Green Fruit Removal Dynamics for Development of Robotic Green Fruit Thinning End-Effector

2023 ASABE Annual International Meeting

Magni Hussain, Long He

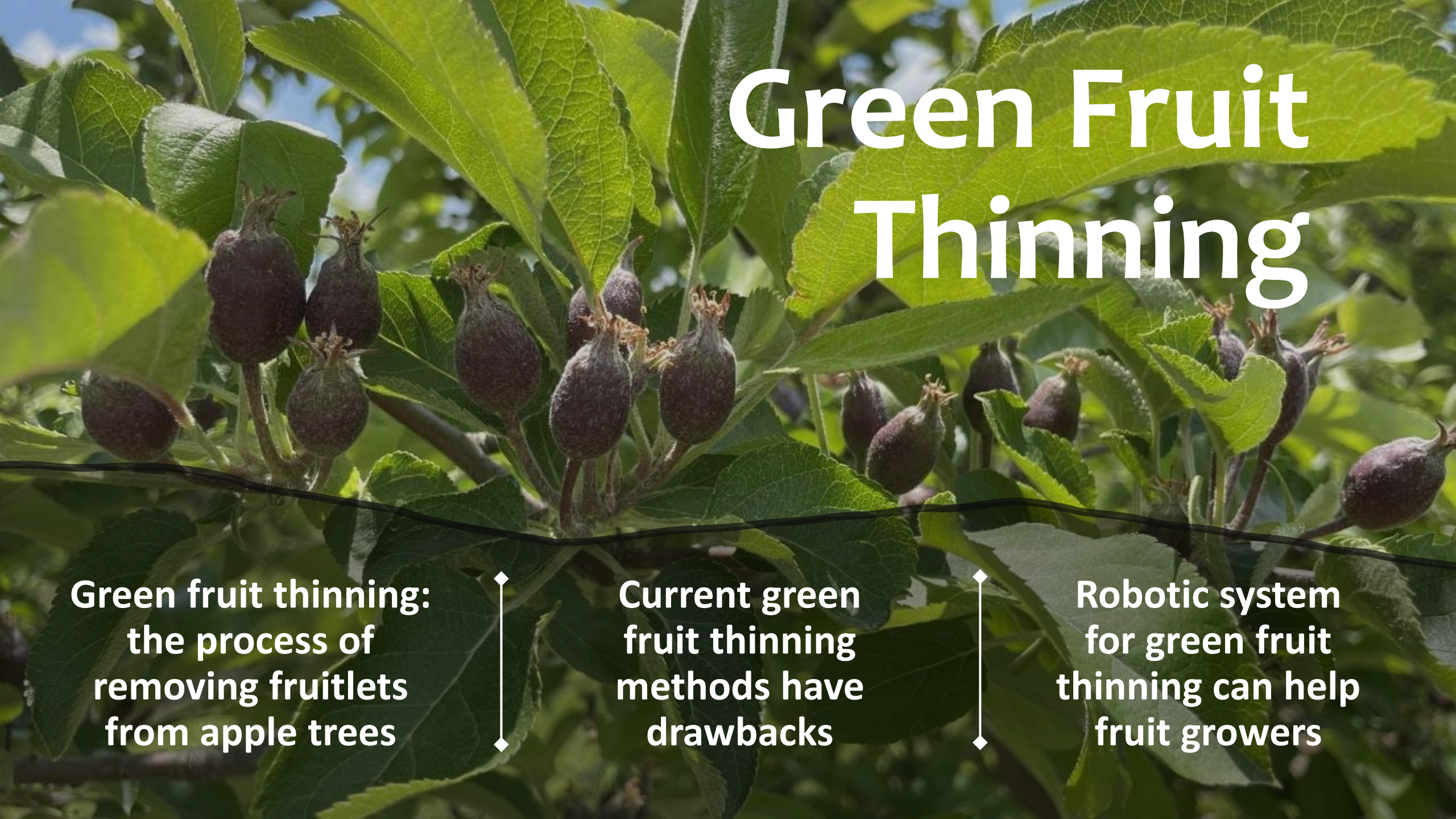
The Pennsylvania State University

Apple Industry

$3.05 billion in utilized production in US

Several tasks for apple production:

