Vegetable Grafting

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Outline

- Introduction
- A Brief History
- Why Grafting
- Grafting Methods
- Application Potentials
- Grafting research units in the United States

Ji'nan, China

Feb. 2008

June 2010

- ***Increased vigor***
- ***Enhanced cold tolerance***
- ***Improved yield and quality***
- ***Increased disease resistance***

June 2010


PURE C

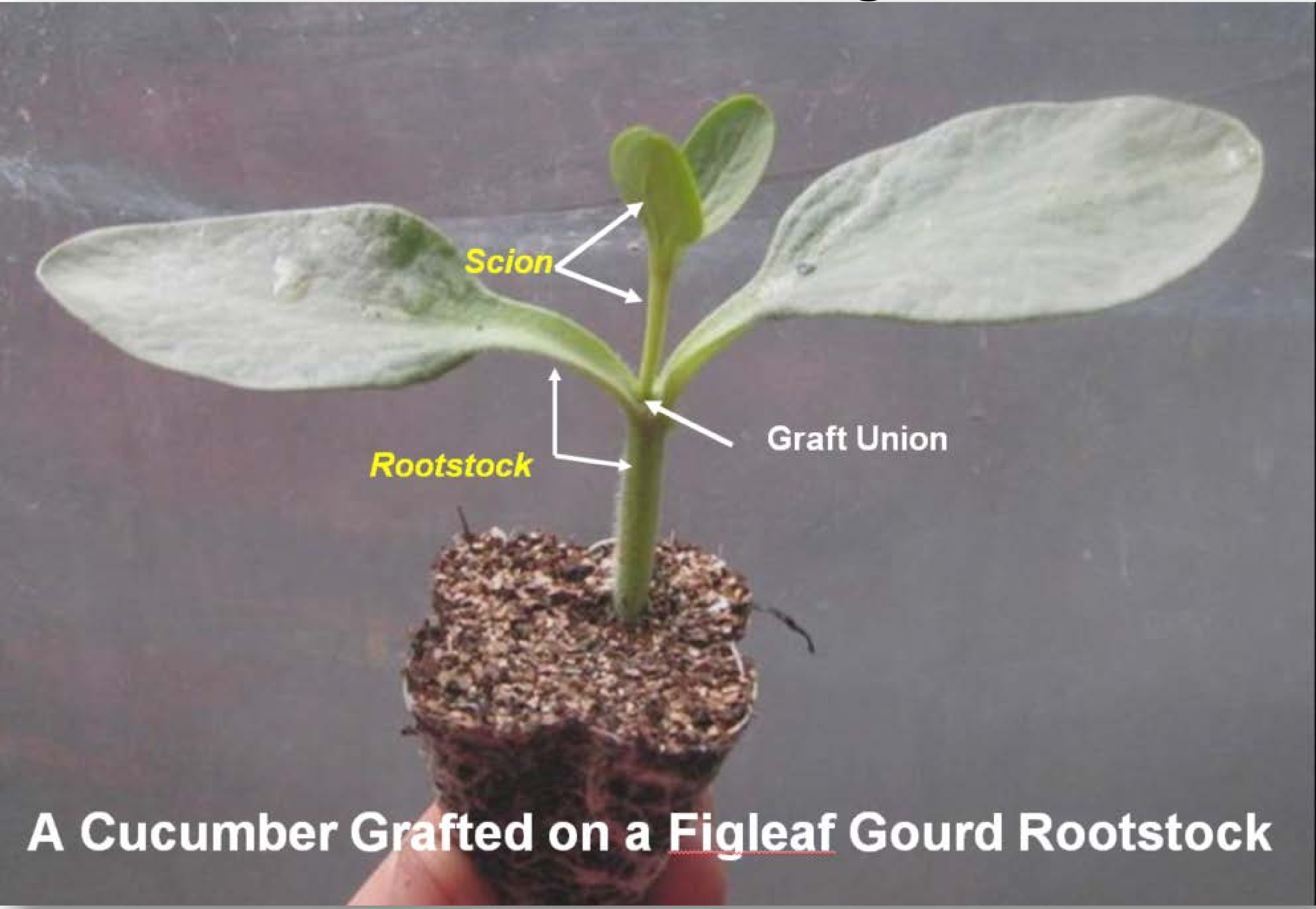

四心”——育苗工作者态度达标
用心、耐心、精心、诚心

Lisbon, Portugal 2010

--Increased vigor and yield


Gainesville, Florida 2010
--Disease Resistance

What is Grafting?




BEAUFORT

Grafting, an Old Technology

- Grafting traces back to antiquity with fruit and nut crops
  - In ancient Chinese literature (1560 BC)
  - Discussed in the agricultural writing of **Aristotle** (384-322 BC) and **Theophrastus** (371-287BC)
  - Pear grafting was discussed in "*Qi Min Yao Shu*" (***Si-xie Jia***, 386-543)

氾胜之书

齐民要术: 起自耕农，终于醯醢，资生之事，靡不毕书

Vegetable Grafting

- Opo squash grafting was first described by ***<u>Sheng-zhi Fan</u>*** (100 BC)
- Later detailed by ***Si-xie Jia*** (286-543): sow 10 seeds in a circle, bundle growing vines and sealed them with soil, when stems fused, select only one vine to grow, resulting in large guards.
- Similar method described by Hong (1643-1715) in Korea.

History--continued

- The real grafting of vegetables was done by a watermelon farmer in Japan (1927) to overcome Fusarium wilt disease. This technique quickly spread in Japan and then Korea from late 1920s to early 1930s.
- It then has been practiced for many years in east Asia to overcome issues associated with intensive cultivation on limited arable land.
- Vegetable grafting was introduced to Europe and other countries in the late 20th century.
- Later, grafting was introduced to North America from Europe and it is now attracting growing interest, both from greenhouse growers and organic producers.

The current picture

- In Asia
  - 1990: 59% and 81% of fruit vegetables were grafted in South Korea and Japan, respectively
  - 2000: the number was close to 100% (except for tomatoes)
- Over 40 million grafted tomato seedlings are used annually in North American greenhouses, and several commercial trials have been conducted for promoting use of grafted melon seedlings in open fields.
- Tomato grafting has been increasing in the US.
- More researchers from University and USDA ARS are getting into grafting research

The most recent published data for amount of area under cultivation of select cucurbit crops and percentages of total crop grafted within stated country

Country	Crop	Area under cultivation (ha)	Grafted seedlings used (%) Estimated values
South Korea	Watermelon	23,179	98
South Korea	Cucumber	5,853	95
South Korea	Oriental melon	7,077	95
France	Melons	not reported	1–3
France	Cucumber	not reported	1–3
Spain	Melons	not reported	1–3
Spain	Cucumber	not reported	1–3
Honduras	Watermelon	2,000	not reported
Honduras	Melons	500	not reported
Guatemala	Watermelon	1,000	not reported
Guatemala	Melons	50	not reported
United States	Watermelon	250	not reported
Mexico	Watermelon	1,000	not reported
Mexico	Melons	100	not reported

Source: Erard, 2004; Hoyos, 2004; Camacho, 2007; Chadwell, 2007, Huh, 2007.

Grafting cucurbits

Japan: watermelon; Cucurbita moschata; fusarium wilt
Russia: watermelon and melon; C. maxima; cold tolerance, early harvest

1920

1940

Japan: Polyploid watermelon; bottle gourd
Europe: Greenhouse cucumber and melon; fusarium wilt, higher yield, cold and drought tolerance; economic evaluation

1960

Japan: Bottle gourd; lost fusarium wilt resistance
Europe: Emerging diseases; combining grafting with other practices for soilborne disease control

1980

Japan: Grafting robot; Cucurbita spp. rootstock showed potential negative impacts on fruit quality
Europe: Emerging diseases led to reevaluation of rootstocks

2000

Phased-out of MB
U.S.

The 1st International Vegetable Grafting Symposium, 3/17-21, 2014

Why Grafting, the Advantages

- The phase out of **Methyl Bromide** Fumigation made the control of soil-borne disease difficult
- Resistance to some soil-borne diseases
    - **Fusarium wilt**: melon, cucumber and tomato
    - **Bacterium wilt**: tomato, eggplant.
    - **Verticillium wilt**: tomato.
- Resistance to root-knot nematodes: cucumber, melon, watermelon, tomato, eggplant.
- Grafting can transfer resistance against the carmine spider mite from *Lagenaria* rootstocks to *Cucurbita* scions.
- Some rootstocks can render grafted plants resistant to some viruses.

- **Enhanced vigor and cold hardiness**
- **Often increase fruit size, yield and quality**

