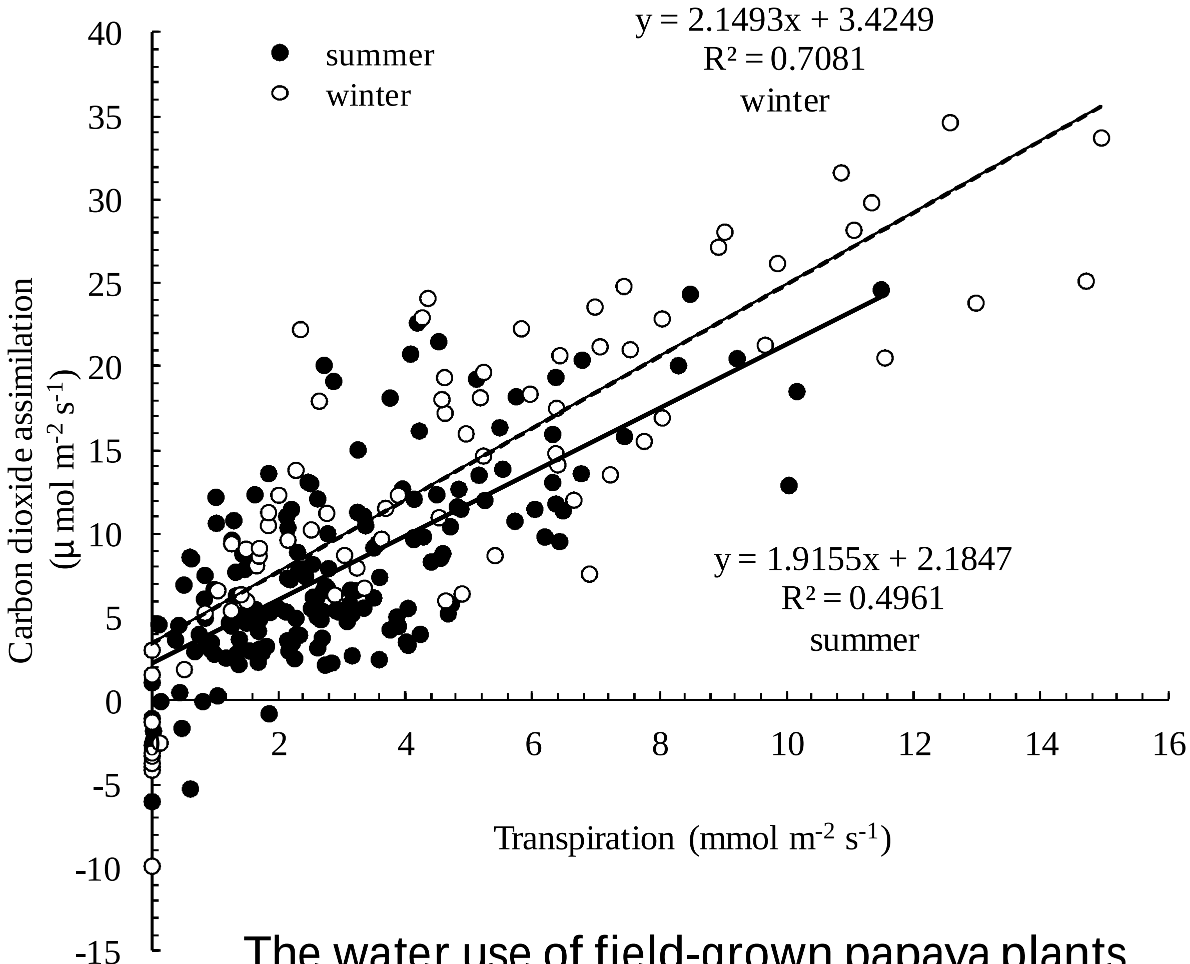
The crop was irrigated with a drip/fertigation system providing supplemental irrigation of **10** (winter) and **16 L per plant per day** (summer)

WUE_{winter} =77/15 = 5gCO_2 kg H_2O^{-1}
WUE_{summer} = 50/10 = 5gCO_2 kg H_2O^{-1}



Reduced whole-canopy photosynthesis and transpiration in papaya in the summer were due to high leaf temperatures (T_{max}=43.9ºC)(due high radiation and high air temperature) and high VPD_{air} (4.0kPa) that caused stomatal closure.

