Vegetable Grafting: Value of Recombination

Sustainable Vegetable Production

Zheng Wang, PhD
University of California Cooperative Extension
September 19, 2019

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In the next 75 minutes…

- Vegetable grafting: what, why, and how
- Use of vegetable grafting
- Challenge of expanding the adoption
- Questions

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Successful crop production = good genetics x management

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Good genetics: contain desirable traits
Good management: grow in the right condition

"Standard" Variety Development

1. Resource demanding
   … e.g., time, money, technical
2. Compromise … in end, all varieties are imperfect

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What if one variety did not need to contain all desirable traits?

What if the non-commercial plants already contain the traits?

What if important traits could be delivered to farmers faster?

Farmer's practical questions

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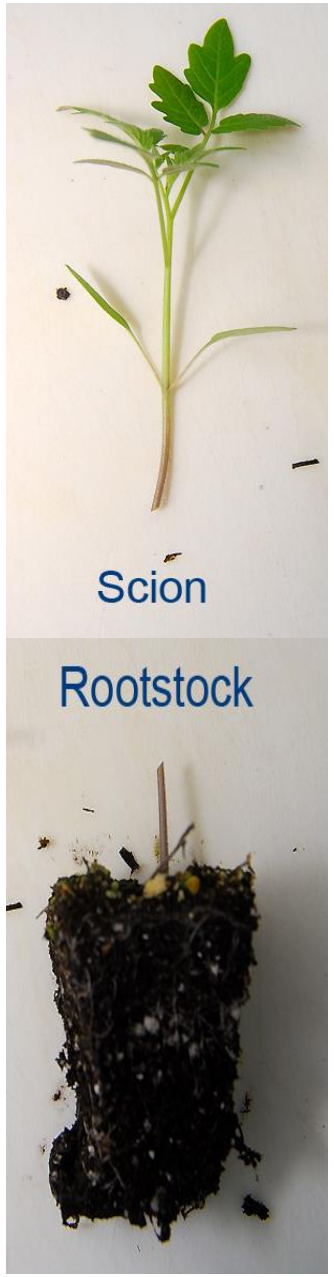
Vegetable Grafting



- Organ transplantation;
- Creates a physical hybrid;
- Makes faster and more effective use of genetics in production

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Vegetable Grafting

requires 2 varieties; may use more

Scion: 'recipient'

- supplies shoot
- fruit marketable but roots flawed

Rootstock: 'donor'

- supplies roots
- fruit not marketable but roots better

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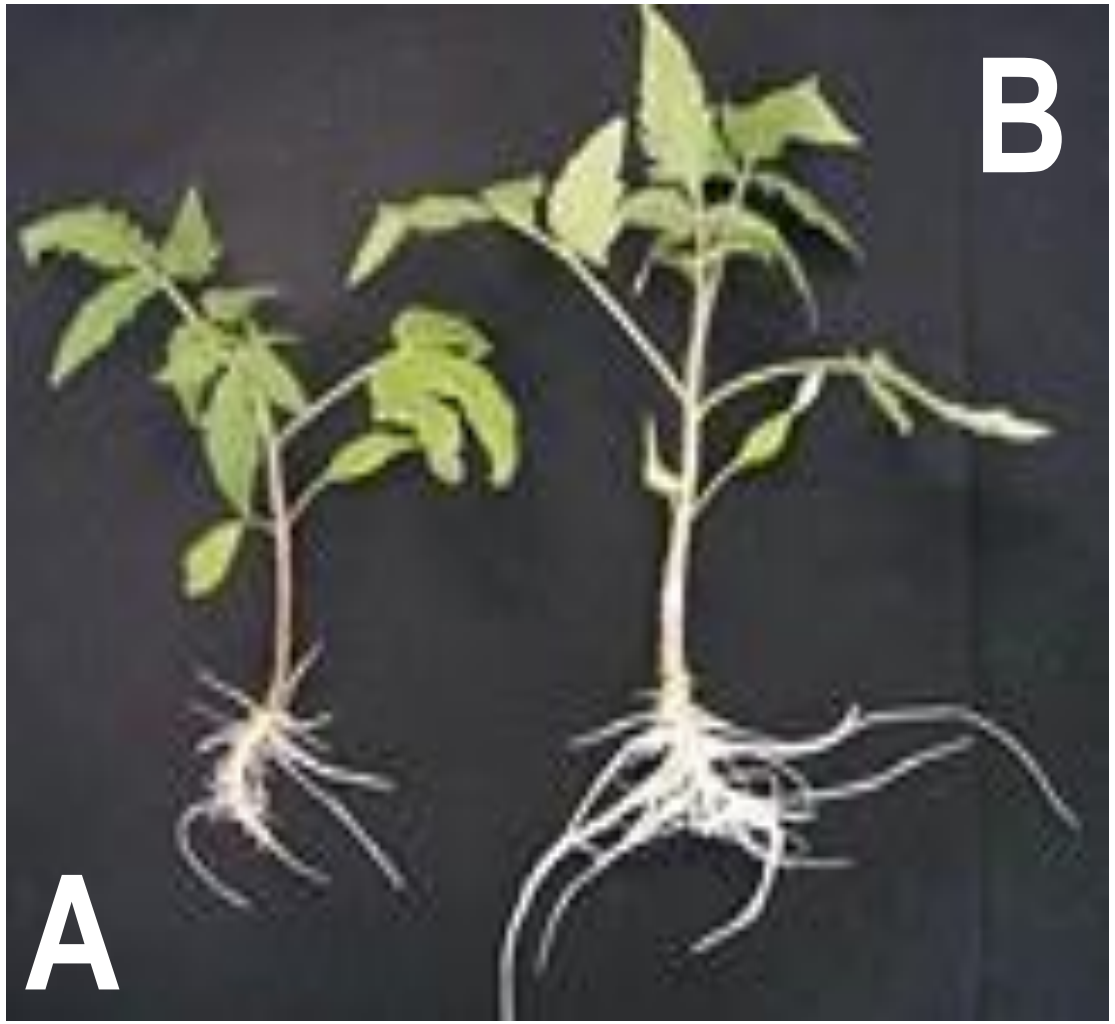
vegetable grafting

scion



rootstock

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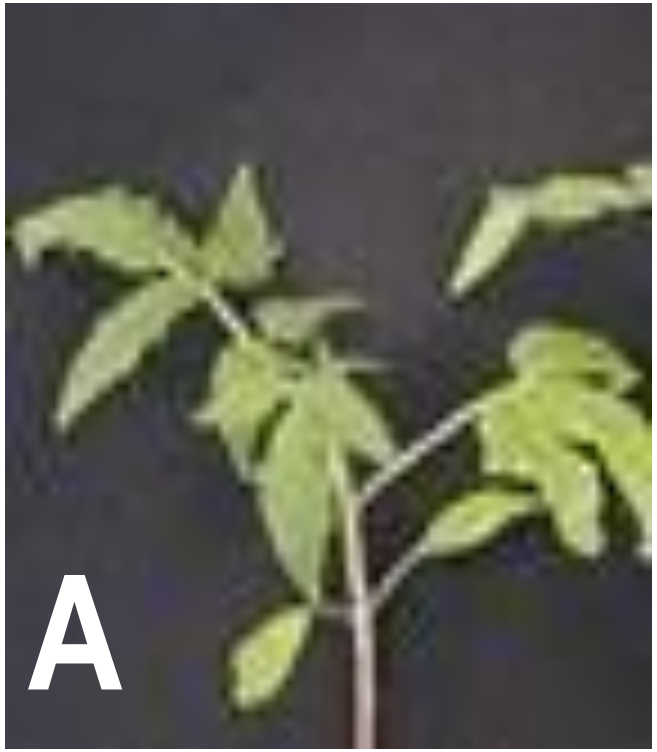
cut



rnia
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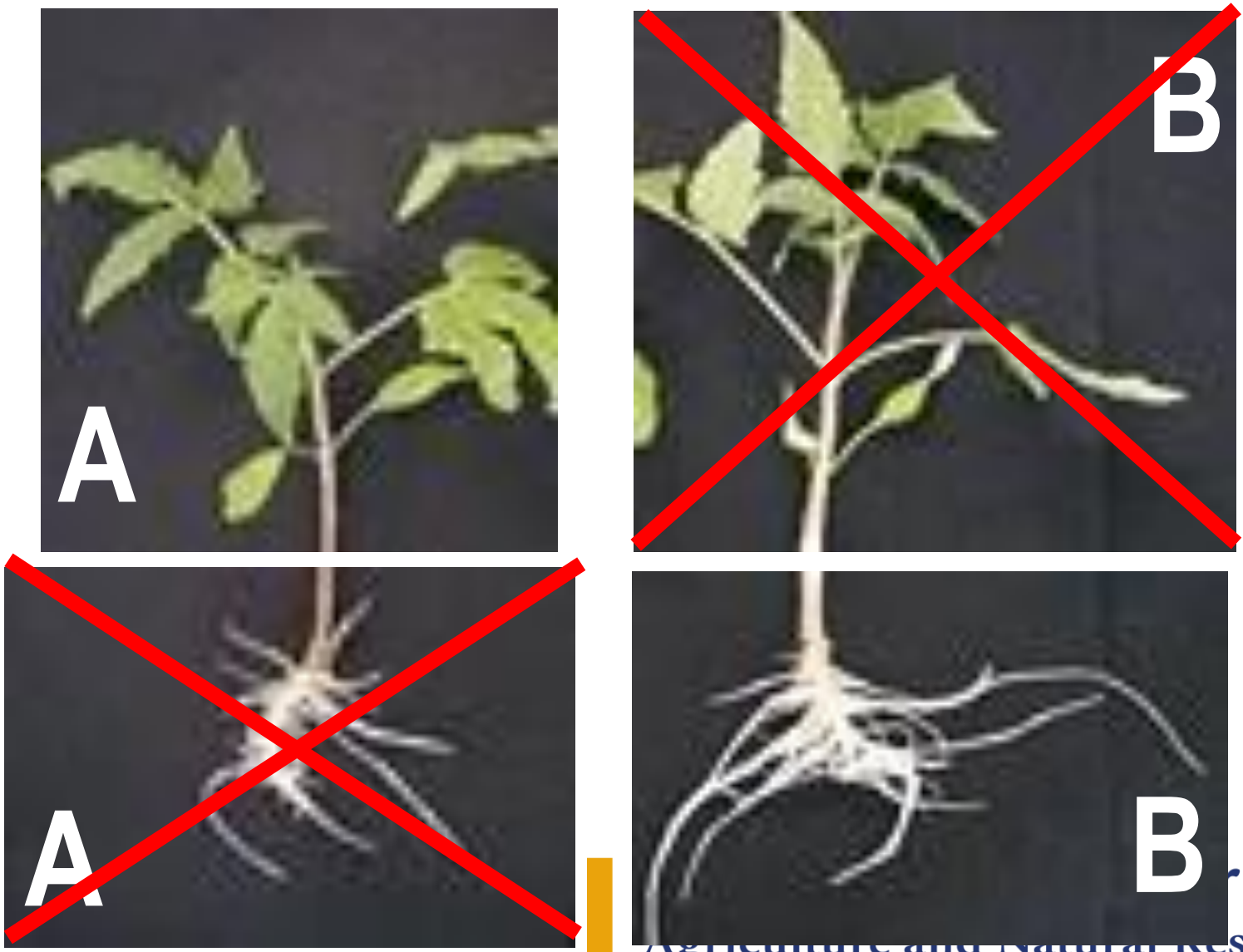
discard



rearrange

rnia
sources

combine and secure

several ways possible

U nia
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Grafted plants are production tools.