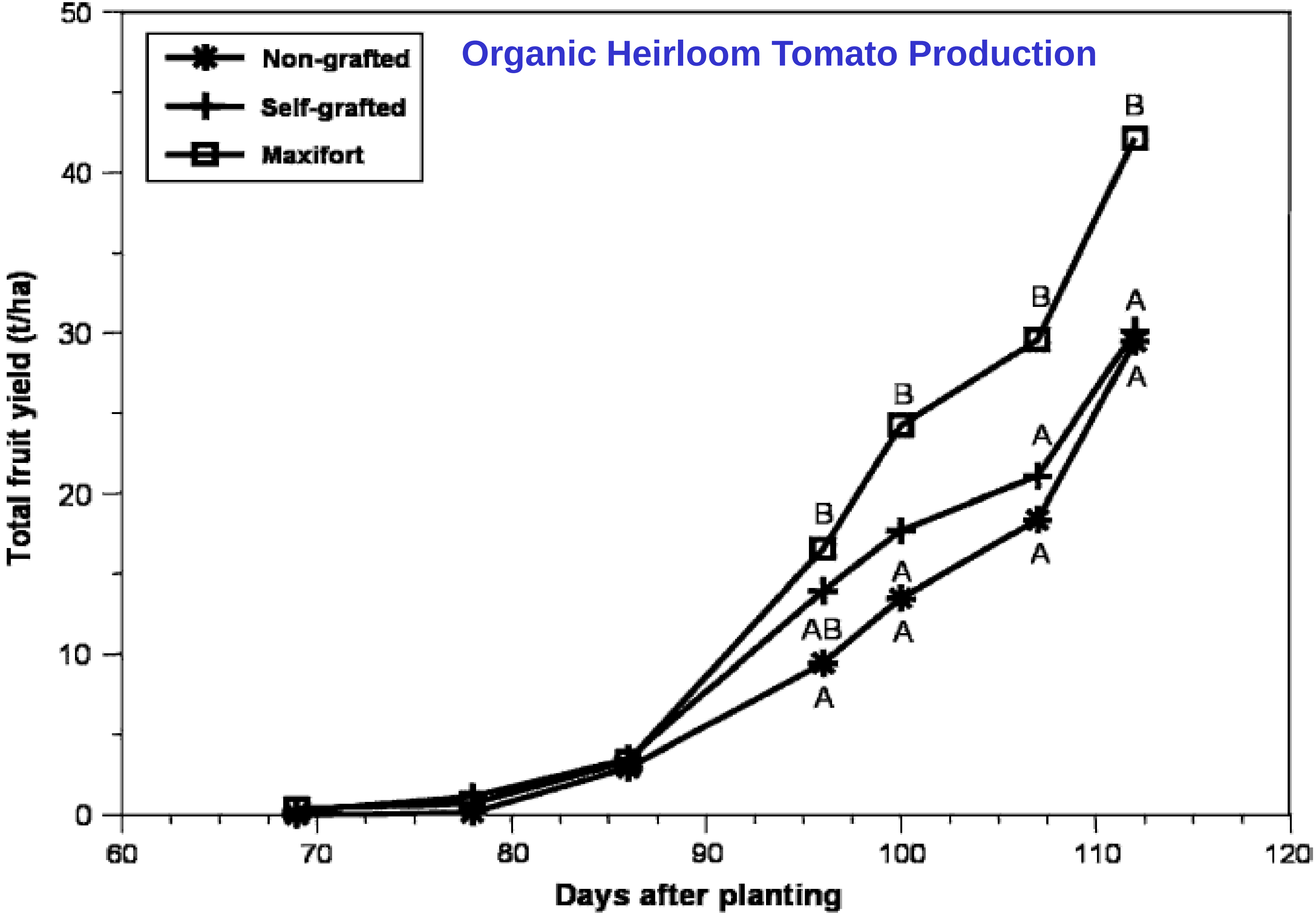


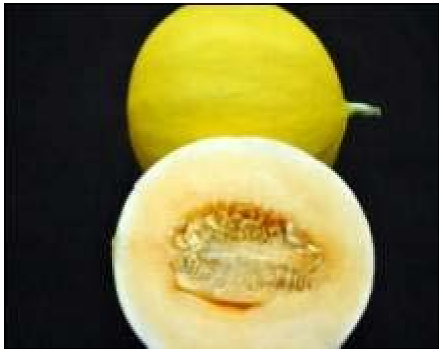
Fig. 6. Total fruit yield of grafted and nongrafted tomato cv. German Johnson for standard and twin-row cultural training systems (CEFS, 2006). Cumulative total yield was analyzed for each harvest date, and the results of a mean separation test with a protected least significant difference ($P = 0.05$) are shown.

2012, Missouri

- **Scion cultivars:** German Pink and Ananas Noire
- **Rootstocks:** Maxifort, Beaufort, Multifort, Colosus and RST-04-106T

- **Grafted varieties had the potential to enhance early yield and increase overall yield in high tunnels**

Scion: 'Honey Yellow' (HY) and 'Arava' (Ar);



'Honey Yellow' Honeydew melon

'Arava' Galia melon

C. metulifer

Rootstock: 'Strong Tosa' (Cucurbita maxima × C. moschata) and Cucumis metulifer (CM)

(Guan and Zhao, HortScience, 2014, 49:1046-1051)

Fruit quality

Grafting did not exhibit significant effects on sensory properties of ‘Honey Yellow’ melon

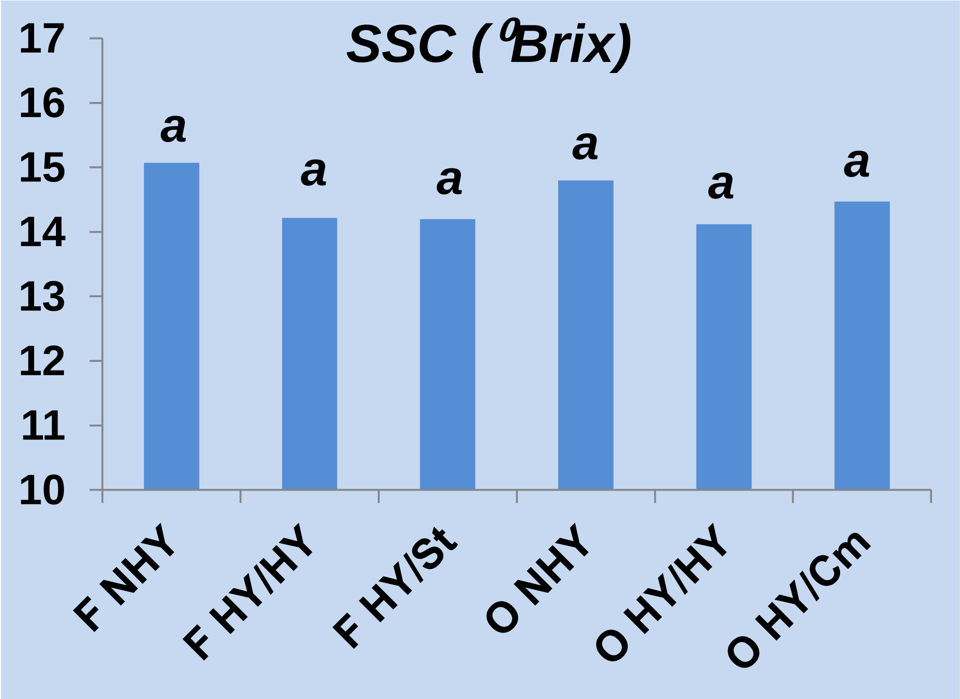
‘Honey Yellow’

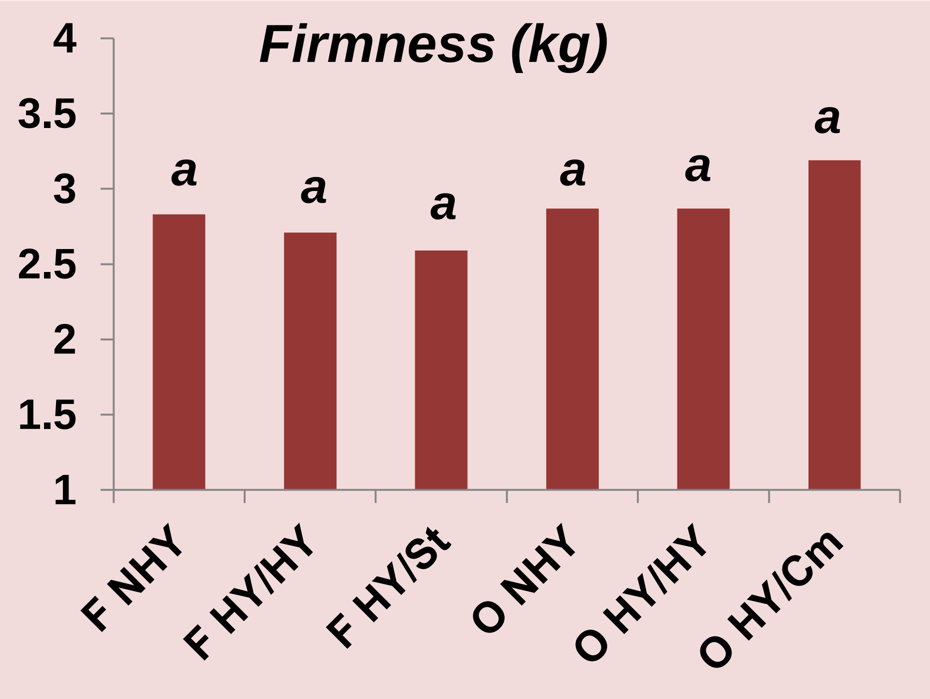
(1-9 hedonic scale)

Treatment	Overall acceptability	Flavor liking	Firmness liking
F NHY	6.00 a	5.74 a	5.85 a
F HY/HY	6.10 a	5.96 a	6.09 a
F HY/St	5.98 a	5.81 a	6.08 a
O NHY	6.18 a	6.14 a	5.92 a
O HY/HY	6.04 a	6.02 a	5.74 a
O HY/Cm	5.95 a	5.77 a	5.95 a

(Journal of the Science of Food and Agriculture. DOI: 10.1002/jsfa.7050)

Grafting did NOT affect SSC and firmness of HY melon





(Guan and Zhao)