However, high temperature did not affect photochemical efficiency (F_v/F_m) when assessed by chlorophyll fluorescence (F_v/F_m)



The water use of field-grown papaya plants during four days:

Summer:

2.5 L H_2O m^{-2} leaf area day^{-1} $plant^{-1}$

Winter:

4.2 L H_2O m^{-2} leaf area day^{-1} $plant^{-1}$

Papaya (summer and winter)

2 µmol CO_2 mmol H_2O^{-1}

4.8 g CO_2 kg H_2O^{-1}

0.208 L H_2O g CO_2^{-1}

0.0020 mol CO_2 mol H_2O^{-1}

496 mol H_2O^{-1} mol CO_2

C3:

2.48 µmol CO_2 mmol H_2O^{-1}

6.1 g CO_2 kg H_2O^{-1}

0.164 to 0.5 L H_2O g CO_2^{-1}

0.0025 mol CO_2 mol H_2O^{-1}

400 mol H_2O^{-1} mol CO_2

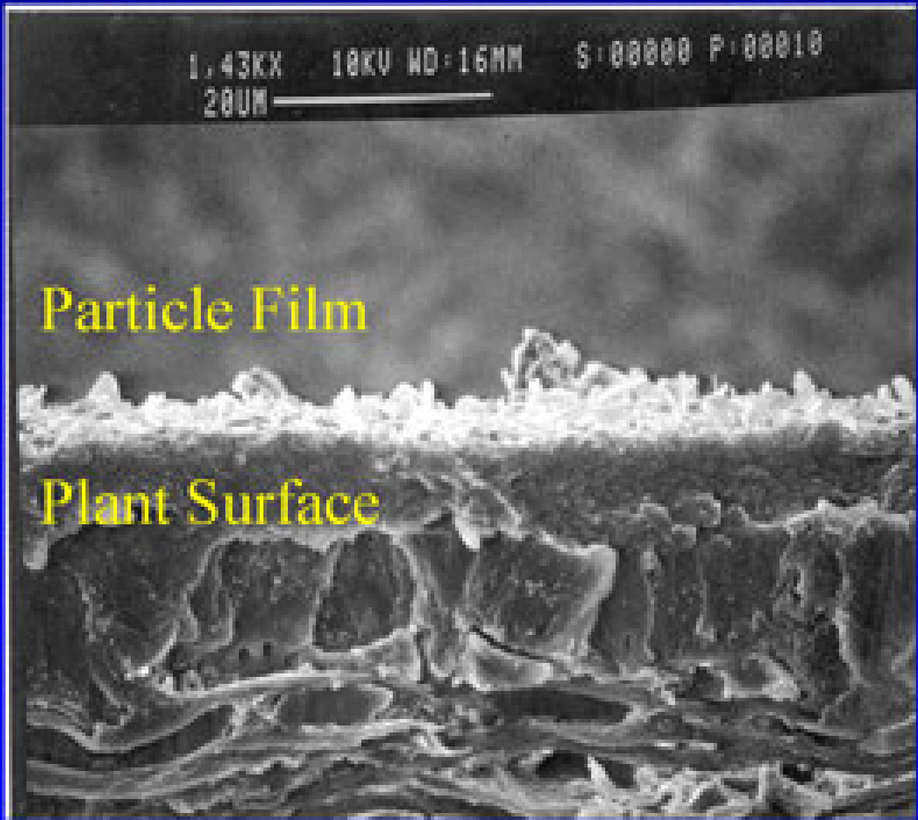
C4:

2 to 5 g CO_2 kg H_2O^{-1}

What strategies to reduce negative effects of high PPF on photosynthesis in summer

Particle film

What is a 'Particle Film'?