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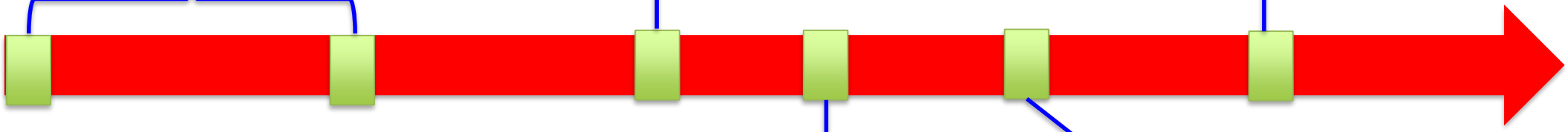
China: Grafting started in 500s.
Japan and Korea: Farmers began using grafting as a tool for combating diseases and enhancing growth in 1920s – 1930s.

From 1950s – 1980s, development of breeding technology gave plant disease resistance. Grafting started in Europe.

During 2010s, vegetable grafting are used in various production systems across US and Mexico. More federal- and state-funded programs bring institutional collaborations.



During 1990s, grafting started in Canada and Holland for hydroponic greenhouse.

During 2000s, grafting started in US and Mexico for hydroponic greenhouse.

From: Chieri Kubota, OSU

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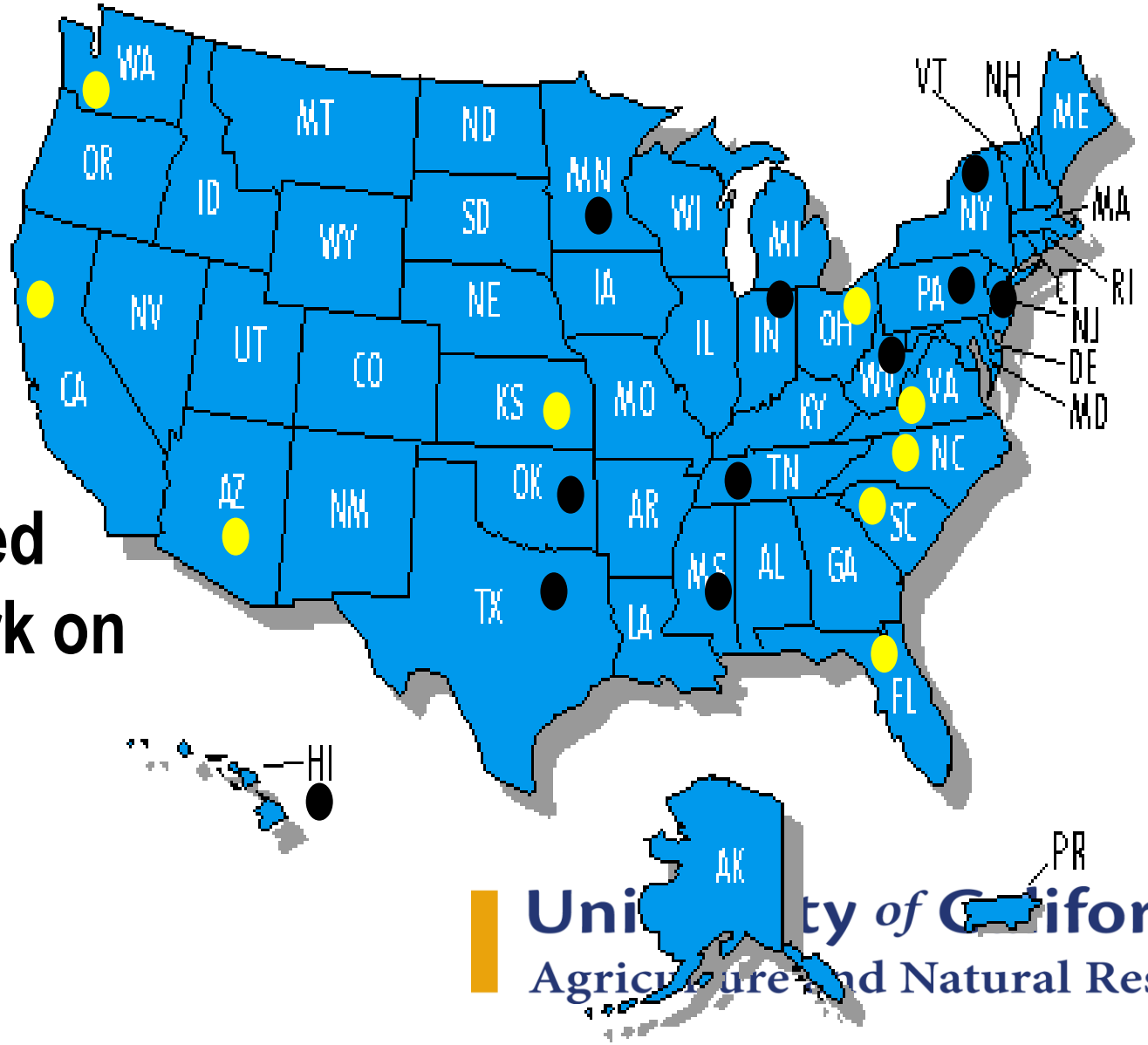
USDA-NIFA SCRI: 2011-2016 and 2016-2020

SCRI Team

other academic teams that have worked or now work on vegetable grafting



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2011-2015: how to produce high quality grafted transplants

2016-2020: how to take the best use of grafted plants in different production systems

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Grafted plants can be more:

(1) resistant to biotic, abiotic stresses,

(2) vigorous in root system,

(3) resource-efficient (e.g., water and fertilizer),

(4) productive (yield potential), but

(5) expensive

than nongrafted counterparts.

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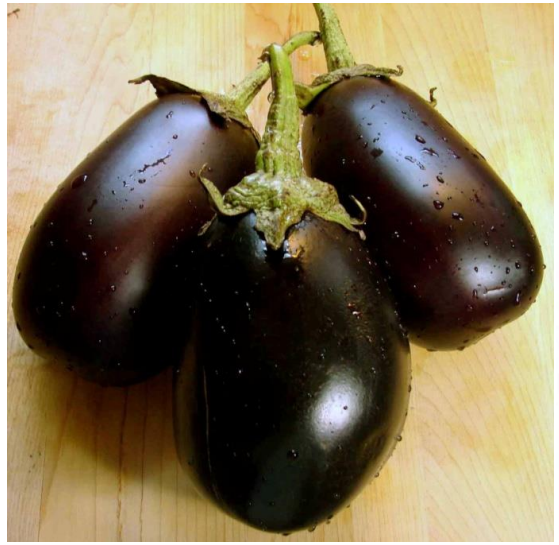

Vegetables grafted most often

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To have a successful grafted plant…

Growing scion and rootstock seedings (match stem diameter)

Grafting

Healing

Finished seedlings ready for shipping or transplanting

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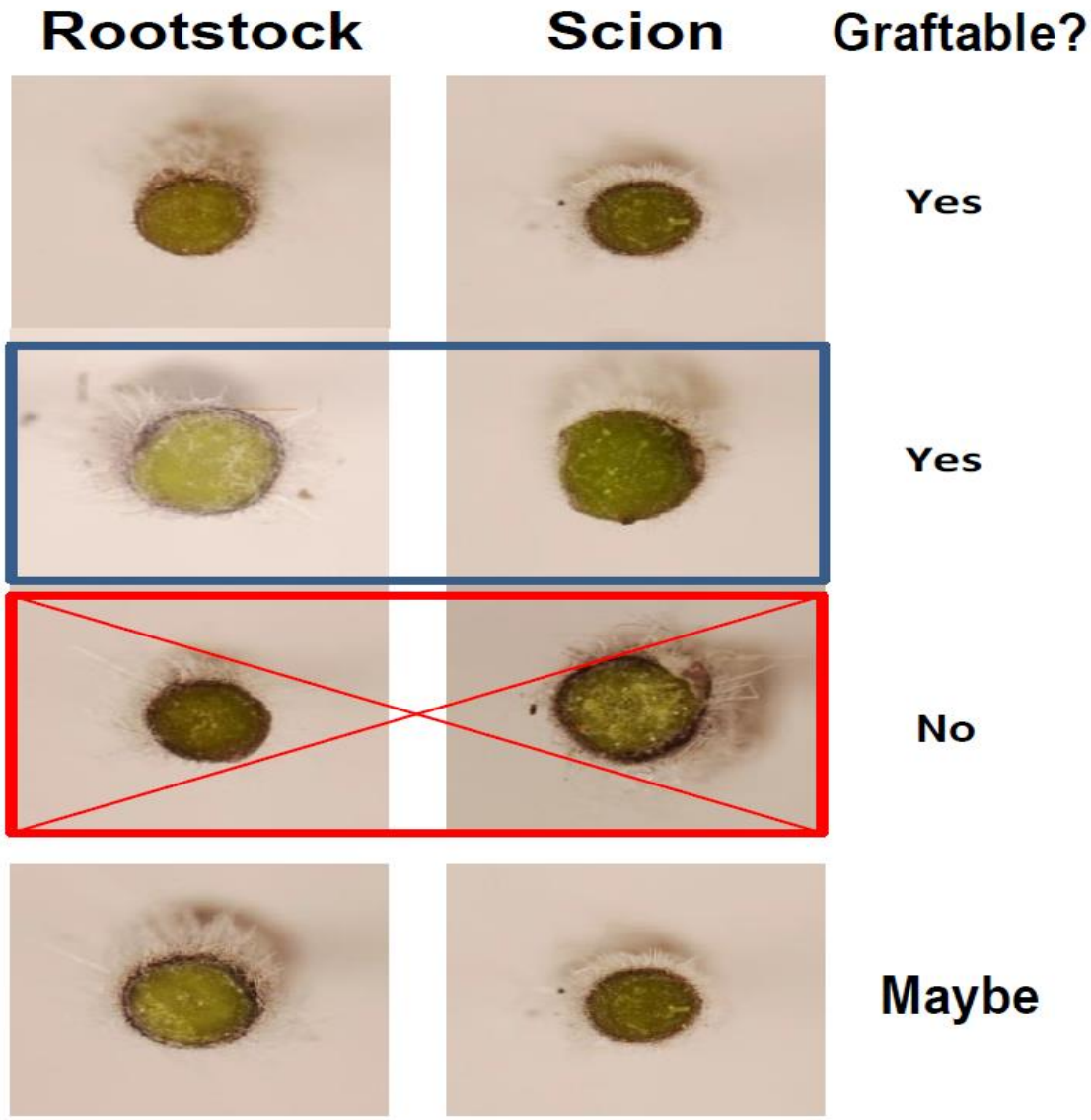
- Rootstock and scion varieties grow at different rates (vigor variation).
- The stem diameters of both plants must be similar in order to be grafted.
- Staggered grafting is recommended due to different growth rates and high cost of rootstock seeds.