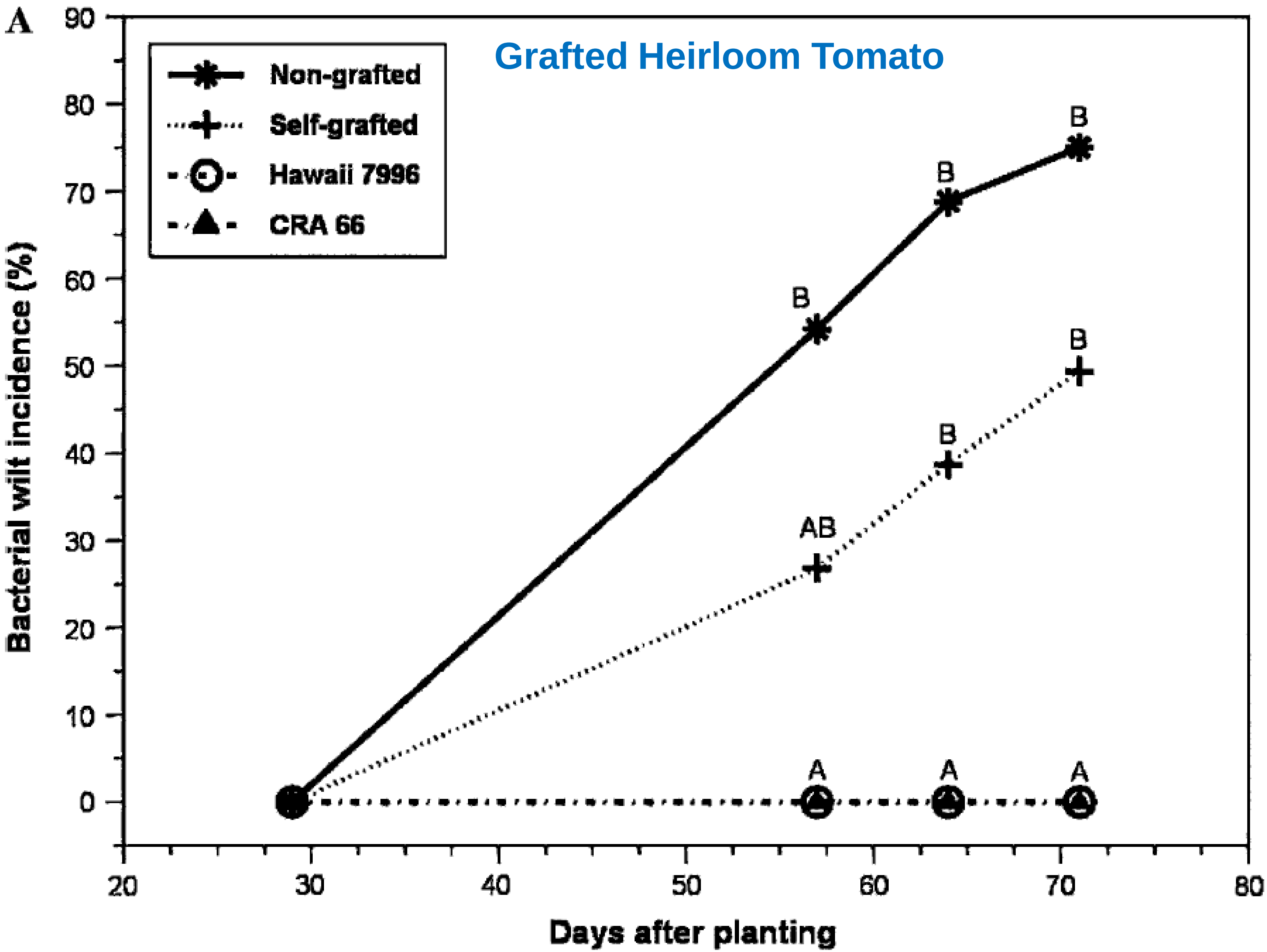
Table 1. A list of crops and diseases reported to be controlled by grafting.

(HortScience, 2012, 47:164-170)

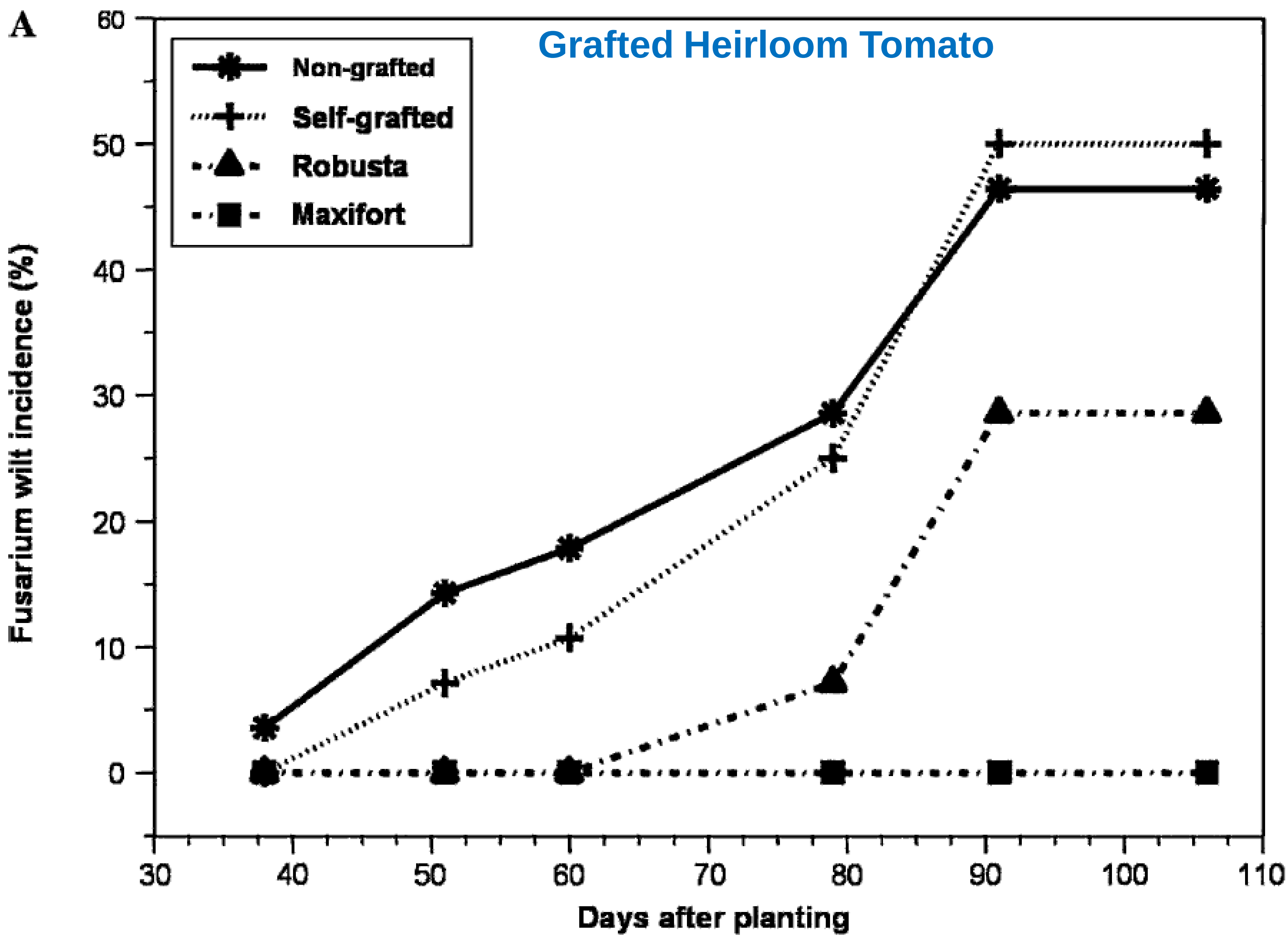
Crop	Disease	Organism	Reference
Cucumber	Fusarium wilt	*Fusarium oxysporum*	Pavlou et al., 2002
	Phytopthora blight	*Phytopthora capsici*	Wang et al., 2004
	Root-knot nematodes	*Meloidogyne* spp.	Giannakou and Karpouzas, 2003
	Verticillium wilt	*Verticillium dahliae*	Paplomatas et al., 2002
	Target leaf spot	*Corynespora cassicola*	Hazama et al., 1993
	Black root rot	*Phomopsis sclerotiodes*	Wiggell and Simpson, 1969
Melon	Fusarium wilt	*Fusarium oxysporum*	Bletsos, 2005
	Vine decline	*Monosporascus cannonballus*	Cohen et al., 2000
	Root-knot nematodes	*Meloidogyne* spp.	Siguenza et al., 2005
	Gummy stem blight	*Didymela bryoniae*	Crinò et al., 2007
	Verticillium wilt	*Verticillium dahliae*	Alabouvette et al., 1974
	Black root rot	*Phomopsis sclerotiodes*	Alabouvette et al., 1974
Cucurbita sp.	Spider mites	*Tetranychus cinnabarinus*	Edelstein et al., 2000
Watermelon	Fusarium wilt	*Fusarium oxysporum*	Murata and Ohara, 1936
	Root-knot nematodes	*Meloidogyne* spp.	Maroto-Borrego and Miguel, 1996
	Verticillium wilt	*Verticillium dahliae*	Paplomatas et al., 2002
	Virus complexes	CMV, ZYMV, PRSV, WMV-II	Wang et al., 2002
Eggplant	Verticillium wilt	*Verticillium dahliae*	Bletsos et al., 2003
	Corky root	*Pyrenochaeta lycopersici*	Ioannou, 2001
	Root-knot nematodes	*Meloidogyne* spp.	Ioannou, 2001
Tomato	Bacterial wilt	*Ralstonia solanacearum*	Grimault and Prior, 1994
	Fusarium wilt	*Fusarium oxysporum*	Harrison and Burgess, 1962
	Corky root	*Pyrenochaeta lycopersici*	Bradley, 1968
	Root-knot nematodes	*Meloidogyne* spp.	Ioannou, 2001
	Verticillium wilt	*Verticillium dahliae*	Paplomatas et al., 2002
	Tomato yellow leaf curl	ToYLCV	Rivero et al., 2003

CMV, Cucumber Mosaic Virus; ZYMV, Zucchini Yellows Mosaic Virus; PRSV, Papaya Ringspot Virus; WMV-II, Watermelon Mosaic Virus II.

Photo: Dr. Wayne Fish
--a Fusarium infected watermelon field



A
Grafted Heirloom Tomato
Non-grafted
Self-grafted
Hawaii 7996
CRA 66
Bacterial wilt incidence (%)
Days after planting
90
80
70
60
50
40
30
20
10
0
20
30
40
50
60
70
80
B
B
B
B
B
AB
A
A
A



A
Grafted Heirloom Tomato
Non-grafted
Self-grafted
Robusta
Maxifort
Fusarium wilt incidence (%)
60
50
40
30
20
10
0
30
40
50
60
70
80
90
100
110
Days after planting

Root Nematodes

***Ungrafted:* 4.6**
***Self-Grafted:* 4.4**
***Grafted:* 0-0.8**

Galls rated at a 0-5 scale.