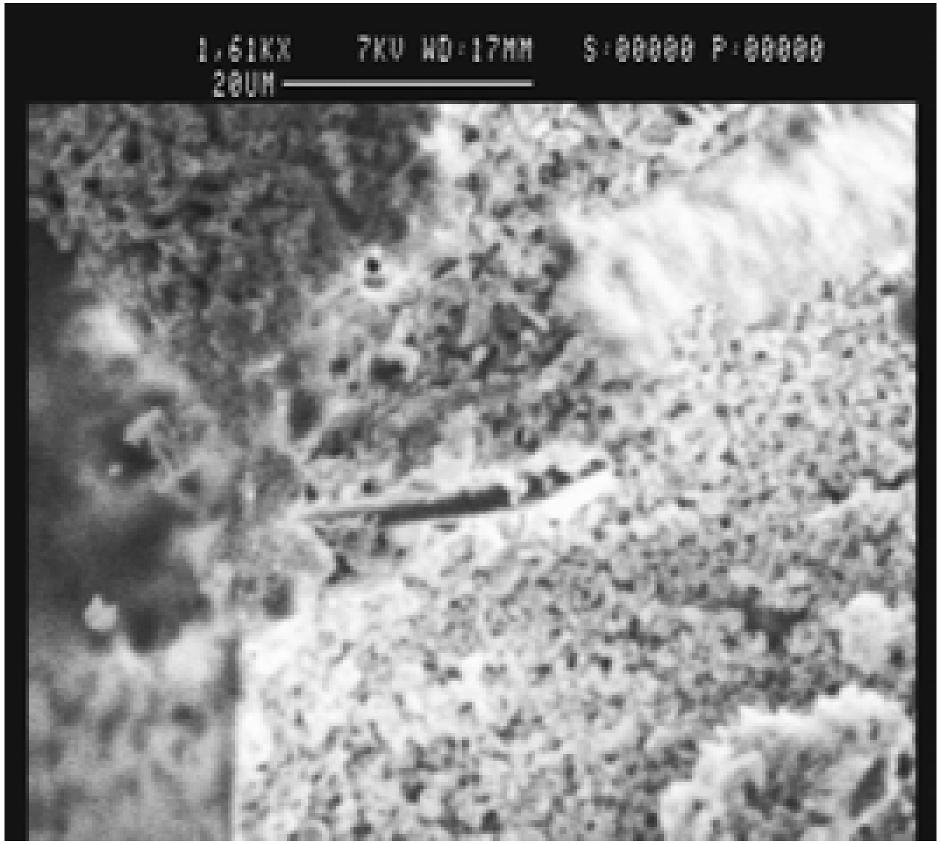
- A microscopic layer of mineral particles
- allows water and carbon dioxide to pass through the film

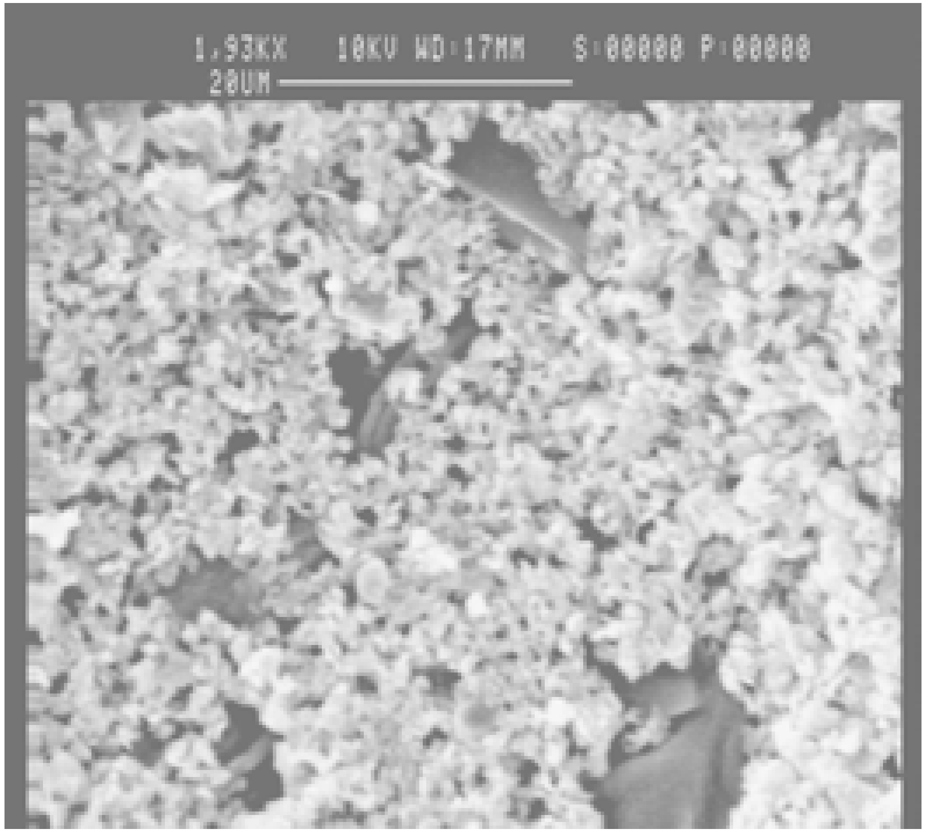
Source:
Dr. David Michael Glenn USDA, ARS, West Virginia, USA