RS and scion seedling stem diameters must be similar (1.5 – 3.0 mm).

Courtesy of M. Kleinhenz, OSU

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Supplies used for grafting

Photo: P. Devi, WSU

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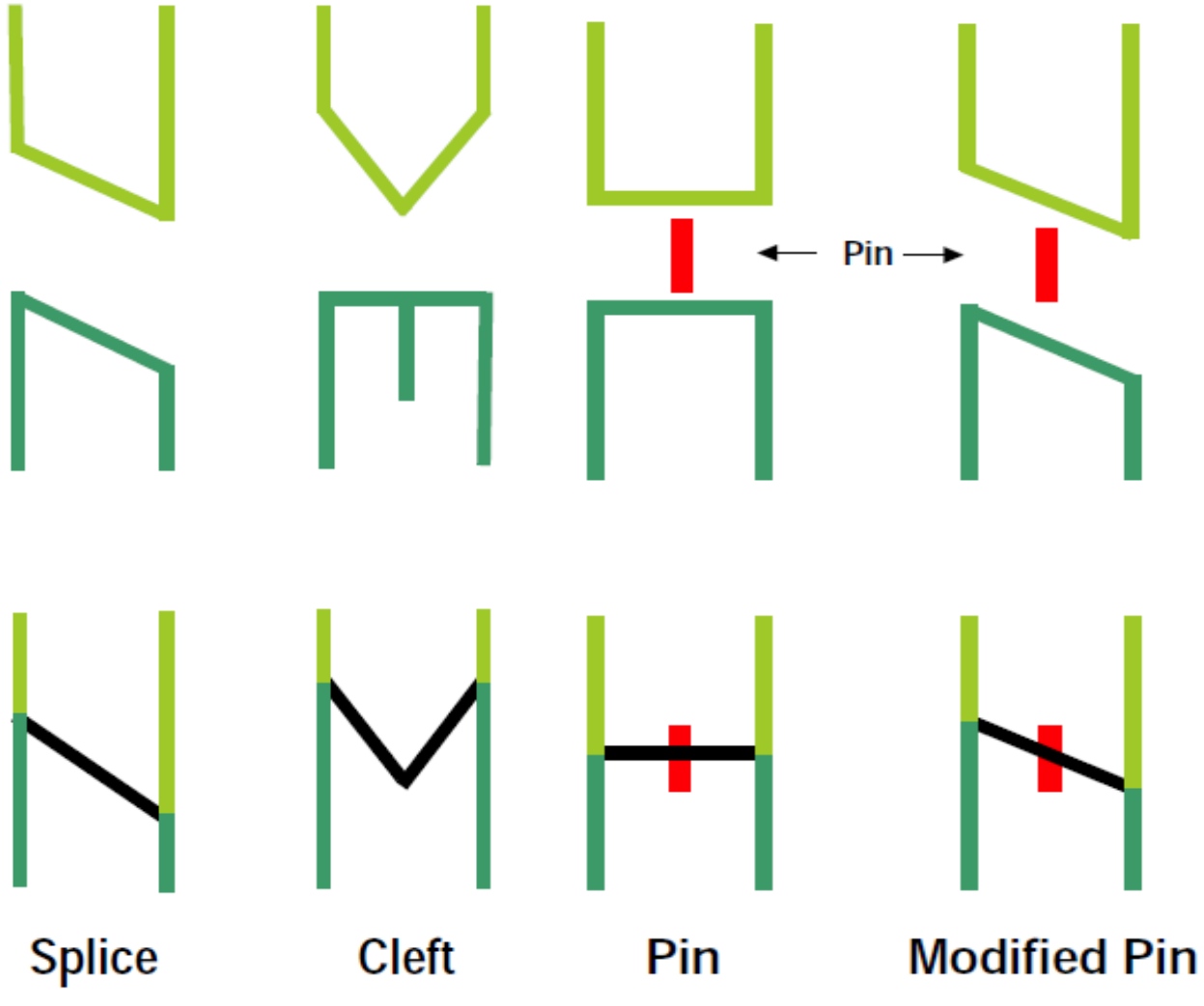
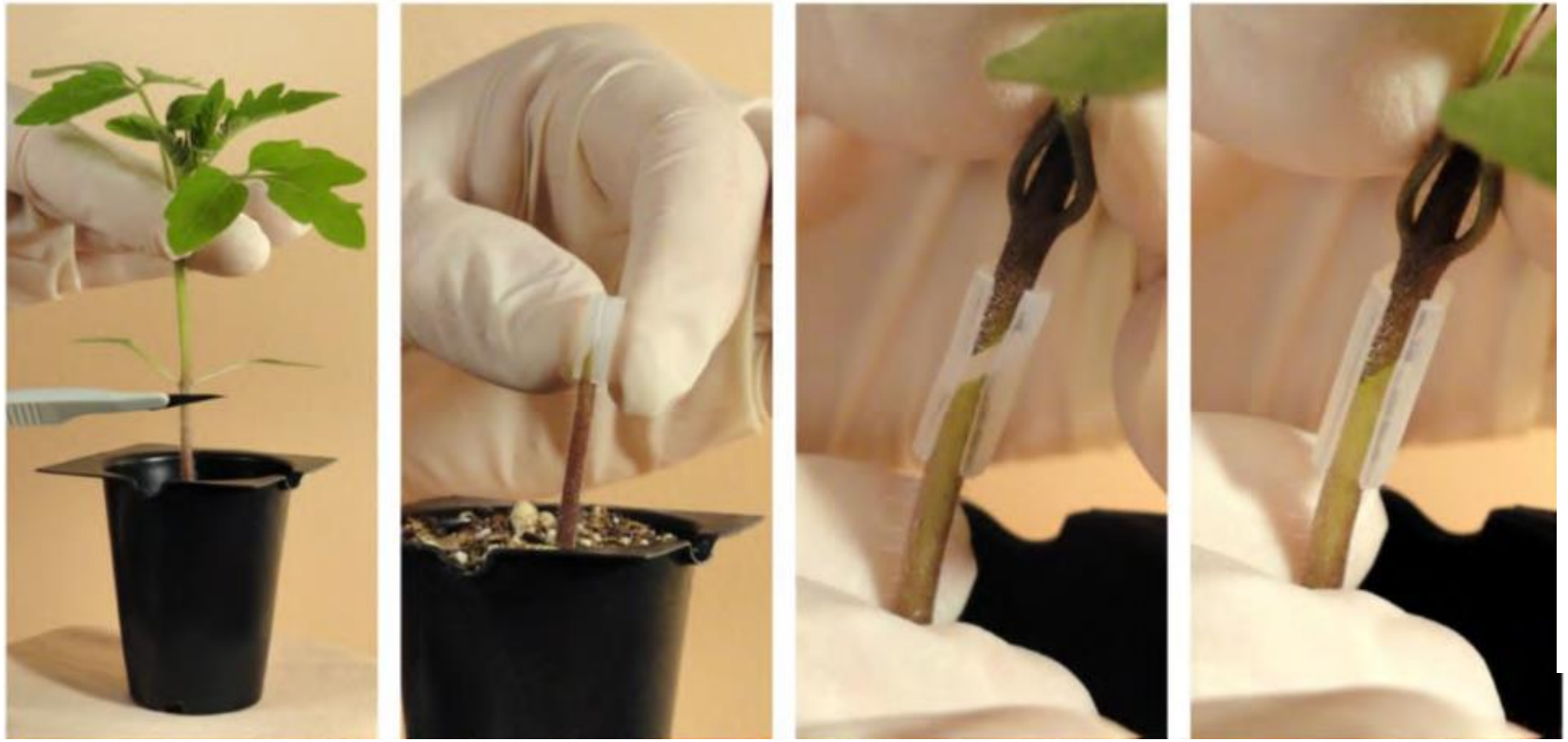
Grafting methods for solanaceous crops



From: Lee (2003)

Splice grafting tomato involves 45° angle cuttings for both scion and rootstock.



Rootstock should be cut below cotyledon.

Scion can be cut below or above to match the diameter.