- Harvesting
- Pruning
- Thinning


Green Fruit Thinning
Green fruit thinning: the process of removing fruitlets from apple trees
Current green fruit thinning methods have drawbacks
Robotic system for green fruit thinning can help fruit growers

Robotic Green Fruit Thinning System

Project Goal: to develop a robotic green fruit thinning system for apple production

FRUIT REMOVAL END-EFFECTOR

THINNING VISION SYSTEM

PATH PLANNING & SEQUENCING

SYSTEM INTEGRATION

PHASE 1

PHASE 2

Study Outline

GREEN FRUIT REMOVAL DYNAMICS

END-EFFECTOR PROTOTYPE

Experimental setting

CULTIVARS: GOLDRUSH, FUJI, GOLDEN DELICIOUS

GREEN FRUIT SIZE

15 cm – 30 cm

MAY – EARLY JUNE 2021

Fruit Removal Dynamics

Goal: test common thinning techniques to determine optimal method for robotic green fruit thinning

PULLING METHOD

CUTTING METHOD

Fruit Removal Dynamics

PULLING METHOD

DIGITAL FORCE GAUGE

PULLING PVC WITH STEM GROOVE

PROCEDURE:

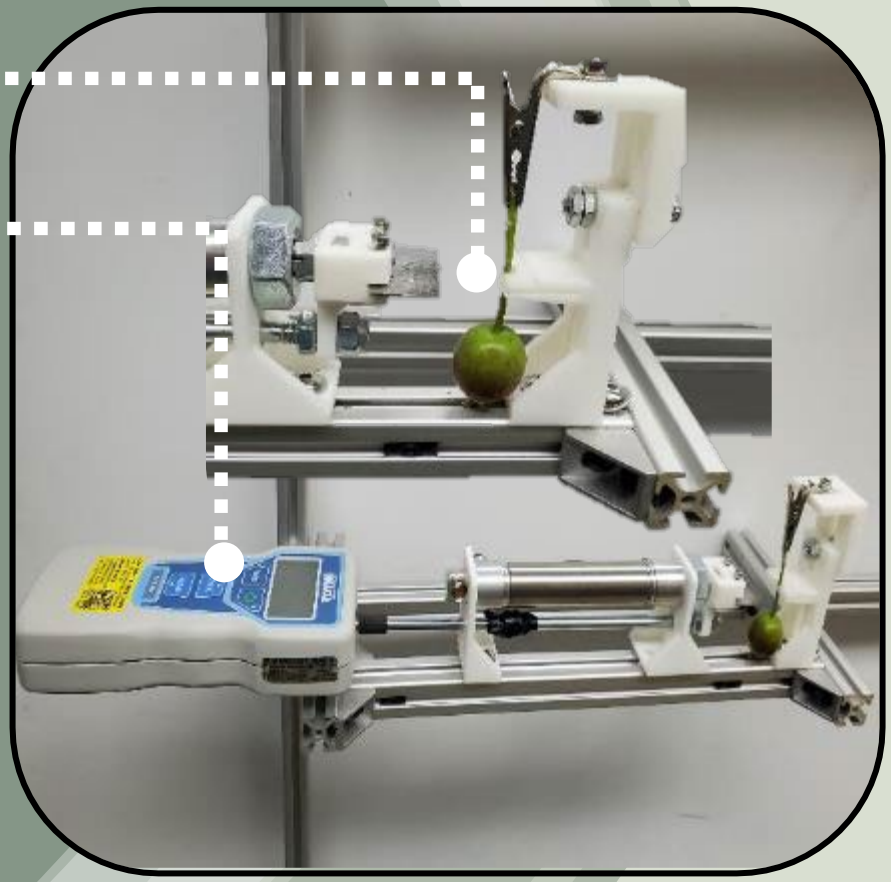
1. Measure fruit/stem dimensions
2. Pull target fruit with digital
3. Record force and detachment location

Fruit Removal Dynamics

CUTTING METHOD

STEM-CUTTING SETUP

DIGITAL FORCE GAUGE



PROCEDURE:

1. Collect green fruit from orchard
2. Measure fruit/stem dimensions
3. Hang fruit from stem holder
4. Push gauge slowly until stem cuts
5. Record force