Stomates are not blocked

After initial application

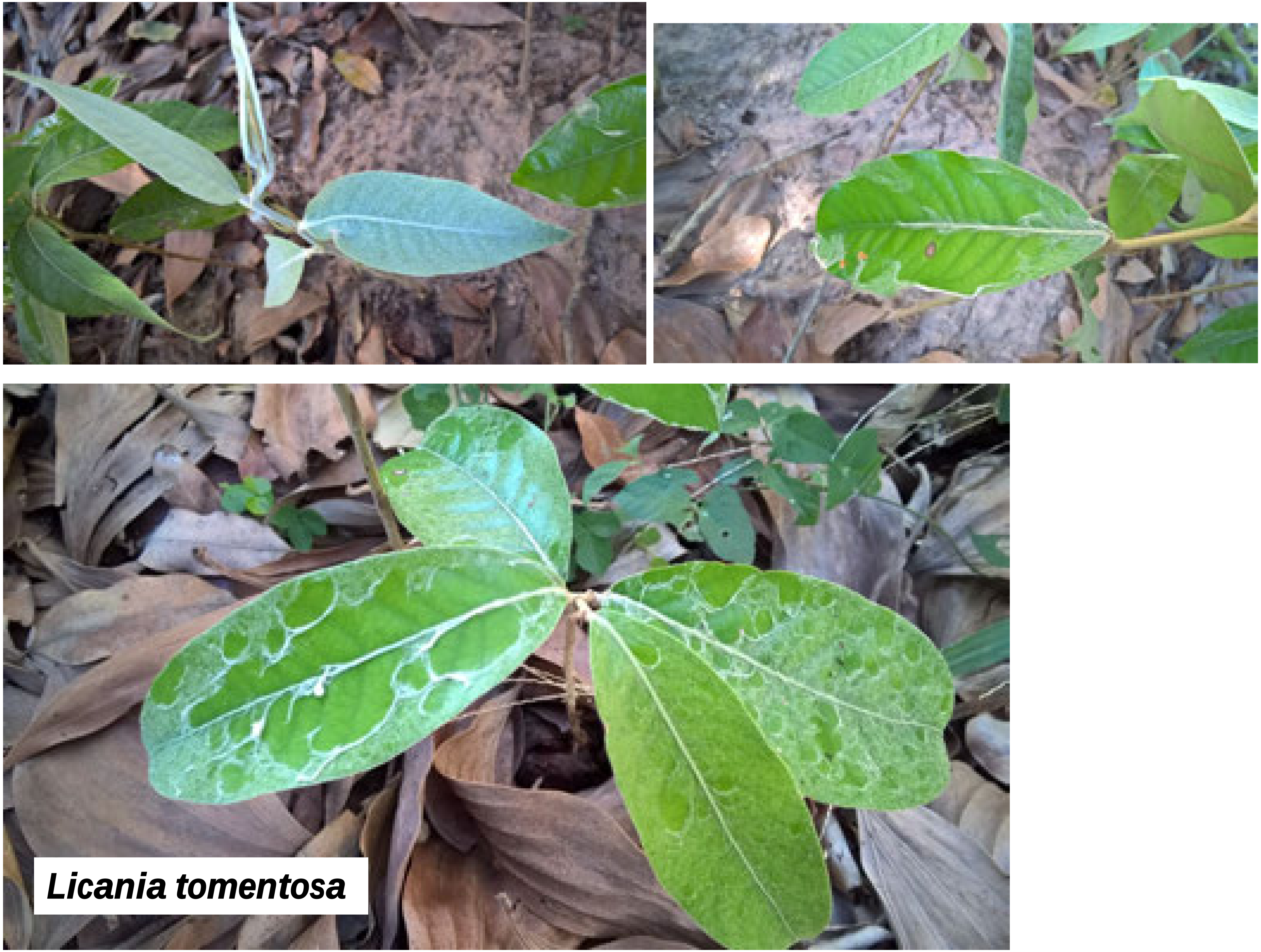
After 24 hours





Reflective surfaces are common plant adaptation

- Plants “use” pubescence and cuticular waxes to reduce environmental stresses and reduce disease and insect damage
- Particle film technology builds on this strategy of a reflective plant surface that repels insects