Photo by C. Rivard, KSU

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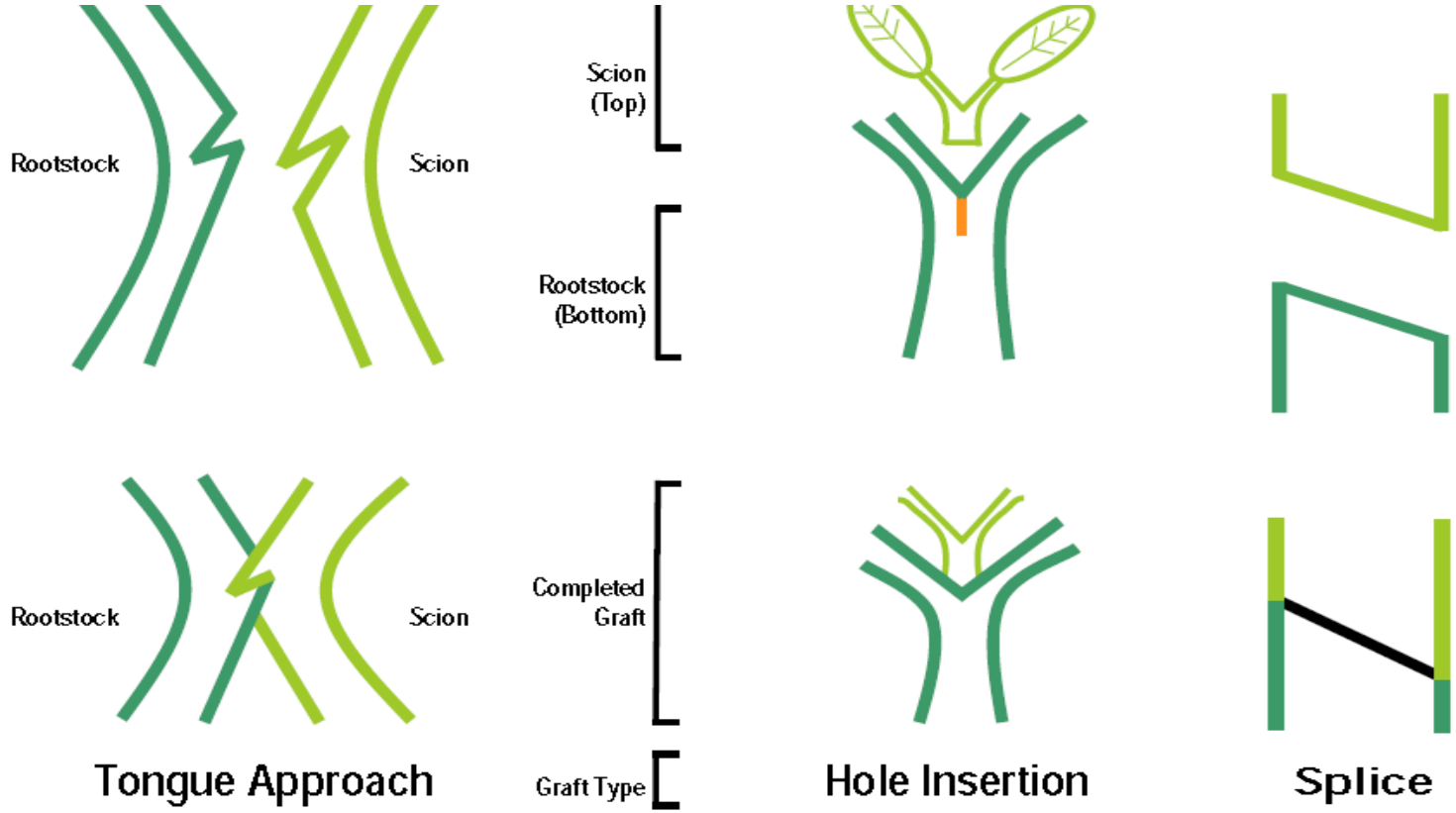
Grafting methods for cucurbit crops



From: Lee (2003)

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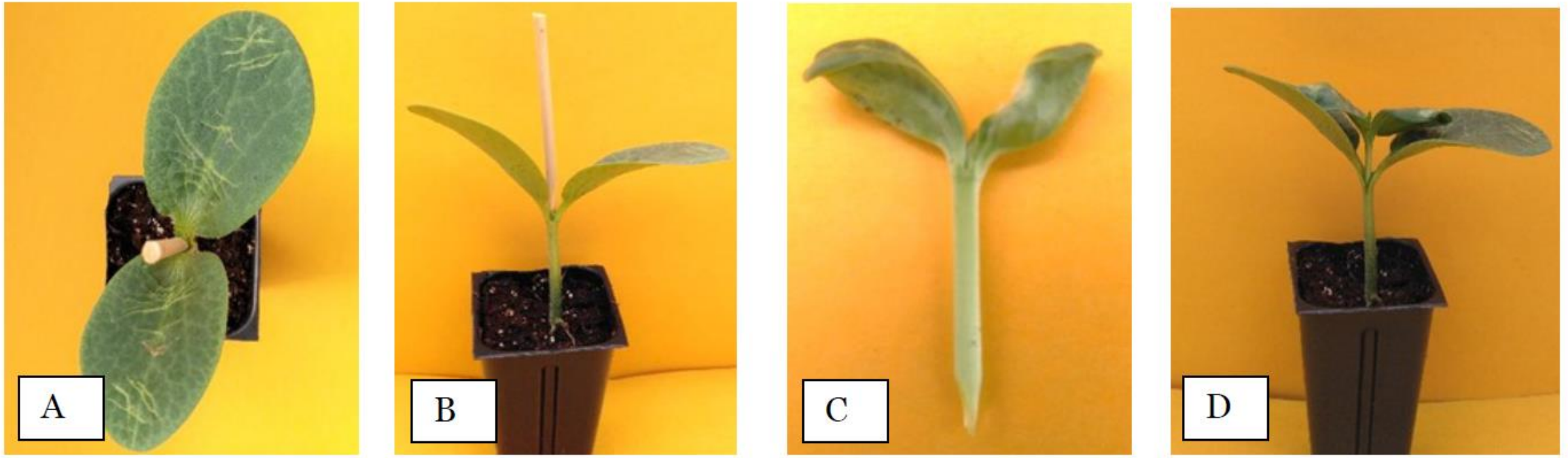

Hole insertion: hole creation (A and B), two sides 45° angle wedge (C), insertion (D).

Courtesy of C. Miles (WSU) and X. Zhao (Univ. of FL)

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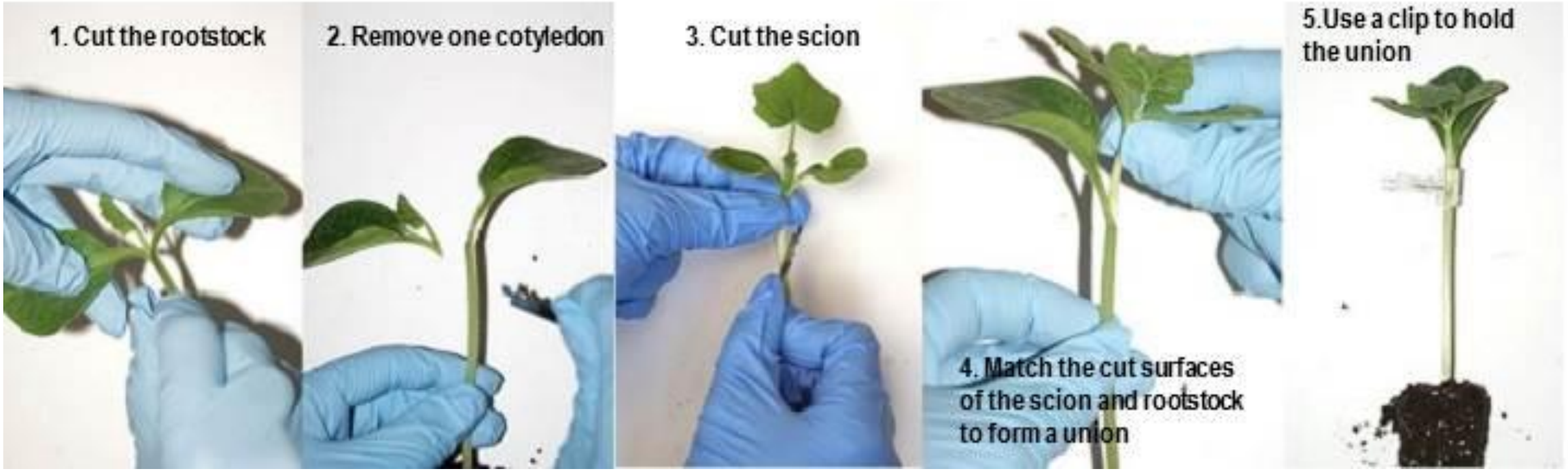

One cotyledon method used for cucurbit grafting

Courtesy of C. Miles, WSU

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Grafting is a process of reconnecting the two wounded plants. So they must be healed before going to the field.

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Healing conditions

Humidity (high, over 90%)

Temperature (70 – 84 degree F)

Light (light can be provided if temperature is under control)

Healing conditions for tomato

Temperature	21–29 °C (70–84 °F)
Humidity	> 90% (the first 3-5 days)
Light	Provide light if temperature can be controlled

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Healing conditions for watermelon

Temperature	28–29 °C (82–84 °F)
Humidity	> 95% (the first week)
Light	Provide light if temperature can be controlled

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Healing chamber in the greenhouse using natural light

Healing chamber in the greenhouse using artificial light

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Healing takes about 7 to 10 days.

A: Full coverage with black cloth to block light and maintain humidity.

B: Remove black cloth and use white fabric/plastic 3-5 days after grafting.

C: Open the side for air ventilation and better adaptation.

D: Move plants out of the chamber.