Fruit Removal Dynamics Results

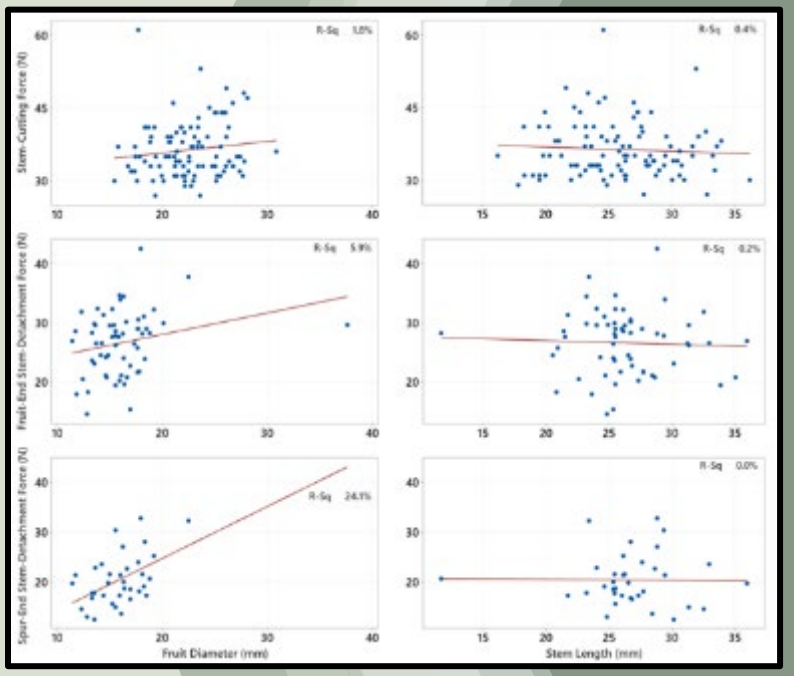
CULTIVARS	STEM-CUTTING FORCE (N)	SPUR-END PULLING FORCE (N)	FRUIT-END PULLING FORCE (N)	PULLING DETACHED LOCATION (%)	
				FRUIT-END	SPUR-END
FUJI	36.3 ± 5.8^{A}	$20.5\pm5.1^{D,E}$	$26.6\pm5.4^{B,C}$	28%	72%
GOLDEN DELICIOUS	37.1 ± 8.6^{A}	$19.5\pm4.2^{D,E}$	$23.7\pm6.7^{C,D}$	50%	50%
GOLDRUSH	27.5 ± 5.2^{B}	19.1 ± 3.5^{E}	$23.5\pm5.2^{C,D}$	60%	40%
OVERALL	33.6±8.0	19.9±0.6	24.8±0.5	42%	58%