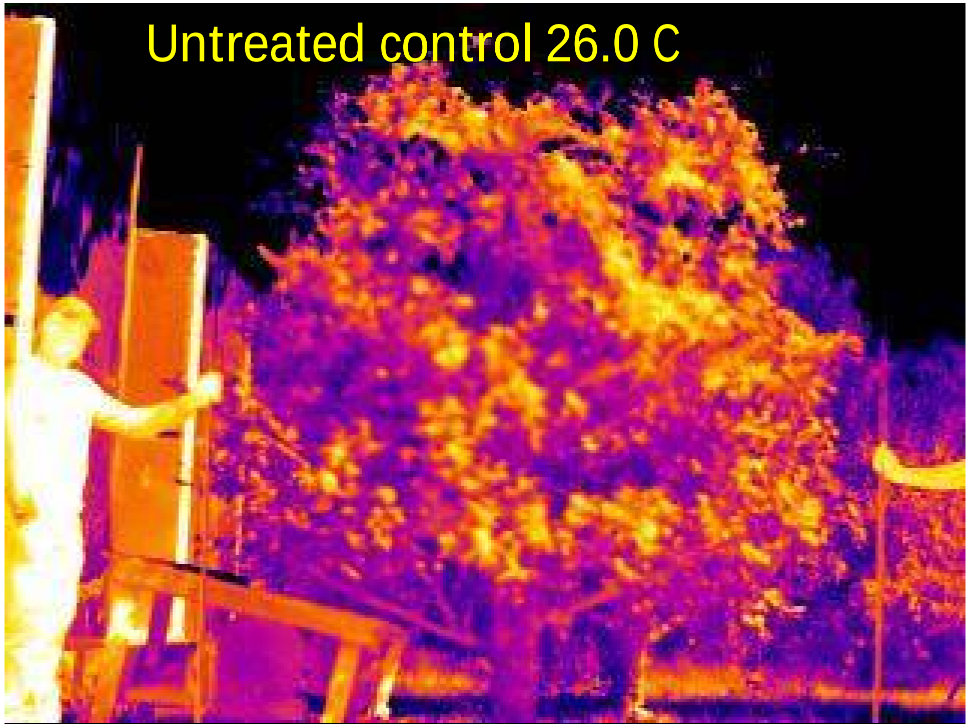
Licania tomentosa

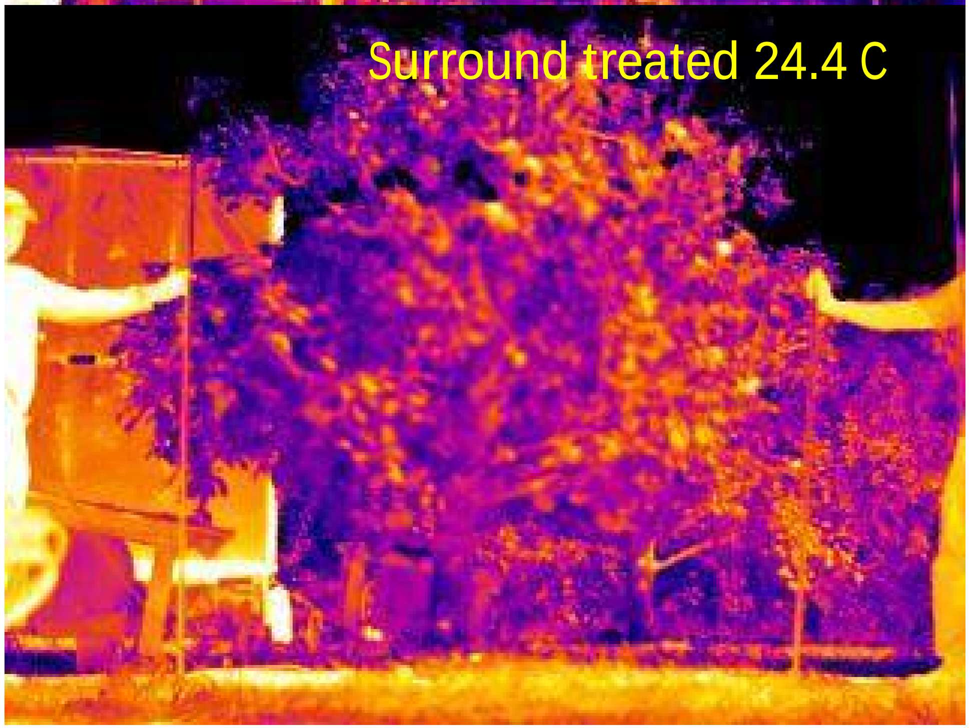
3% kaolin

Source:
Dr. David Michael Glenn USDA, ARS, West Virginia, USA

12% kaolin

Source:
Dr. David Michael Glenn USDA, ARS, West Virginia, USA





Infrared image of apple trees