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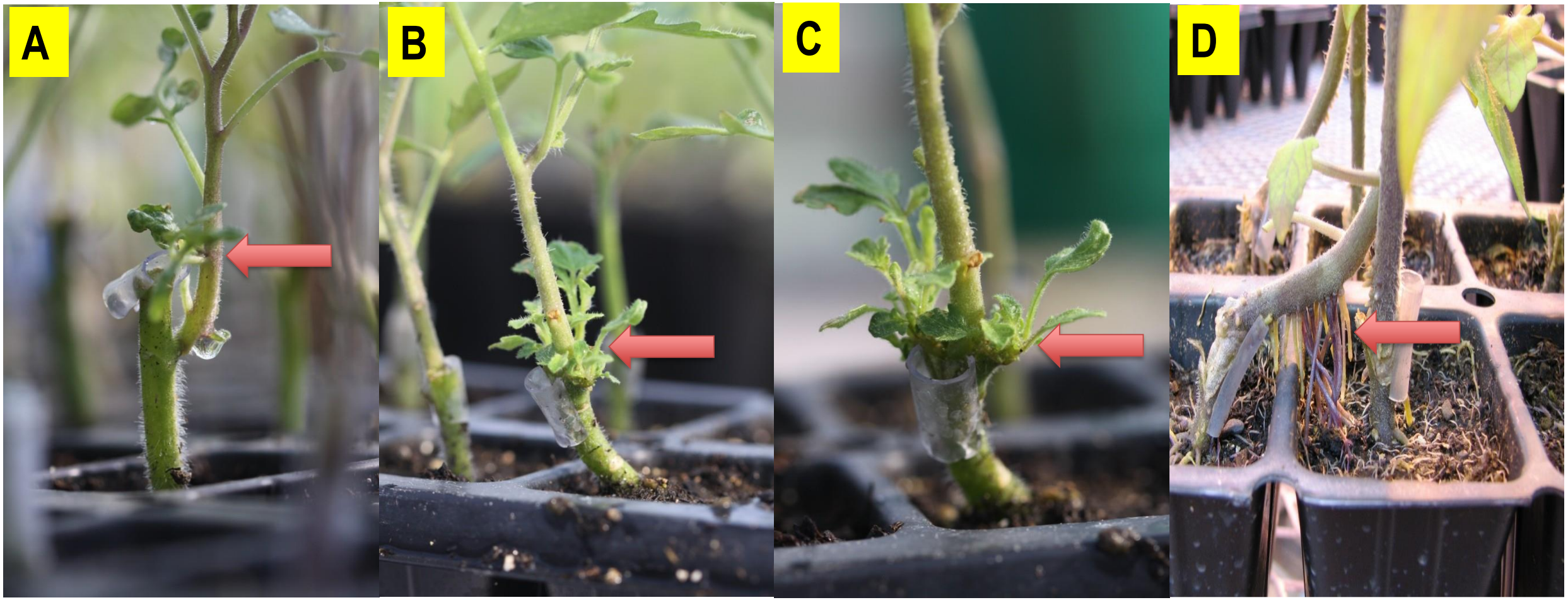

Unsuccessful grafted plants usually cause rootstock shoot and scion root growth or suckers from the graft union. Scion has died, and rootstock shoot forms (A). Suckers (B and C) should be removed to prevent yield reduction. Scion root (D) will affect disease resistance.

Source: VPSL-OSU

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Grafted vegetables are now grown in different settings for multiple purposes.

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Using Grafted Plants may allow fruit growers to …

- reduce crop protectant use, costs
- maintain, enhance production on limited land base (assign fixed and variable costs of production more flexibly)
- maintain yield under low fertility, moisture

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Main Reasons to Use Grafted Plants

- serious soil-borne disease
- susceptible, strongly preferred variety
- small land base, few other control options
- vigor, yield very important (enhance, maintain market presence)

Grafted plants grown in the greenhouse look to increase yield and nutrient use efficiency.

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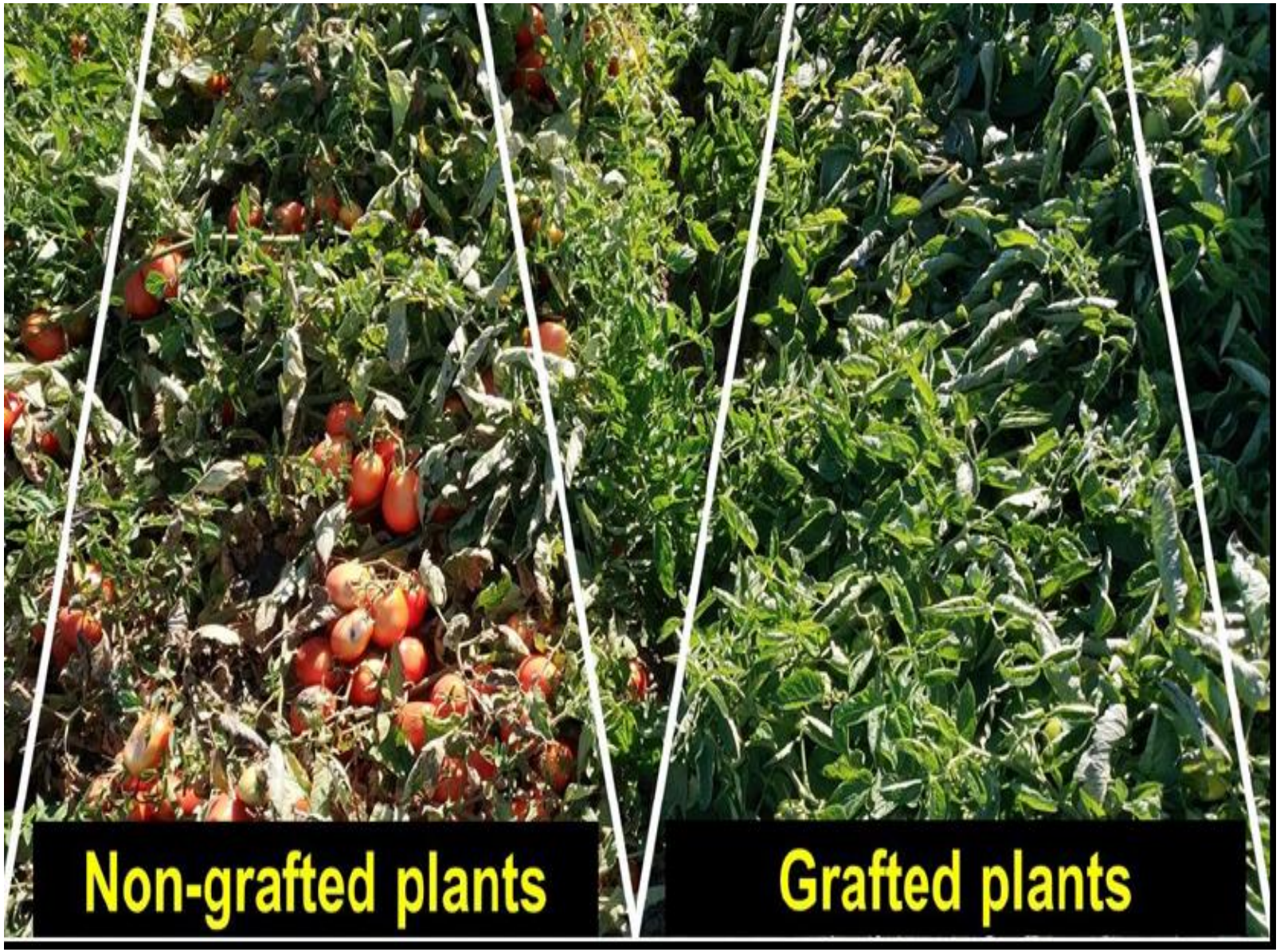

Grafted plants grown in the field usually tolerate soil-borne disease, increase and extend canopy growth to protect later fruit, or better adapt to adverse conditions.

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Growing grafted plants in high tunnels has same purposes to those grown in fields. Besides, growth and harvest can be significantly extended.

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Benefits of grafting may not be gained at all situations because…

1. Dozens of rootstocks and scions make thousands of combinations. They are different in many aspects.
2. Rootstock-scion incompatibility may exist and nullify the effects.
3. Improper planting and mis-management will cause yield reduction.

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Description of Commercial Solanaceous Rootstocks

Common Tomato Diseases and Pests and Susceptibility Characteristics

Rating rootstock (RS) characteristics is complex because strains of pathogens differ and plant responses to them are rarely “yes” or “no.” Therefore, approaches to and outcomes of rating RSs differ. This table was compiled using only publicly available information provided by seed companies in catalogs and at websites. Companies refer to RSs generically as “resistant” (R below). Others describe RS resistance to a disease or pest as high, full or complete (HR below) or partial or intermediate (IR below). Others use numerical scales which have been converted to R, HR and IR below.

Date Last Updated	Rootstock Variety	Crop Scion	Product URL	Developer	Bacterial Wilt	Corky Root Rot	Fusarium Wilt Race 1	Fusarium Wilt Race 2	Fusarium Wilt Race 3	Fusarium Crown and Root Rot	Phytopthora Blight	Potato Y Virus	Southern Blight	Verticillium Wilt Race 1	Verticillium Wilt Race 2	Root-knot Nematode	Tomato Mosaic Virus	Tomato Spotted Wilt Virus
November 02,2017	Aegis F1	Tomato	Click Here	Takii Seed	IR	IR	HR	HR		HR				HR		HR	R	
November 02,2017	Anchor-T F1	Tomato	Click Here	Takii Seed	IR		HR	HR						HR		HR	R	
November 02,2017	Armada F1	Tomato	Click Here	Takii Seed	IR	IR	HR	HR		HR				HR		HR	R	
November 02,2017	Arnold	Tomato	Click Here	Syngenta		HR	HR	HR		HR				HR		HR	HR	
November 02,2017	B.B. F1	Tomato	Click Here	Takii Seed	IR	IR	HR	HR		HR				HR		HR	R	
January 08,2019	BHN 1087	Tomato		BHN Seed	R	R	R	R	R	R				R		R		
January 08,2019	BHN 1088	Tomato		BHN Seed		R	R	R	R	R				R		R		R
January 07,2019	Bowman	Tomato	Click Here	Sakata	IR	IR	HR	HR	HR	HR				HR	HR	IR	HR	
January 24,2019	Bruce RZ F1	Tomato	Click Here	Rijk Zwaan		HR	HR	HR		HR				HR			HR	
November 02,2017	Camel F1	Tomato	Click Here	Takii Seed	IR		HR	HR		HR								

By 2019, there are at least 60 commercially available solanaceous rootstocks.