Pulling force << Stem-cutting force

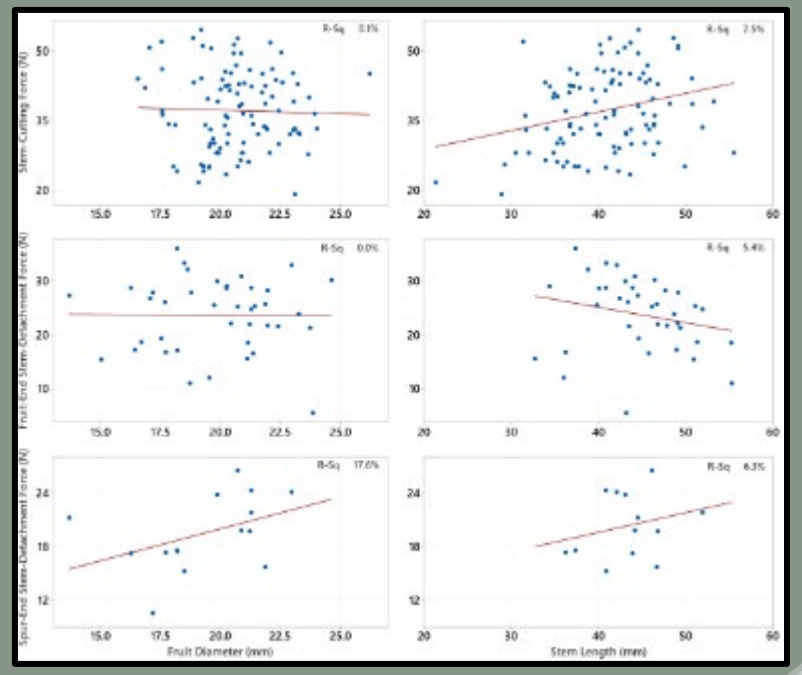
High spur-end detachment when pulling

Force-Size Relationship

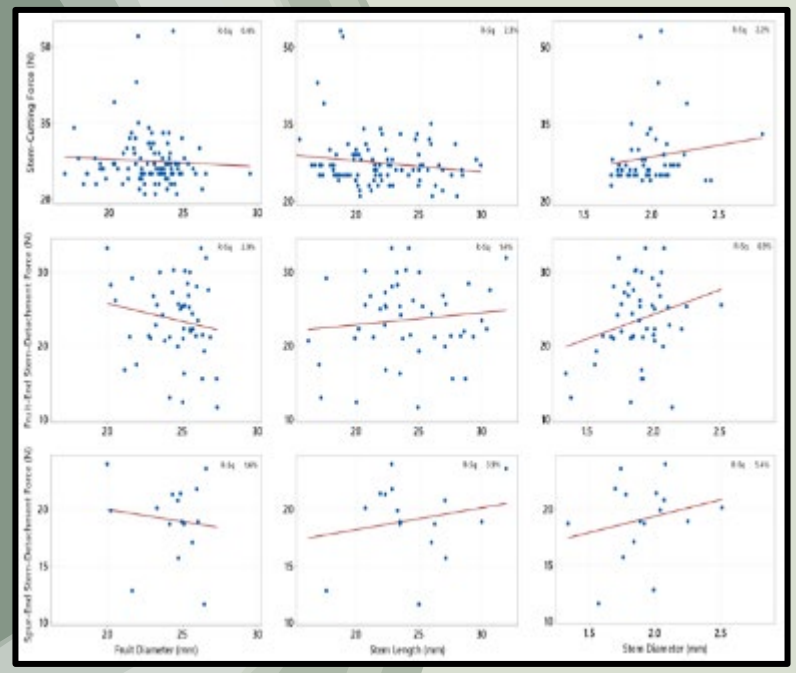
GOLDRUSH



FUJI



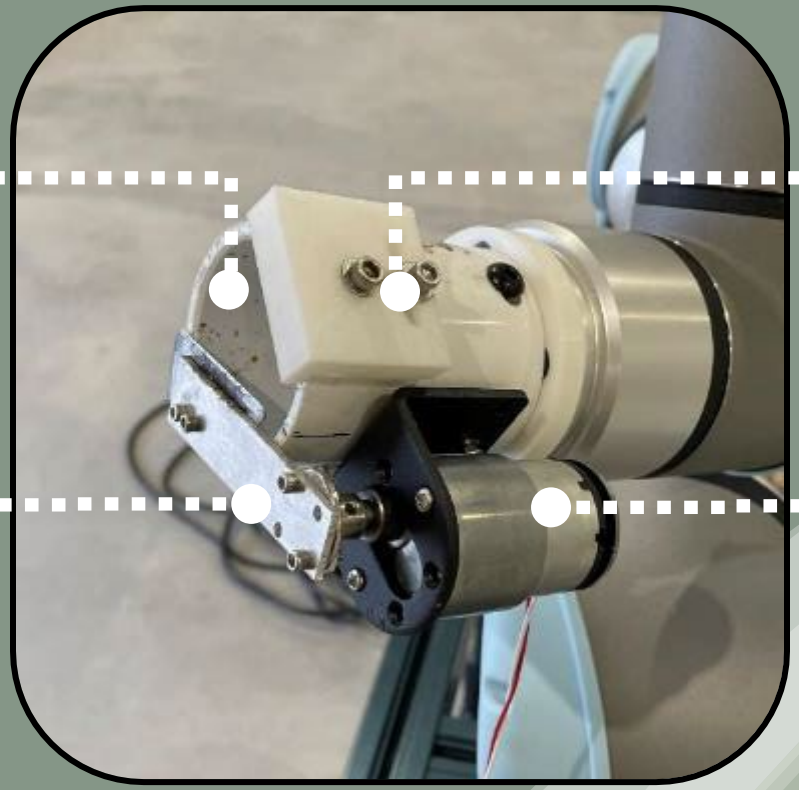
GOLDEN DELICIOUS



No meaningful relationships between fruit dimensions and removal force for any cultivar
No force control needed – select motor that can deliver enough force