Dr. Xin Zhao, personal communication

Organic melon

Treatment	Gall index (GI)	Number of J2/100 cm^3 of soil
Honey Yellow		
NGHY	7.14 a	378.2 a
HY/HY	6.70 a	515.6 a
HY/Cm	0.08 b	1.2 b
Arava		
NGAr	5.2 a	200.2 a
Ar/Ar	4.45 a	140.2 a
Ar/Cm	0.15 b	4.8 b

Treatment	Total yield kg/plant	Marketable yield kg/plant
Honey Yellow		
NGHY	4.94 a	3.85 a
HY/HY	4.30 a	3.58 a
HY/Cm	3.81 a	3.26 a
Arava		
NGAr	5.84 a	4.22 a
Ar/Ar	5.68 a	3.59 a
Ar/Cm	5.20 a	2.34 a

Greenhouse experiment

HY/Cm

HY/St

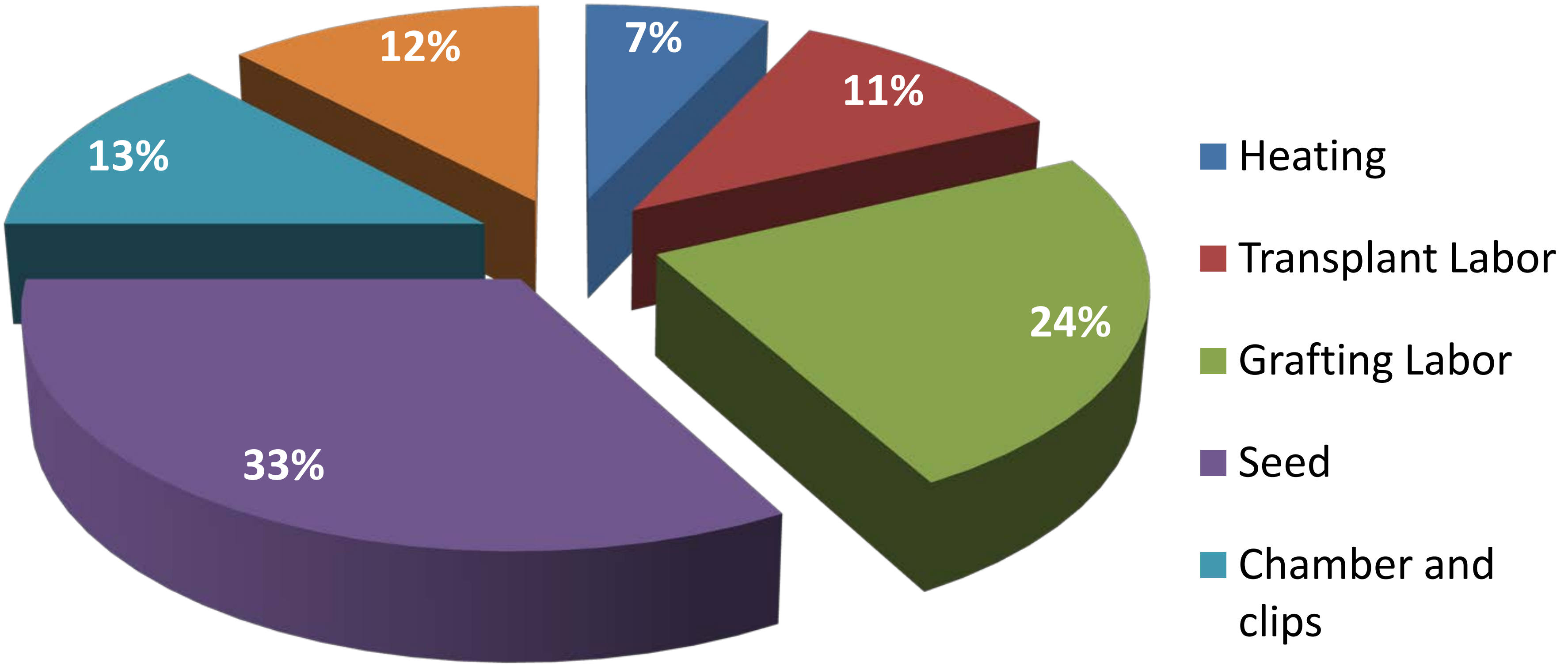
NHY

Treatment	Gall index	Egg mass index	Number of eggs
NGHY	5 a	5 a	110,027 ab
NGST	5 a	5 a	145,280 a
NGCm	0.8 c	0.4 b	2,395 c
HY/ST	5 a	5 a	68,003 b
HY/Cm	1.6 b	0.4 b	3,339 c

(Guan and Zhao)

Disadvantages of Grafting

- **Cost**
  - Labor, if manually
  - Cost ,for a Robot if automatically
  - Cost for rootstock: not cheap
- **Grafting Incompatibility**
- **Fruit quality could be down:** it depends on the combination of rootstock/scion varieties



The cost of grafted tomato seedlings in PA

Grafted and non-grafted transplant production costs were $0.59 and $0.13 in NC, and $1.25 and $0.51 in PA, respectively.

Adapted from Dr. Rivard et al 2010.

Watermelon Grafting

- Non-grafted (seedless) watermelon - $0.28
- Grafted (seedless) Watermelon - $0.75

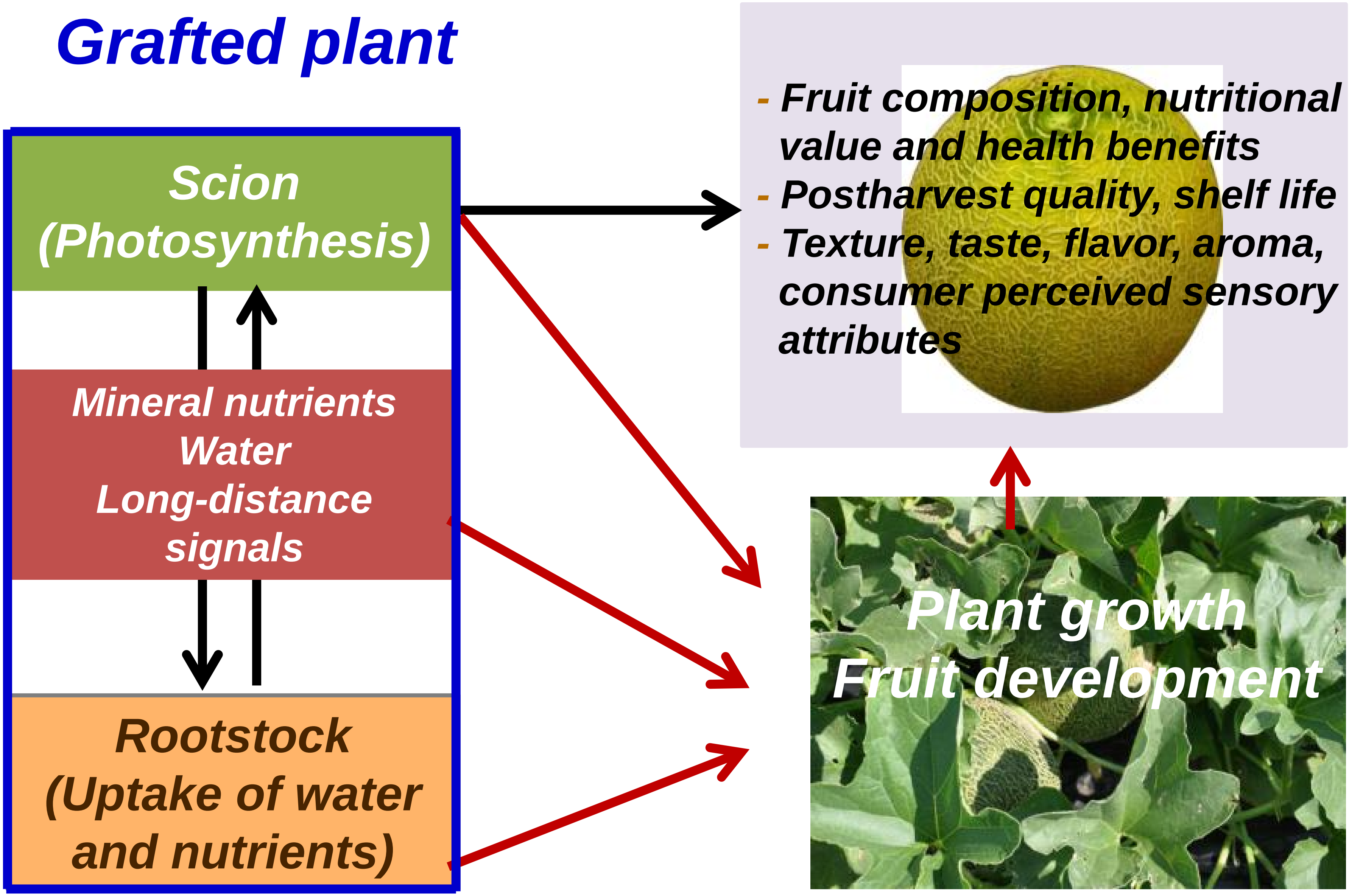
- $704 more per acre (1,500 plants)
- 12.6% return on investment when Fusarium wilt is problematic

Adapted from Dr. Wayne Fish

Why grafting works?

- The roots!
  - A stronger, more vigorous root system
  - More water and mineral nutrients uptake
  - Often more cold hardy: roots of figleaf gourd function at 8°C, while roots of cucumber function above 10°C
  - Need less water and fertilizer

Grafted plant



(Guan, 2014)

Defense mechanisms involved in disease resistance of grafted vegetables

- Inherent resistance within rootstocks as the first line of defense
- Shift of rhizosphere microbial diversity as a result of grafting
- Contributions of vigorous root systems of grafted vegetables to plant defense
- Grafting-induced systemic defense

- Hormone changes
  - Cytokinins—mostly synthesized in root tips.
  - Auxins and Gibberellins are synthesized in meristems.

Table 4. Endogenous hormone concentration in bleeding xylem sap[z] of eggplants as influenced by rootstocks (Kato and Lou, 1989).

Scion cultivar	Rootstocks	Xylem exudation rate (ml/plant per h)	Hormone concn in sap[y] ($ng \cdot ml^{-1}$) t-Zeatin	GA	IAA	ABA[x]
Hayabusa	VF	6.70	41	1.91	168	78
	Akanasu	5.62	29	0.59	193	40
	Torubamu	6.07	21	0.99	133	84
	Own root	2.38	22	0.47	98	118
Kokuyou	VF	6.62	46	2.13	283	70
	Akanasu	5.58	22	0.57	285	48
	Torubamu	6.11	20	1.09	173	73
	Own root	2.86	32	0.79	96	112
Beikoku daimaru	VF	6.68	48	1.58	371	65
	Akanasu	4.93	41	0.86	480	49
	Torubamu	4.68	29	0.87	356	70
	Own root	5.28	38	0.73	165	46

Phloem protein and mRNA were transported

- A few studies have explored how the scion is affected by mRNA and protein migrating from the rootstock.
  - Ruiz- Medrano et al. (1999), Xoconostle-Ca´zares et al. (1999), and Kudo and Harada (2007) showed that mRNA and Golecki et al. (1998)and Go´mez et al. (2005) demonstrated that phloem proteins from the rootstock can migrate from the rootstock through the phloem to the scion and accumulate in the phloem and apical tissues
  - Another was shown to change leaf morphology of potato scion when grafted onto transgenic modified tomato rootstock (Kudo and Harada, 2007).
  - Tiedemannand Carstens-Behrens (1994) studied the phloem proteins that differed in cucumber (C. sativus) grafted on figleaf gourd (C. ficifolia) or on pumpkin (C. maxima).
  - Ruiz-Medrano et al. (1999) suggest this migration is a novel mechanism likely used to integrate developmental and physiological processes on a whole-plant basis. The phloem proteins role may be in long-distance transport of RNA within plants (Golecki et al., 1998).