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Description of Commercial Cucurbit Rootstocks

Common Tomato Diseases and Pests and Susceptibility Characteristics

Rating rootstock (RS) characteristics is complex because strains of pathogens differ and plant responses to them are rarely “yes” or “no.” Therefore, approaches to and outcomes of rating RSs differ. This table was compiled using only publicly available information provided by seed companies in catalogs and at websites. Companies refer to RSs generically as “resistant” (R below). Others describe RS resistance to a disease or pest as high, full or complete (HR below) or partial or intermediate (IR below). Others use numerical scales which have been converted to R, HR and IR below.

Rootstock Variety	Product URL	Developer	Rootstock Species	Crop Scion	Bacterial Wilt	Fusarium Wilt Race 1	Fusarium Wilt Race 2	Fusarium Wilt Race 3	Fusarium Crown and Root Rot	Rhizoctonia Root Rot	Vertillium Wilt	Root-knot Nematode	Melon Necrotic Spot
November 02,2017	AQ	Click Here	Origene Seeds		watermelon, melon		R	R				R	
November 02,2017	Barricade F1	Click Here	Takii		melon		HR	HR	HR				
November 02,2017	Bass BS-1 F1	Click Here	Origene Seeds		melon, watermelon		R	R	R				
November 02,2017	Bingo	Click Here	Takii	Lagenaria siceraria	watermelon		HR	IR					
January 24,2019	Cobalt	Click Here	Rijk Zwaan	Cucurbita moschata, Cucurbita maxima	melon, watermelon		HR	HR		HR			HR
January 24,2019	Ferro RZ	Click Here	Rijk Zwaan	Cucurbita moschata, Cucurbita maxima	N/A		HR	HR		HR		HR	
November 02,2017	Figleaf Gourd (Cucurbita ficifolia)			Cucurbita ficifolia	cucumber								

By 2019, there are at least 27 commercially available cucurbit rootstocks.

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Rootstock Vigor

High (strong vegetative and/or reproductive growth)	Medium (balanced between vegetative and reproductive growth)	Generative (energy flows into fruit production)

Sowing seeds at different times is recommended due to the vigor variation.

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THE OHIO STATE UNIVERSITY

Relative Seedling Vigor Values of Twenty-Three Tomato Varieties

By Bizhen Hu, Mark A. Bennet, and Matthew D. Kleinhenz[1]

Cultivar	Vigor Value	
	February 27 - March 17, 2014	March 28 - April 15, 2014
Aiboh	106	401
Akaoni	72	2292
Aooni	102	878
Armada	198	3554
Arnold	1727	4008
B.B.	230	2218
Beaufort	1024	2437
Better Boy*	154	1593
Brandywine*	130	1134
Celebrity*	141	1316
Cheong Gang	190	2256
Cherokee Purple*	234	393
Estamino	65	606
Kaiser	513	11504
Maxifort	610	5244
Resistar	315	956
RST-04-105	99	1557
RST-04-106	191	1844
San Marzano 2*	305	3751
Shield	73	391
Stallone	357	4189
Supernatural	154	544
Trooper	3	145

Hu et al. 2016
HortTechnology

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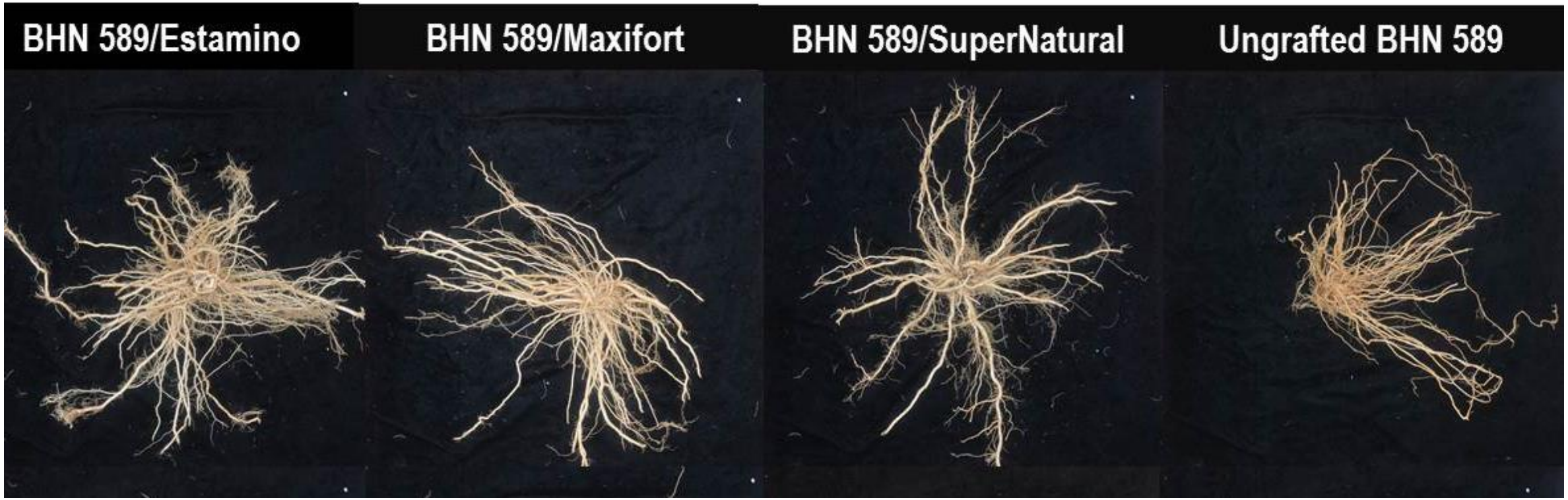

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- Estamino is a strong, generative rootstock that puts a high proportion of energy into fruit (Johnny's Selected Seeds, Paramount Seeds Inc., Territorial Seed Company).

- Maxifort is a vigorous, vegetative rootstock for large fruit and long-season cropping. It is one of the most vigorous rootstocks (Johnny's Selected Seeds, Paramount Seeds Inc.).

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Rootstock-scion Incompatibility

- We know the most about rootstock varieties resistance to soil-borne diseases and nematodes.
- We know less about rootstock varieties resistance to abiotic stresses, vigor, or responses to other production practices.

Not every combination will meet your goals.

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Rootstock-scion Incompatibility

For tomato:

All commercial rootstocks and scions appear to be compatible.

Rootstock-scion Incompatibility

For watermelon:

The compatibility is not assured.

Watermelon rootstock includes:

bottle gourd

squash

interspecific squash hybrids

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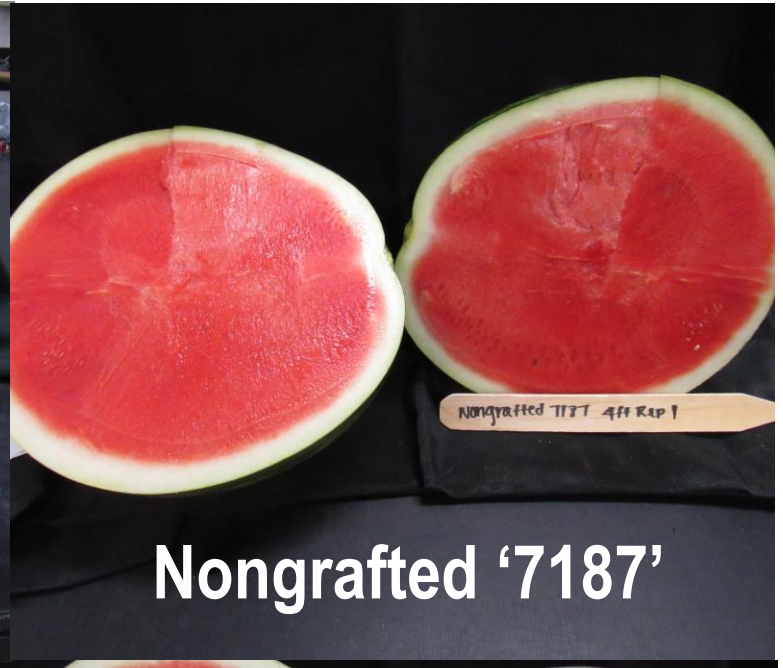
‘7187’ on ‘RS841’



Nongrafted ‘7187’

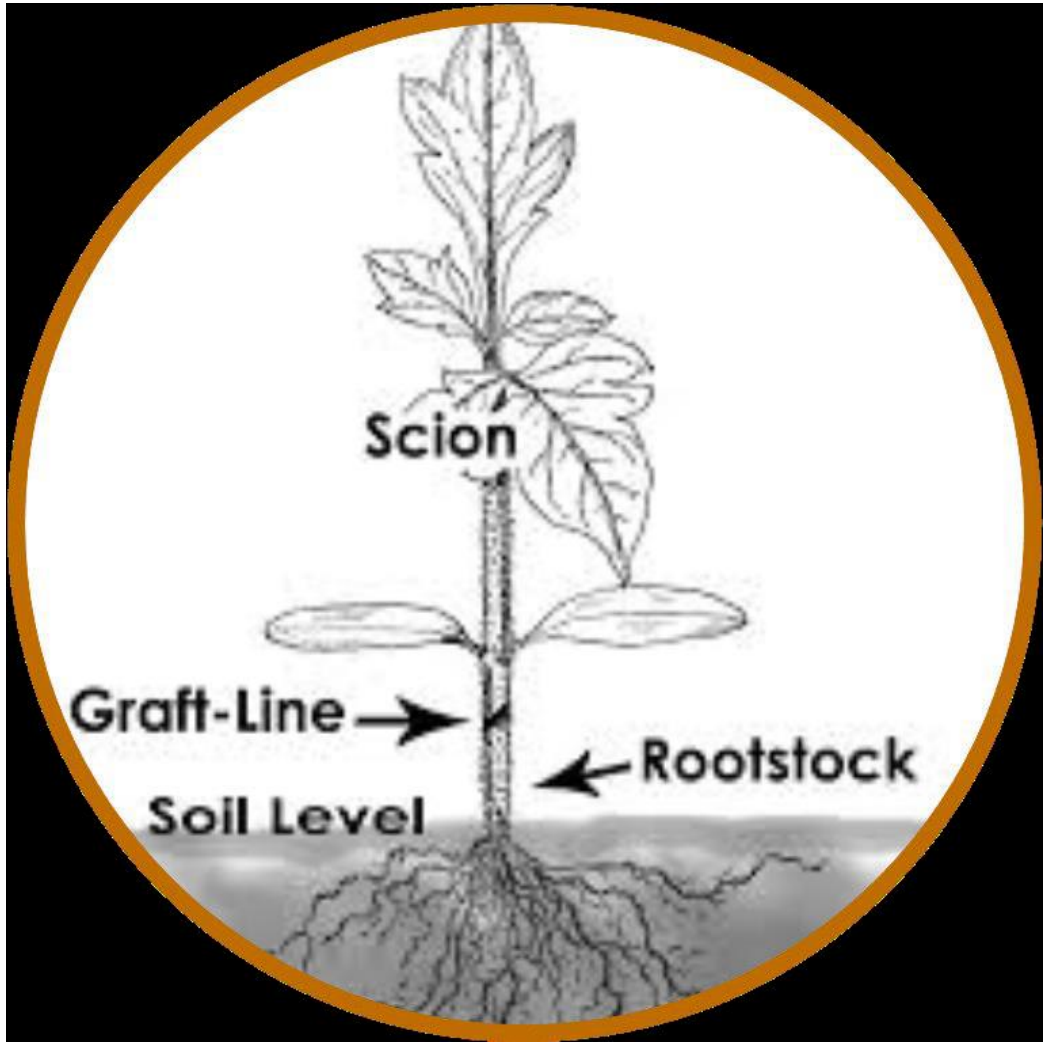
‘Fascination’ on ‘RS841’

Nongrafted ‘Fascination’

Incompatibility affects fruit quality, such as more hollow-heart fruit.