End-Effector Prototype

Fruit removal dynamics motivated stem-cutting end-effector



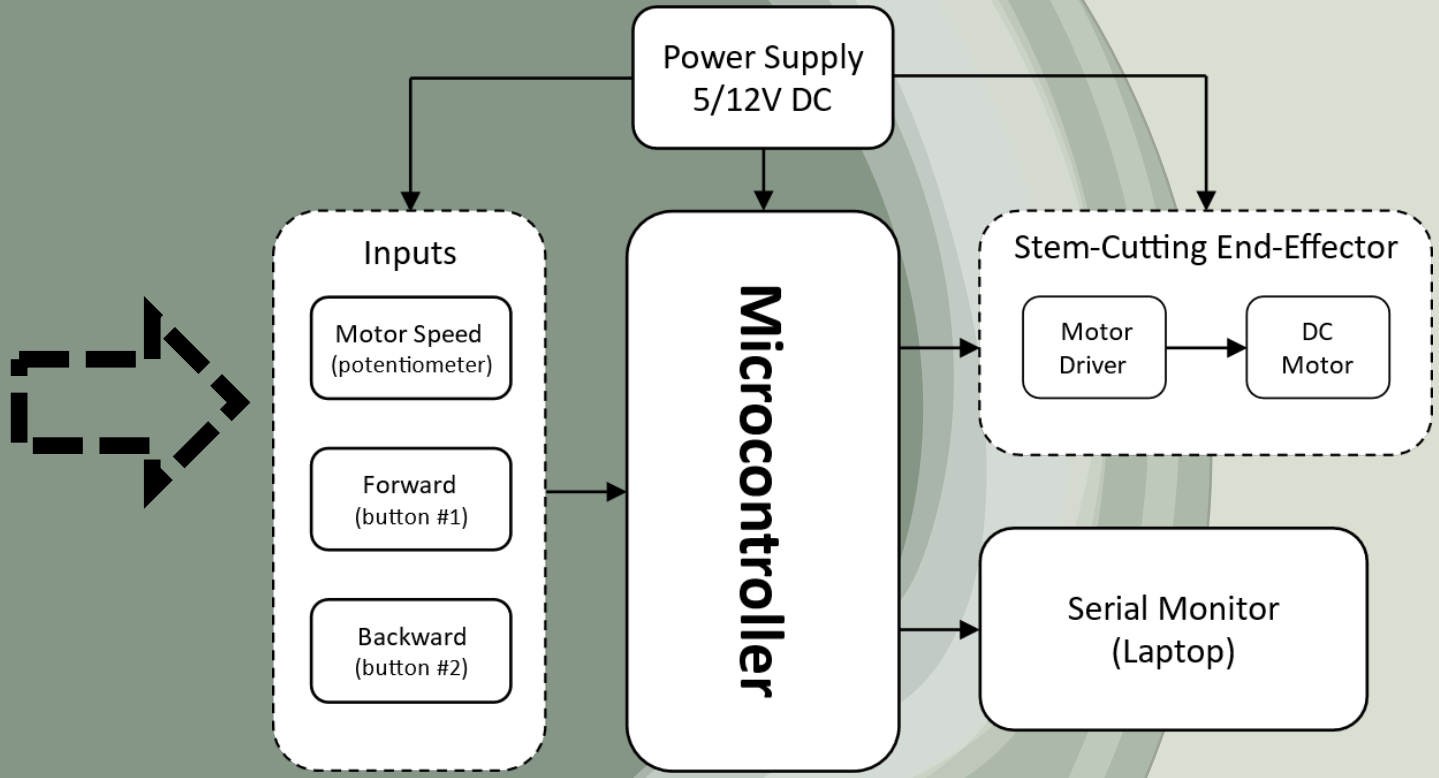
PVC ENCLOSURE

UTILITY BLADE

CUTTING MOUNT

DC MOTOR

Control system diagram

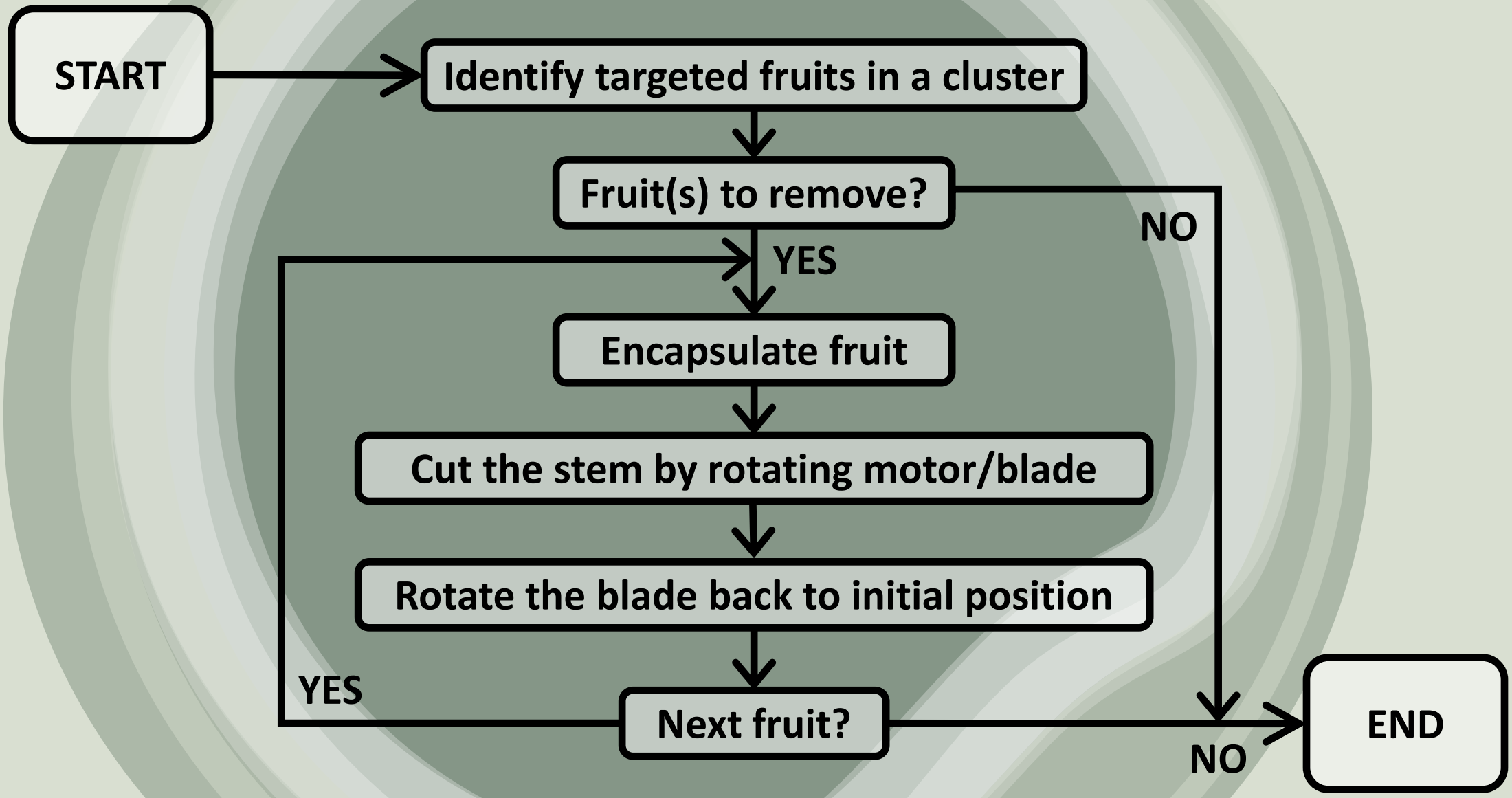


End-Effector Experiments

HANDHELD TESTS

ROBOTIC MANIPULATOR TESTS

Experimental Process



End-Effector Results

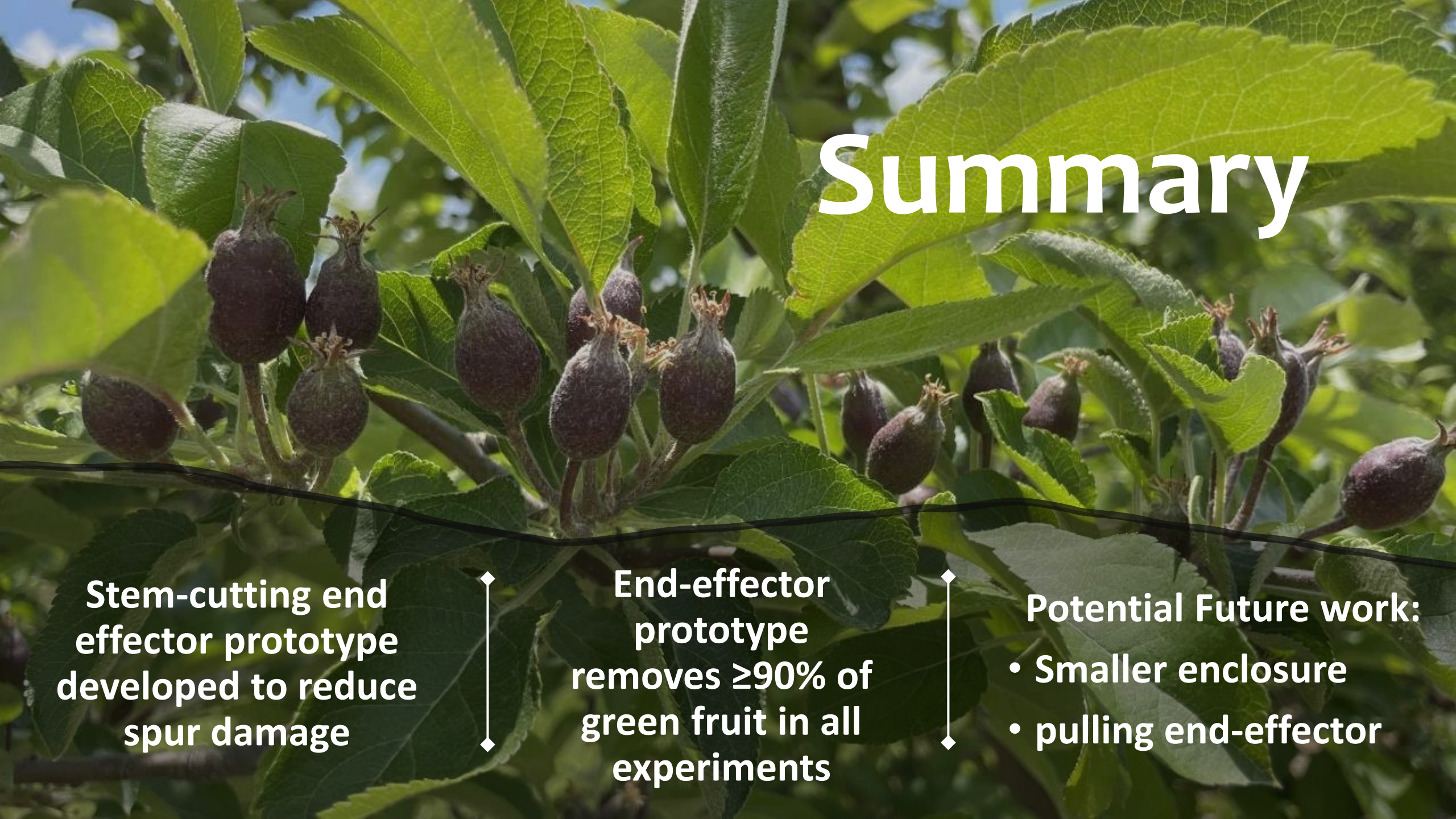
TESTS	CULTIVARS	TOTAL NO. FRUITS	REMOVED FRUITS	SUCCESS RATE
HANDHELD PROTOTYPE	FUJI	50	47	94%
	GOLDEN DELICIOUS	50	48	96%
	GOLDRUSH	50	45	90%
ROBOTIC ARM PROTOTYPE	GOLDEN DELICIOUS	25	23	96%

≥90% of green fruit removed in all experiments

MANIPULATOR CONSIDERATIONS:

1. Offset needed to encapsulate fruit
2. Edge-of-workspace limitations need to be considered

Robotic Green Fruit Thinning Prototype



Summary

Stem-cutting end effector prototype developed to reduce spur damage

End-effector prototype removes ≥90% of green fruit in all experiments

Potential Future work:

- Smaller enclosure
- pulling end-effector

Acknowledgements

Doctoral committee

- Long He (Advisor)
- Paul Heinemann (Advisor)
- James Schupp
- David Lyons

Ag Robotics & Sensing Lab

Project funding sources

USDA NIFA AFRI Grant 2020-67021-31959
Northeast SARE Graduate Student Grant GNE22-285