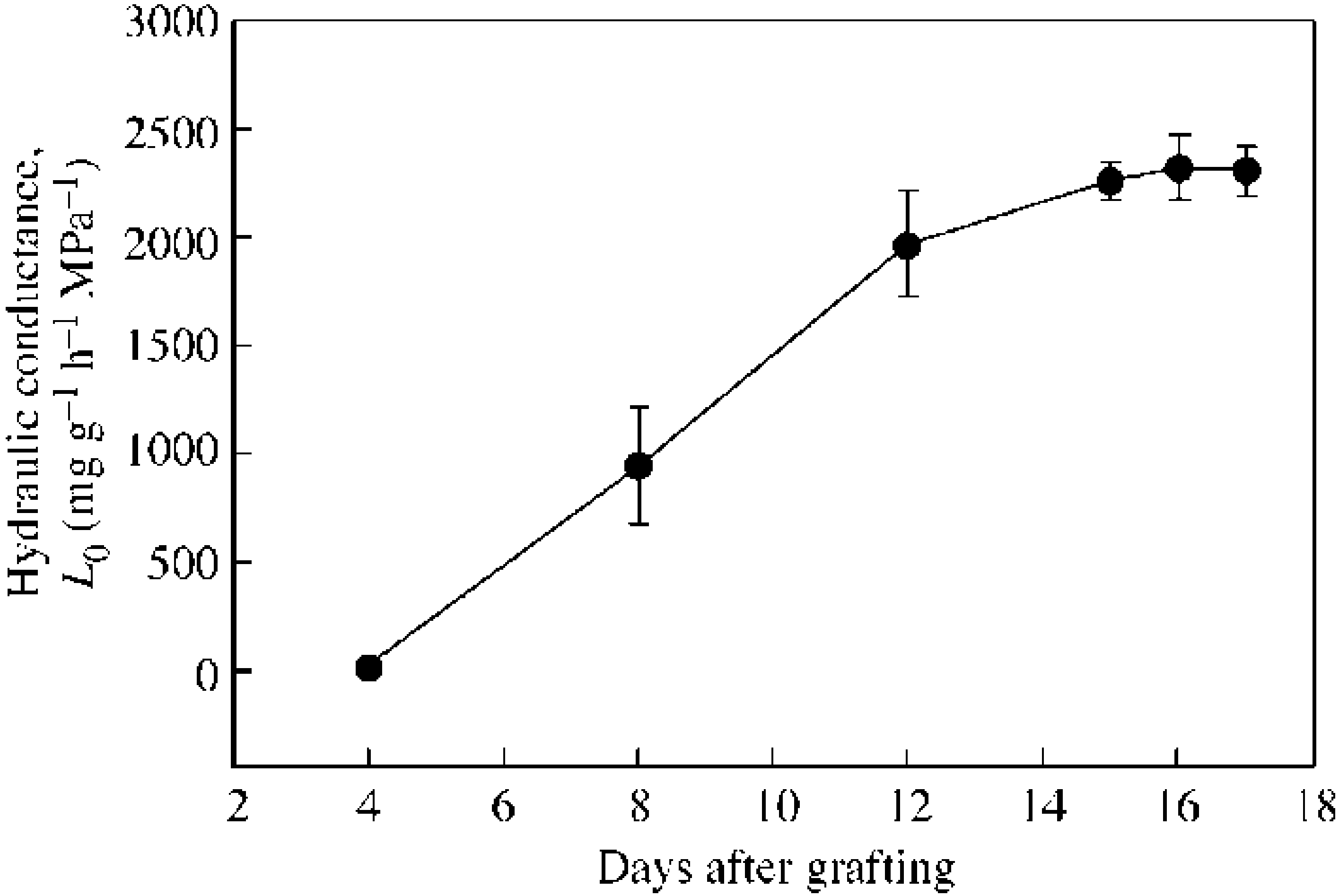
Grafting: Things to Know

- Vegetable grafting is relatively easy, as vegetables are mostly herbaceous in nature: Methods include insertion, tongue approach, tubing, and cleft, etc.
- Grafting best fits crops in high tunnels or other greenhouses—economic reasons.
- Grafting applies for with warm season vegetables for high profits—tomato, watermelon, cucumber.
- **Heirloom** scion varieties are encouraged for grafting: quality and profit; habit or culture.
- Commercial rootstocks more available for Tomatoes: ***try out first!***

The Grafting Flow Chart

- Select scions and rootstocks
- Plant the seeds
- Schedule the best time to graft
- Make the grafts
- Monitor the healing process
- Acclimate the healed grafts
- Plant grafted transplants

The healing process takes over 7 days



Root hydraulic conductance (L_0). Measurements were made using natural exudation.

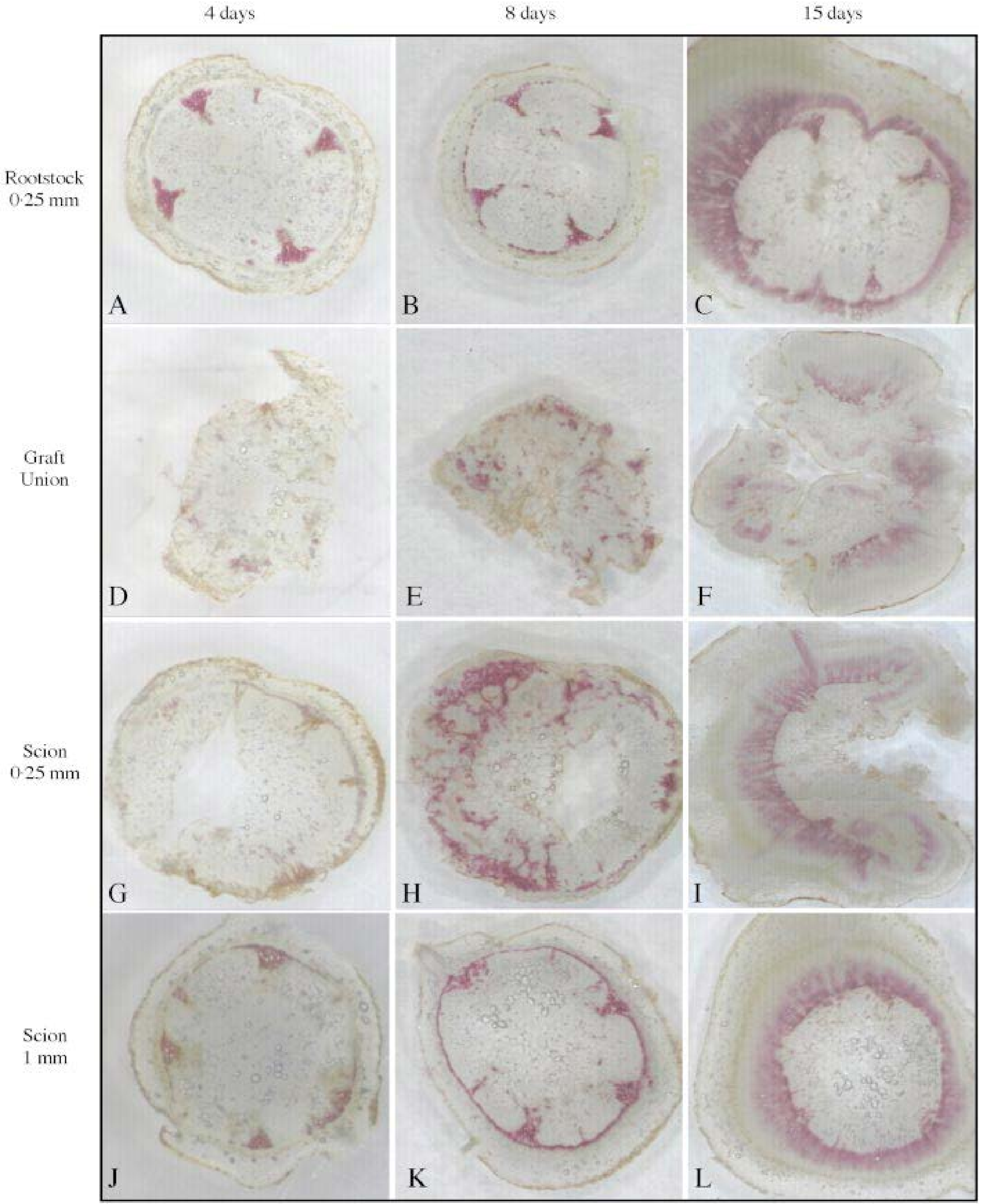


FIG. 3. Wiesner stain (**lignin**) during graft development at day 4 (A, D, G and J), day 8 (B, E, H and K) and day 15 (C, F, I and L). Positive staining is shown as a pink color. (A±C) Sections of the rootstock at 250 mm below the graft union. (D±F) Sections of the graft union. (G±I) Sections of the scion 250 mm above the graft union. (J±L) Sections of the scion at 1 mm above the graft union.