Not all commercial varieties are suitable for grafting, such as 7187.

Same rootstock has different performance when grafting with different scions (Fascination vs. 7187).



Leaving the graft union above soil line is recommended. Why?

- Avoid scion adventitious roots
- Avoid disease transmitting to scion

Leaving the graft union above soil line is difficult in CA. But this may not be a big issue.

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In CA, most fruiting vegetables are using sub-surface drip irrigation. This type of irrigation limits wetting the topsoil, thereby limiting scion root growth and disease transmitting.

Photos from UCANR

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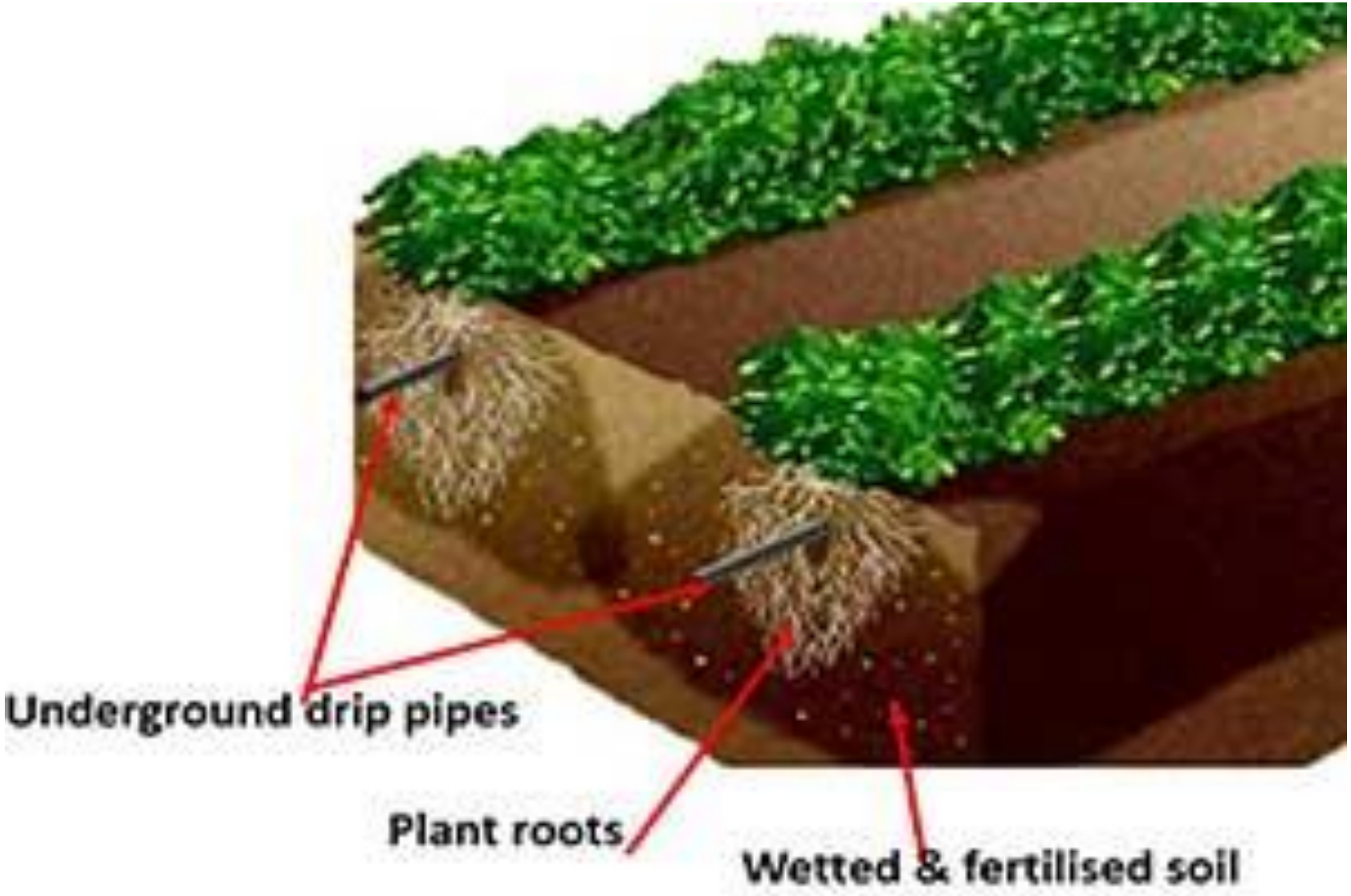

Photos from W.P. Law, Inc.

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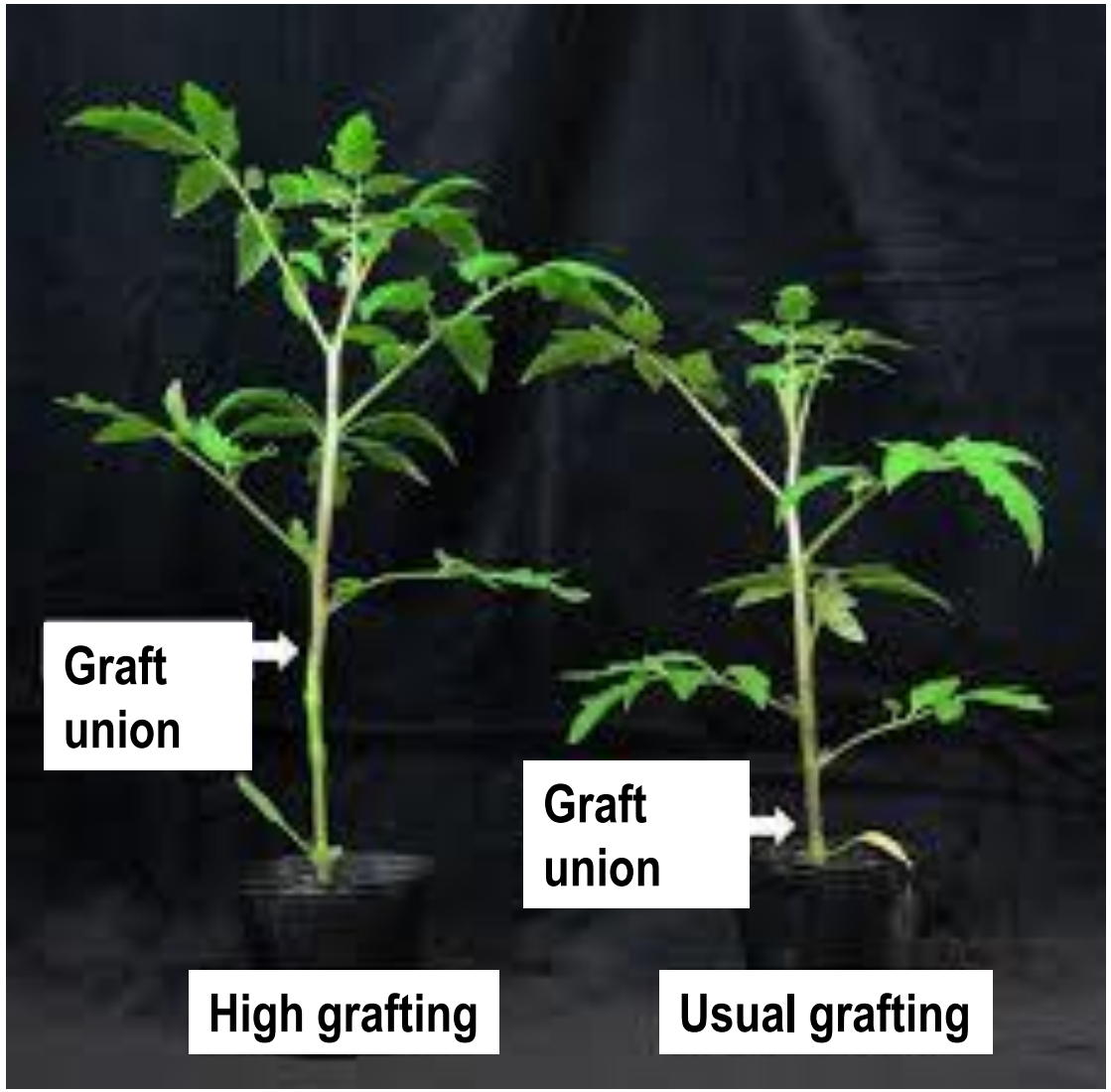
Grafting at a high position may help plants avoid the impacts of burying the graft union.



Uehara and Nakaho (2017)

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In the next 75 minutes…

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Challenges of using grafted plants exist in every step.

- Increased cost
- Complicated variety selection
- More greenhouse space required
- Delayed harvest due to extended vegetative growth
- Is the condition appropriate (adjust irrigation, fertigation…)?

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Seed ($ vs. $$$$)

Tomato

Commercial scion hybrid: 500 seeds < $100, a lot are lower than $30.