Tomato Grafting

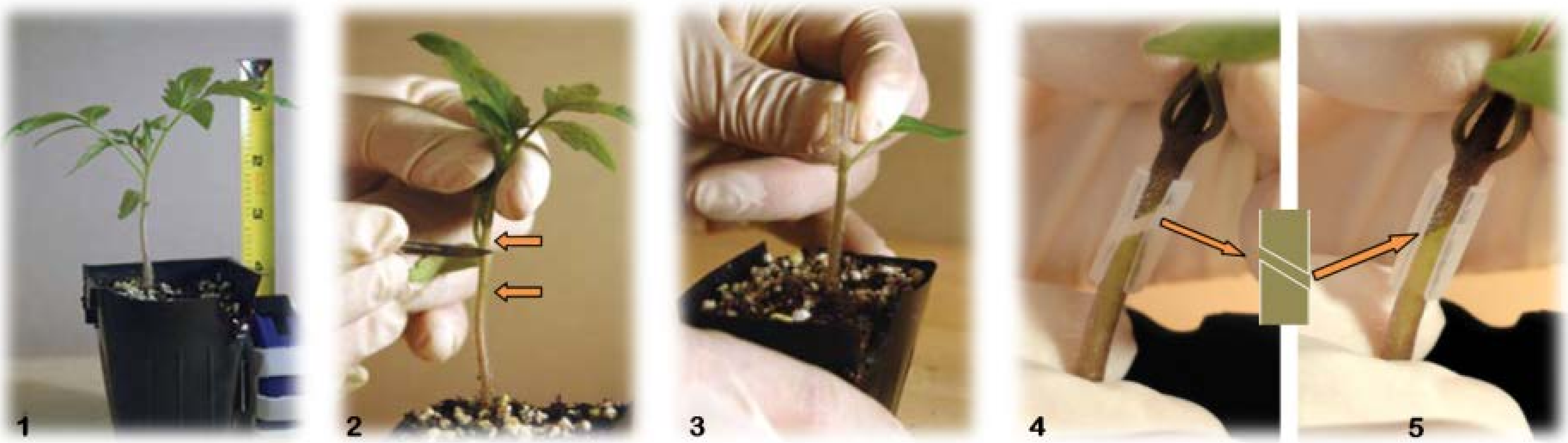
Rootstocks	TMV	Corky Root	Fusarium Wilt		Verticillium Wilt	Root-knot Nematode	Bacterial Wilt	Southern Blight
			Race 1	Race 2				
Beaufort *	R	R	R	R	R	MR	S	HR
Maxifort *	R	R	R	R	R	MR	S	HR
(Unreleased) *	R	S	R	R	R	R	HR	?
TMZQ702 **	R	S	R	R	R	R	MR	?
Dai Honmei ***	R	R	R	S	R	R	HR	?
RST-04-105 ****	R	R	R	R	R	R	HR	MR
Big Power *****	R	R	R	R	R	R	S	HR
Robusta ******	R	R	S	R	R	S	S	?

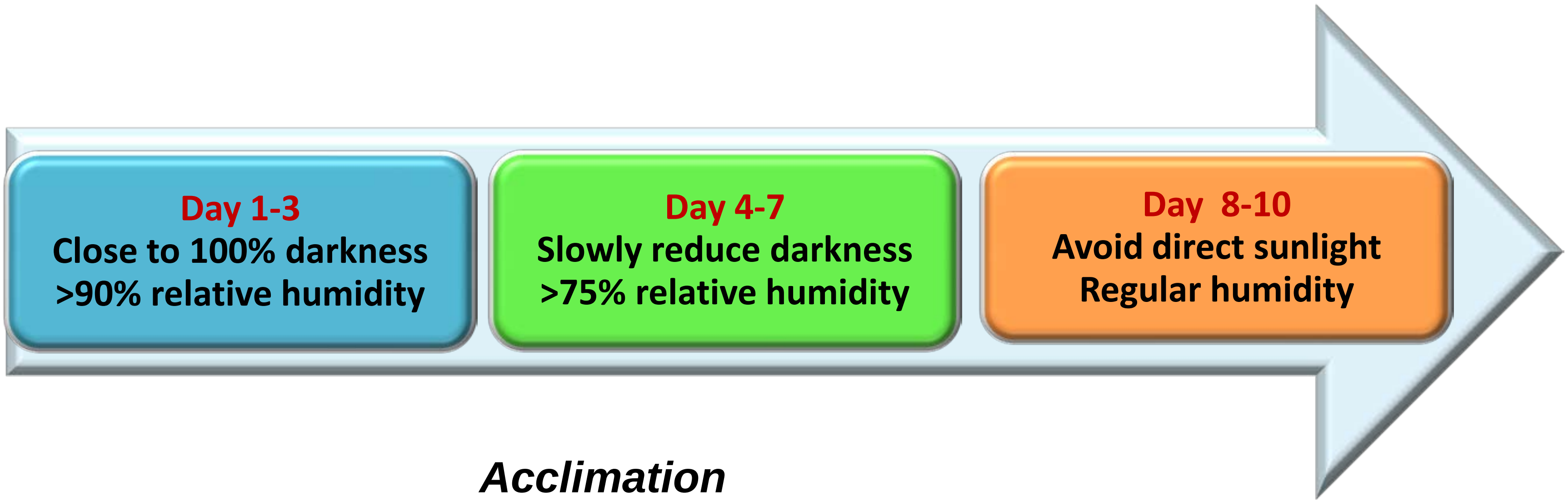
R=Resistant , **HR**=Highly Resistant, **MR**=Moderately Resistant, **S**=Susceptible

*** = De 'Ruiter Seed Co. ** = Sakata Seed Co. *** = Asahi Seed Co.**

****** = D Palmer Seed Co. ***** =Rijk Zwaan ****** = Bruinsma Seed Co.**

Tube Grafting Method





Acclimation


S-2

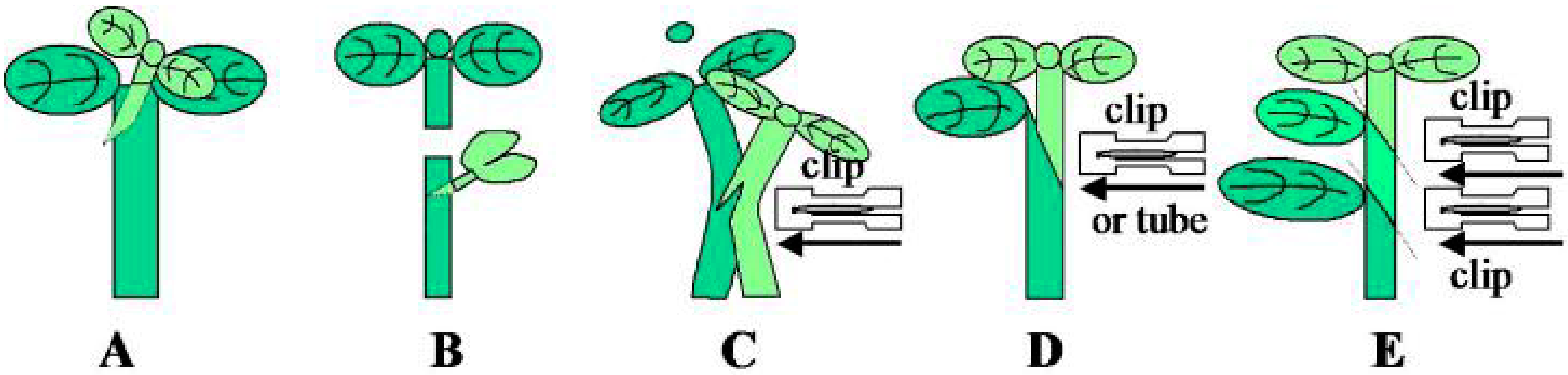
Cleft Grafting

Management of Grafted Tomatoes

- Graft union should be at least 1 inch above the ground when planting
- Keep removing suckers or lateral shoots arising below the graft union
- Keep one or two leaders depending on the rootstock varieties used
- Other management the same as that for normal tomato plants

Remove Suckers

Cucurbit Grafting



Common cucurbit grafting methods (Lee et al. 2010):

A&B, Insertion;

C, Tongue Approach;

D&E Splice

Grafting Cucurbits

0
Scion dead

5
Slowed and stunted

10
Vigorous

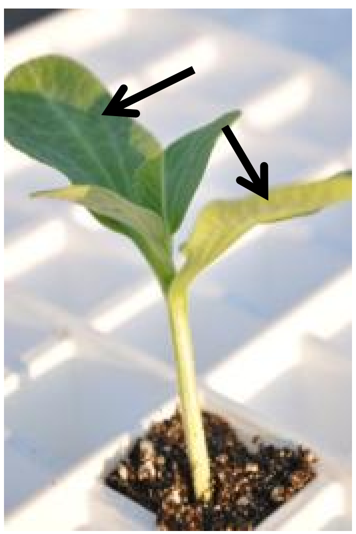
Root excision

Grafting method	Quality rating (0-10)	
	Excised root	Intact root
Hole insertion	9.08 aA	8.63 aA
One-cotyledon	9.50 aA	9.42 aA
None-cotyledon	5.67 bA	5.38 bA
Tongue approach	2.67 cB	7.92 aA

(Guan and Zhao, unpublished data)

- **Root excision did not affect plant quality and growth characteristics of plants grafted with hole insertion and one-cotyledon methods**

- **Plants grafted with hole insertion, one-cotyledon, and tongue approach methods performed similarly with respect to plant quality and growth characteristics**



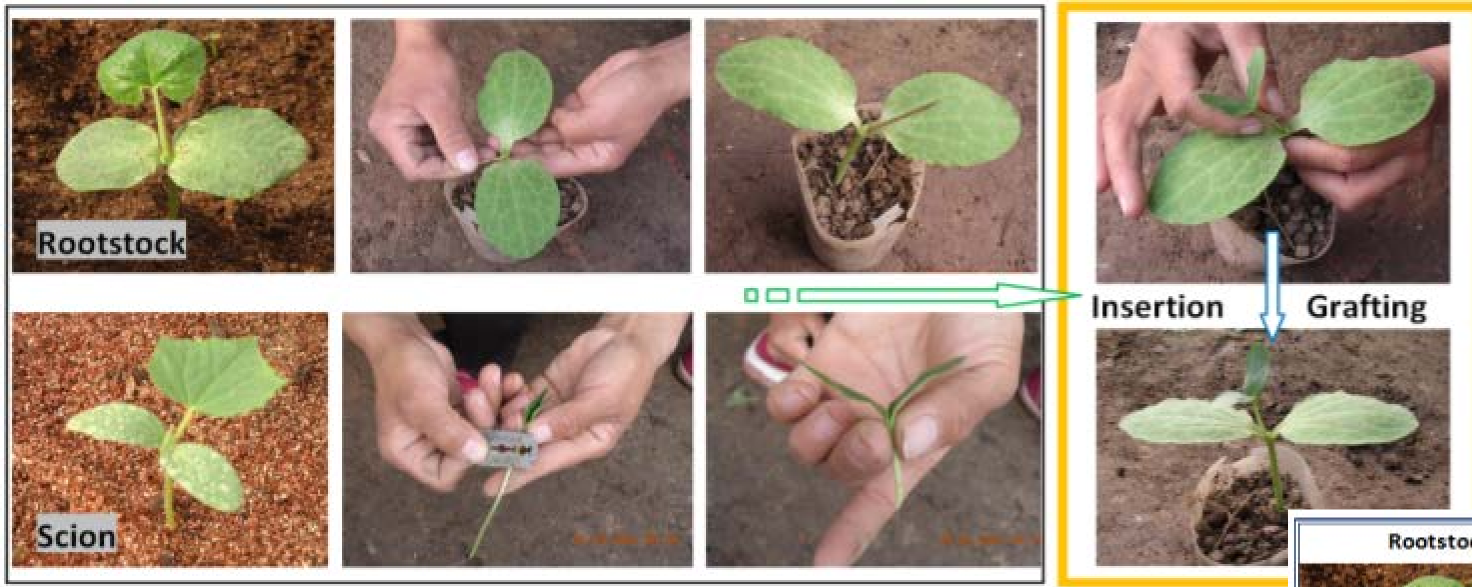
Hole insertion

One-cotyledon

None-cotyledon

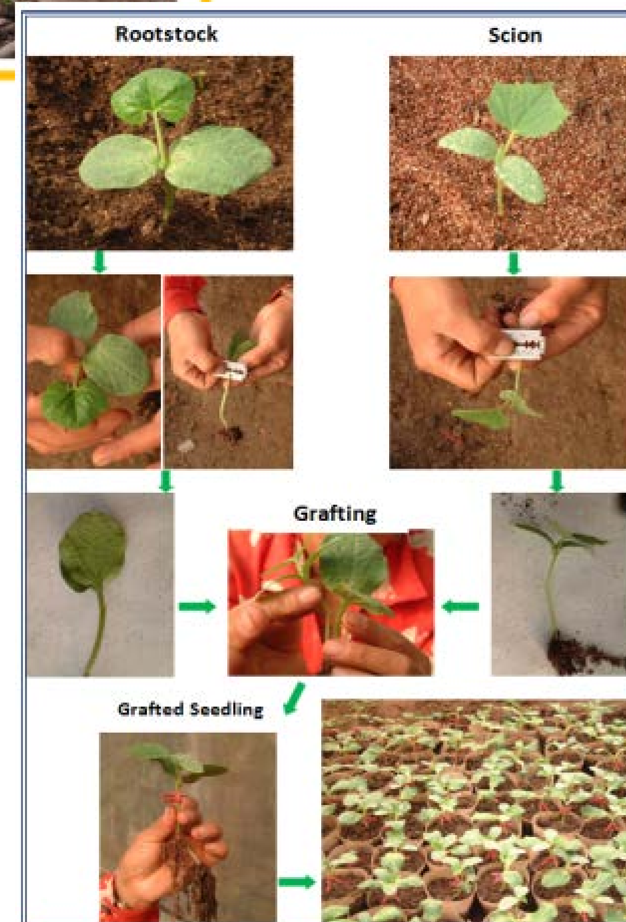
Tongue approach

(Guan and Zhao, unpublished data)



Cucumber Insertion

Tongue Approach



Timing

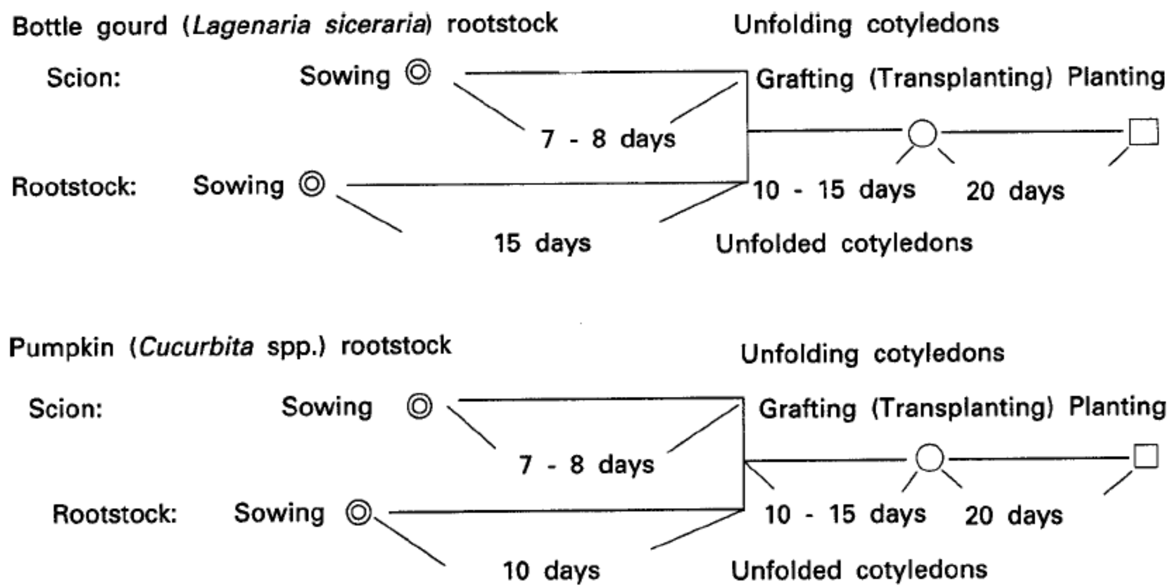
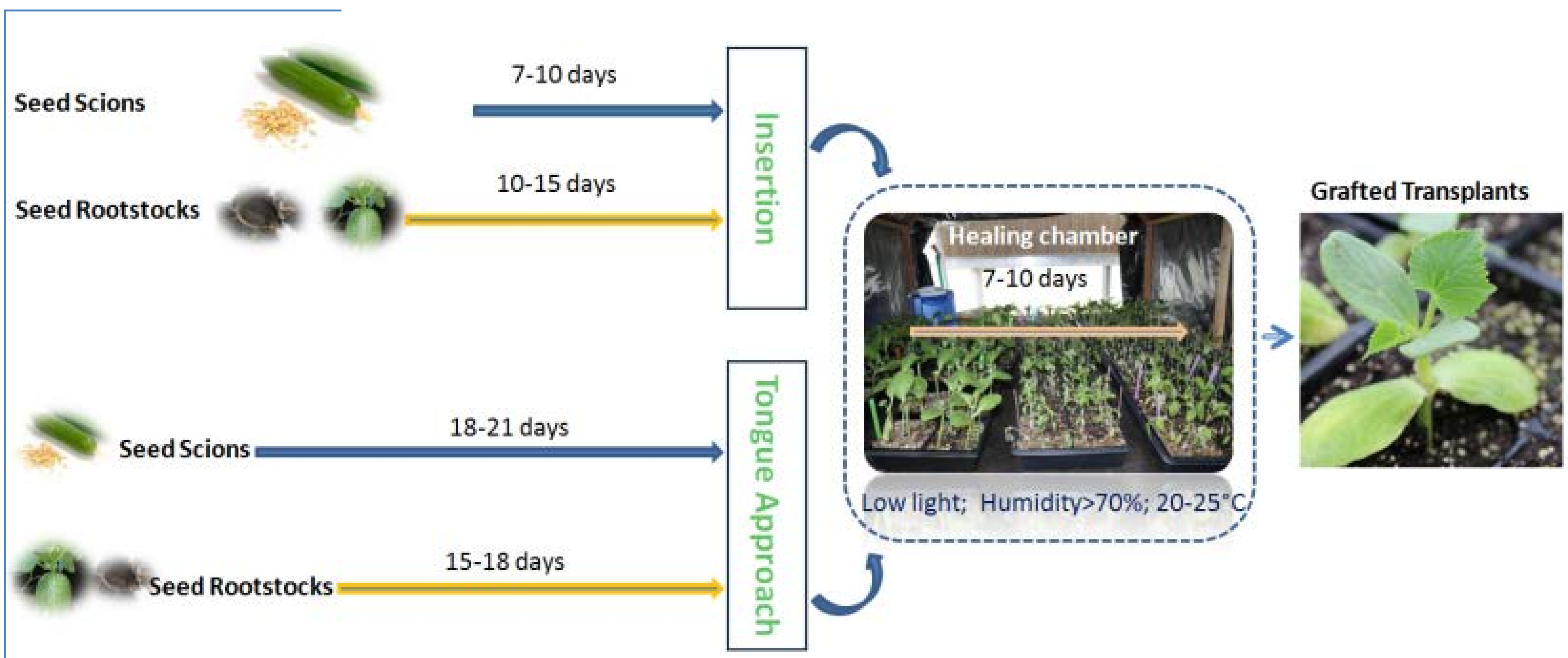
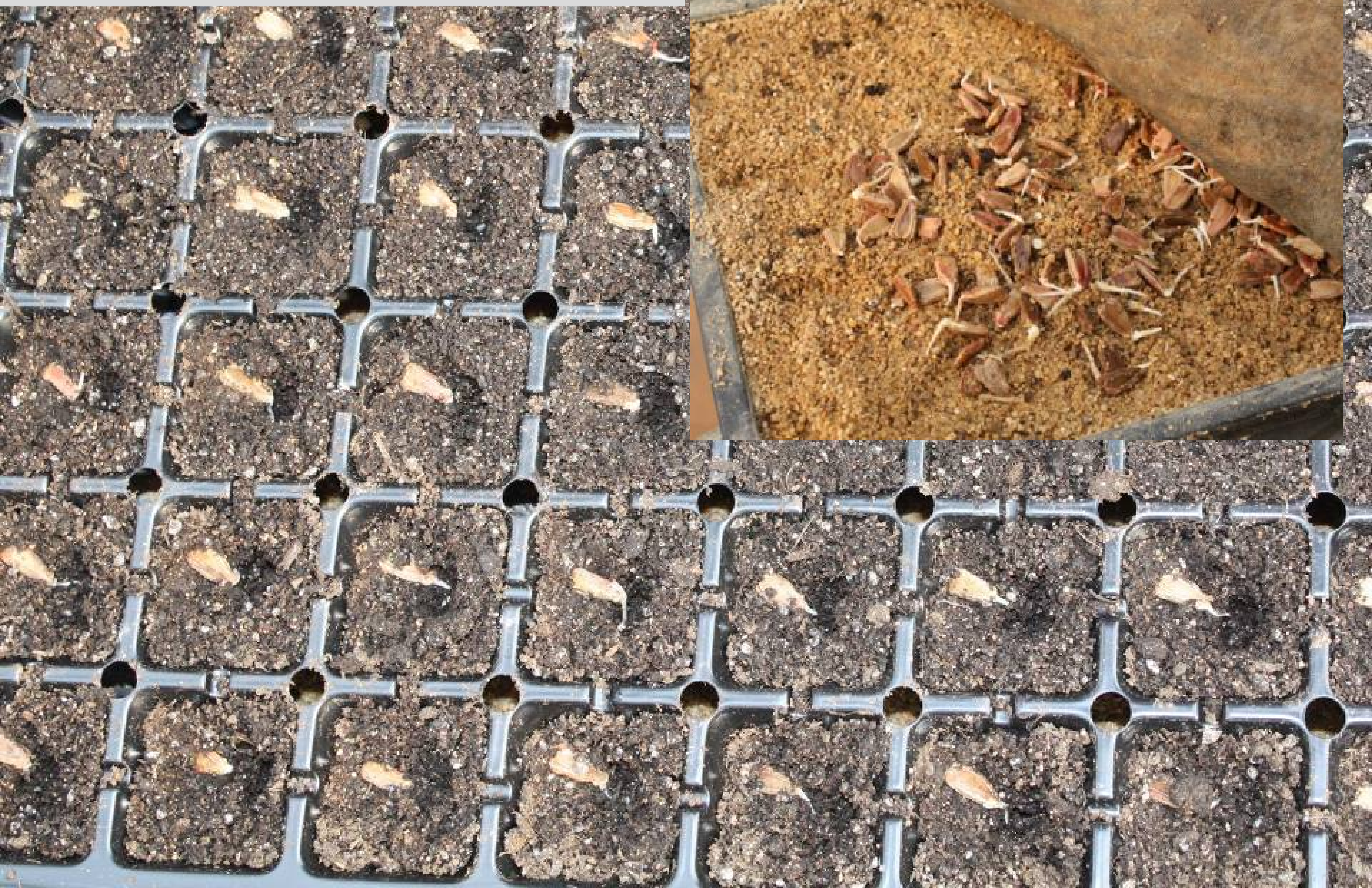