Rootstock: 500 seeds cost $ 150 - $200, a lot are more than $200.

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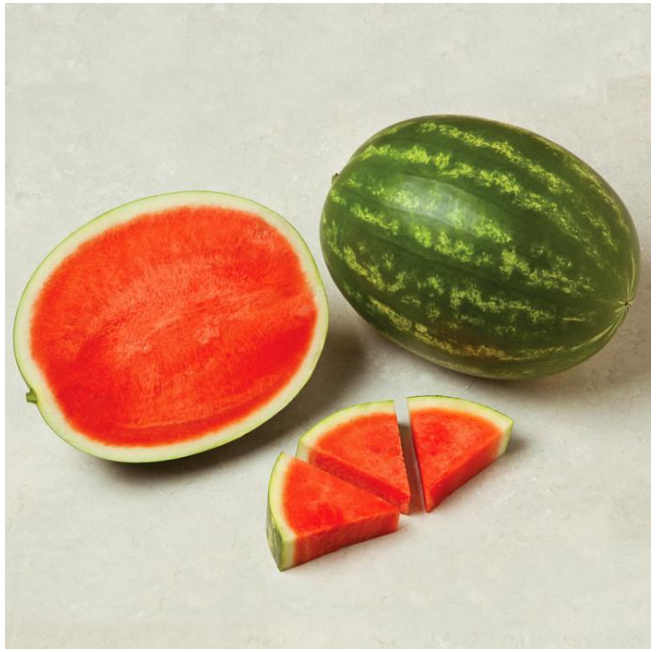
Seed ($ vs. $$$$)



Watermelon

Commercial scion hybrid (seedless): 100 seeds around $50.

Rootstock: price is highly varied. Some rootstocks also work for cucumber and melon grafting.

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Grafting Cost

Affected by species, method used, and production scale

A ballpark cost ranges from 20 cents to $1 per plant (labor, materials, utilities, and depreciation).

Summarized by Chieri Kubota, OSU

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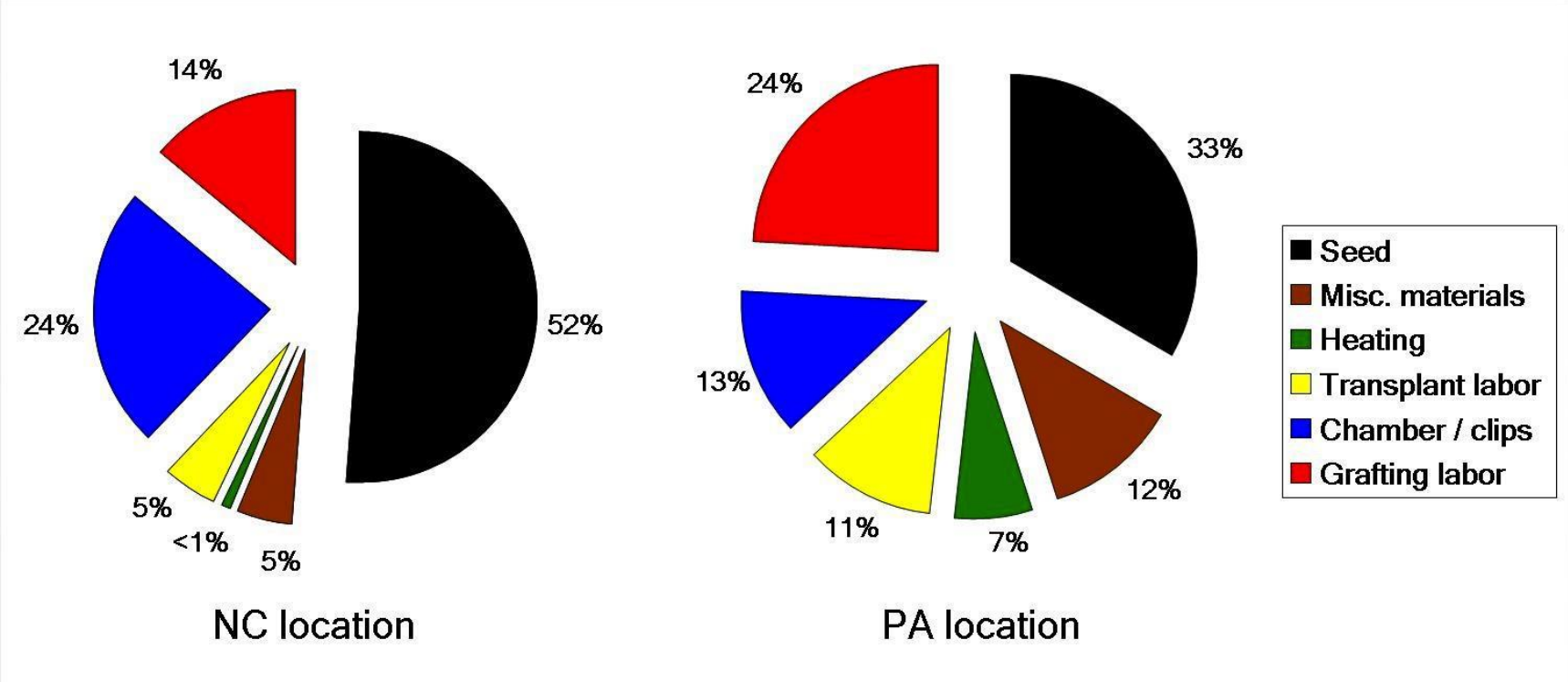
1-acre melon field (2000 plants)

Regular: seeds and seedling production

Grafting: seeds (rootstock and scion), seedling production and grafting cost. Increase of cost can be over $1000 per acre.



C. Rivard et al. (2010)

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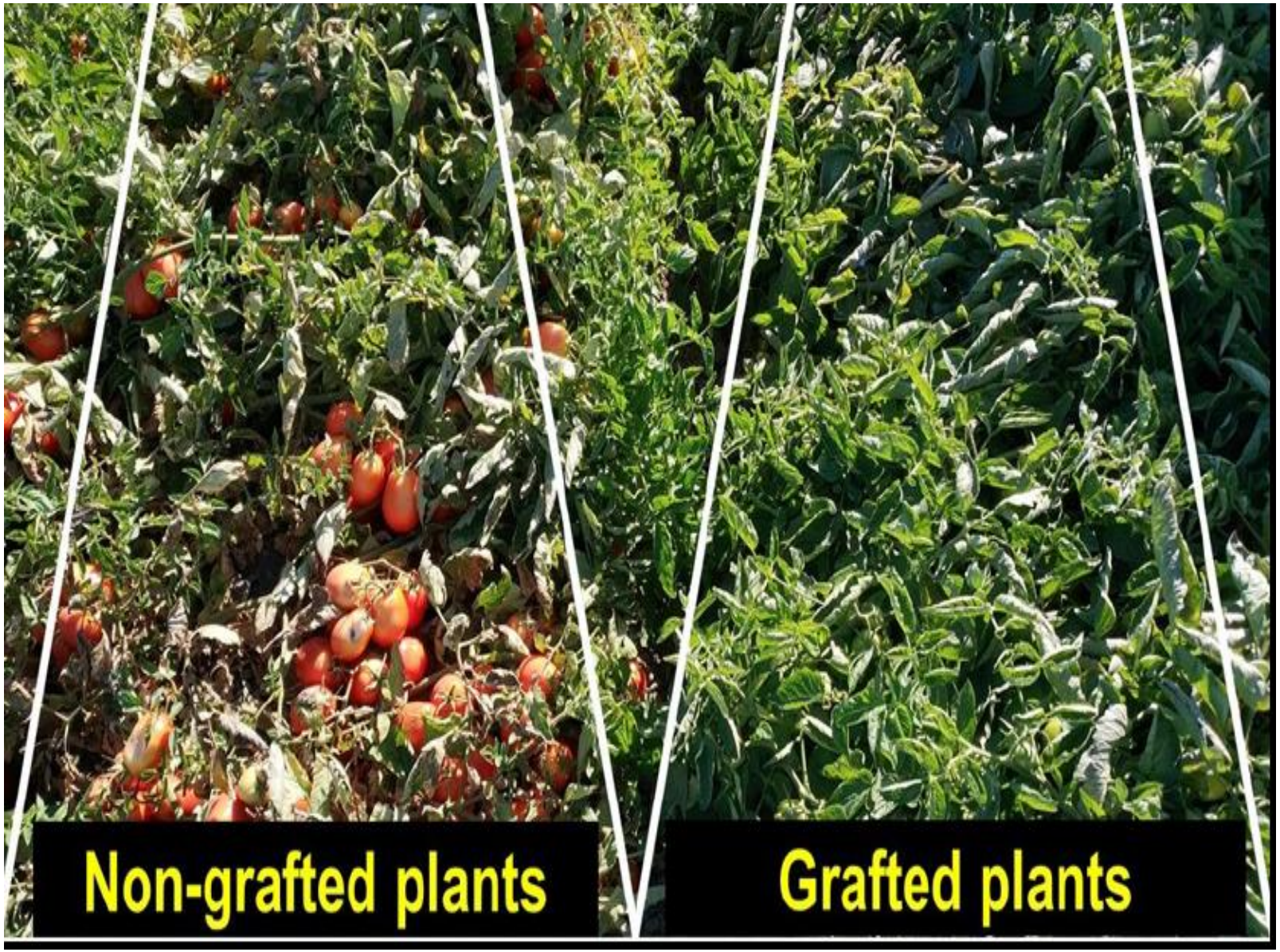

Harvest may be delayed compared to nongrafted plants due to extended vegetative growth.

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We know the merits of grafting. How can we use them more economically?

1. Drop the seed cost (breeder, seed retailor).
2. Develop more rootstocks that don't have elongated vegetative growth (breeder).
3. Drop the cost of grafting, relying on robotic grafter (nursery greenhouse, propagator)
4. Use fewer plants per acre/wider spacing (grower)

Grafted and non-grafted watermelon plants were transplanted at the spacing of 3 feet, 4 feet, and 6 feet (left to right). The corresponding plant population is 2074, 1555 (25% reduction), and 1037 (50% reduction) per acre, respectively (photos were taken on May 24, 2019).

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GOOD LUCK!

THANK YOU

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