Fig. 9. Time schedule of cut grafting for watermelon

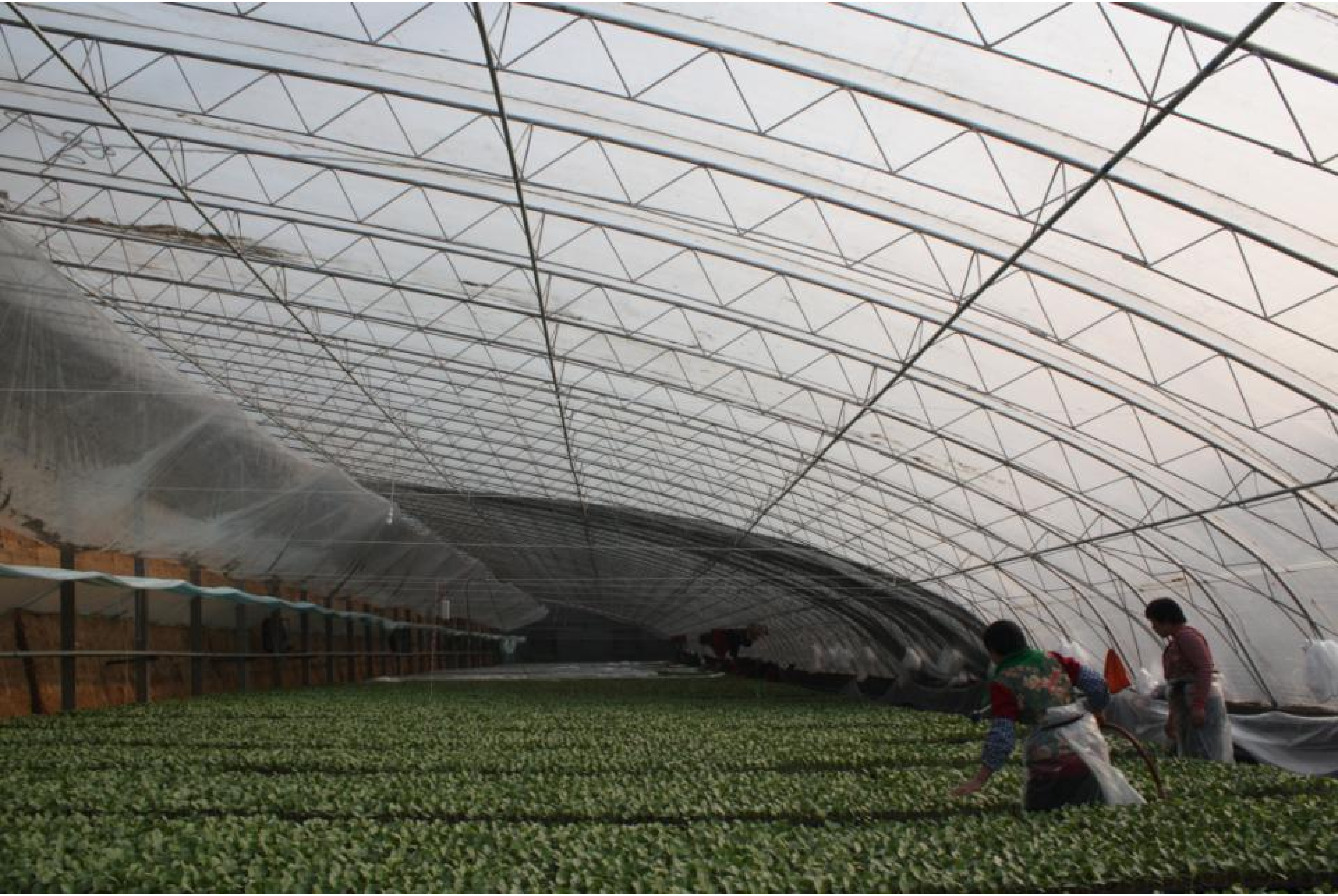


Watermelon Grafting — Insertion Method

Guards--rootstocks




Guards--rootstocks

Cucumber: tongue approach method

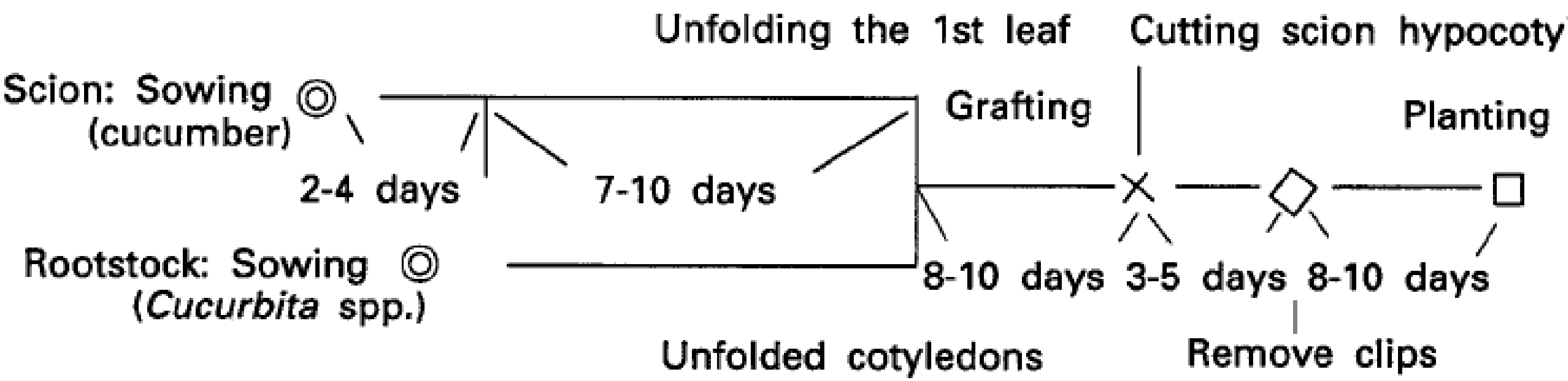
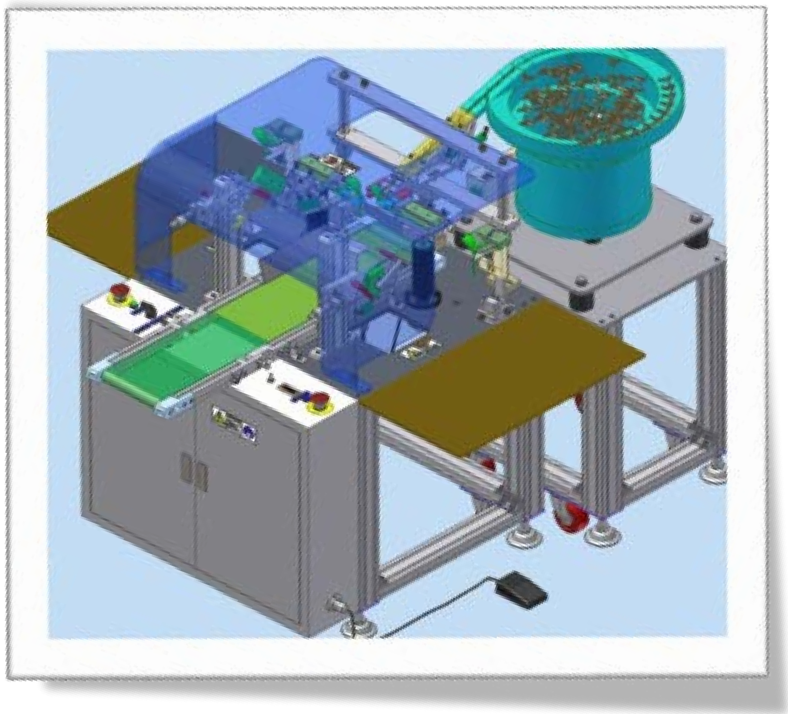


Fig. 6. Time schedule of tongue approach grafting for cucumber plants

Grafting Robot: watermelon and tomato



Grafting Potentials

- Greenhouse production
- High tunnel production
- Field production?

- Organic vs conventional
- Small farms vs big farms

Is it for Gardeners?

- Limited space
  - Rotation is limited
  - Soil-borne disease
  - Root nematodes
  - High Salinity
- Heirloom Tomato possible
- Enhanced Vigor, Yield, quality
- “Hybrid” tomato—**Novelty**
- ***Doable*** at a home setting

http://www.starkbros.com

Resources

- Dr. Xin Zhao of University of Florida.
  - Some slides were from her talk, when we conducted training in Missouri
- SCRI grant led by Dr. Frank Louws of North Carolina State University
- http://www.vegetablegrafting.org

Questions!