Using Marketability Attributes for the Initial Development of a Soft Robotic Gripper for Harvesting Fresh-market Blackberries

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Introduction

Fresh-market Blackberries

- Fresh-market blackberries (*Rubus* subgenus *Rubus*) are grown and sold commercially worldwide.
  - One of the best examples of a wild fruit commercialized through plant breeding efforts on blackberry genotypes (breeding selections and cultivars)
- Fresh-market blackberries are rich in nutraceuticals and have unique flavors that appeal to consumers.
  - Aroma and flavor complexity impacted by basic tastes (sweetness, sourness, and bitterness) and volatile compounds

Fresh-market Blackberry Challenges

- Fresh-market blackberries are primarily hand harvested to ensure fruit maintains quality from harvest to consumption.

- Handling fresh-market blackberries during and after harvest impacts quality and marketability.

- As value and demand grows for fresh-market blackberries, harvest labor shortages and costs impact potential industry expansion.

Blackberry Postharvest Disorders

- Fresh market blackberries are packaged in clamshells and have issues with postharvest disorders.
  - Decay
  - Leakage
  - Red drupelet reversion (RDR)
  - Weight loss

Edgley et al., 2019; Kader, 2002; Yin, 2017

Soft Robotic Grippers

- Made from rubber, silicone, or other flexible and durable materials

- Driven by an actuation mechanism

- Introduced into the fruit harvest sector

Objectives

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Materials and Methods

Blackberry Harvest

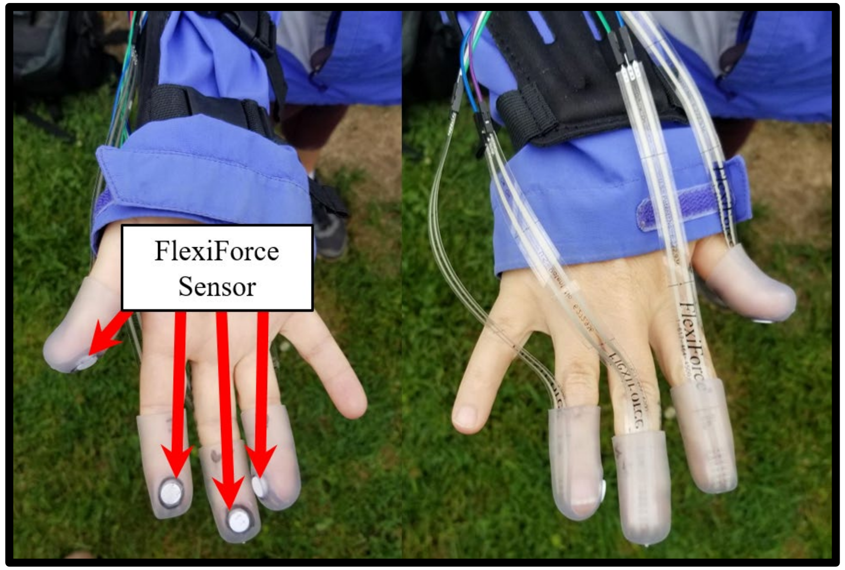
- Blackberries harvested from a commercial growers in Arkansas into 170-g vented clamshells (20 berries/clamshell) in triplicate

- Four cultivars (Natchez, Osage, Prime-Ark® Traveler, and Sweet-Ark™ Caddo) harvested at the shiny-black stage of ripeness

- Blackberries gently hand harvested to compare to berries harvested with a custom-made force sensing apparatus and a soft robotic gripper prototype

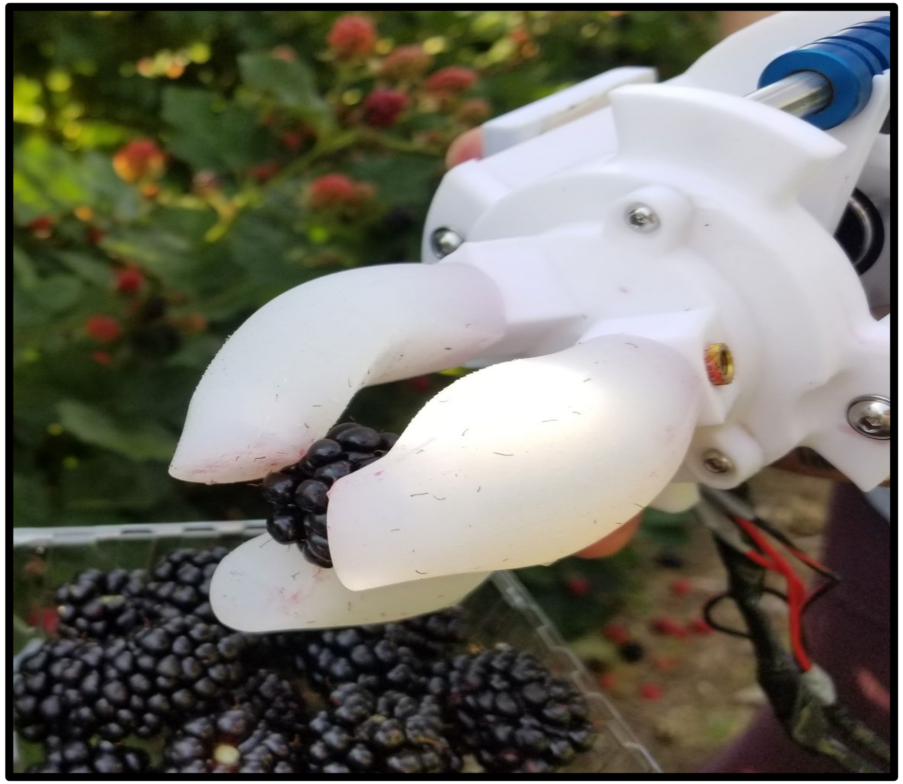
Force-sensing Apparatus (Sensor)

- Blackberries harvested using a custom-made force sensing apparatus to measure forces applied to harvest in 2020
  - Apparatus designed with resistive force sensors placed on silicone finger covers positioned on the thumb and three fingers (index, middle, and ring) of the right hand
  - Voltage data measured by pairing each force sensor with a single power source non-inverting op-amp circuit, then voltage measurements sent through Bluetooth and converted to Newtons (N)
  - Data recording and processing conducted in a portable water-resistant case housed in a backpack



Soft Robotic Gripper Protype (Gripper)

- Blackberries harvested using a 3-prong soft robotic gripper prototype in 2021
  - Gripper designed with a three prong “finger” system made of silicone
  - Internal structure of a “tendon” (36-guage guitar string) offset from the nitinol strip, resulting in inward bending during tendon retraction
  - Custom-designed mechanism mounted beneath the prongs, providing a method for retracting the tendons
  - Berries harvested at a fingertip contact force of 0.69 N
  - Prototype manually placed in position to initiate grasping, harvest, and release of the berry into the clamshell



Blackberry Analysis

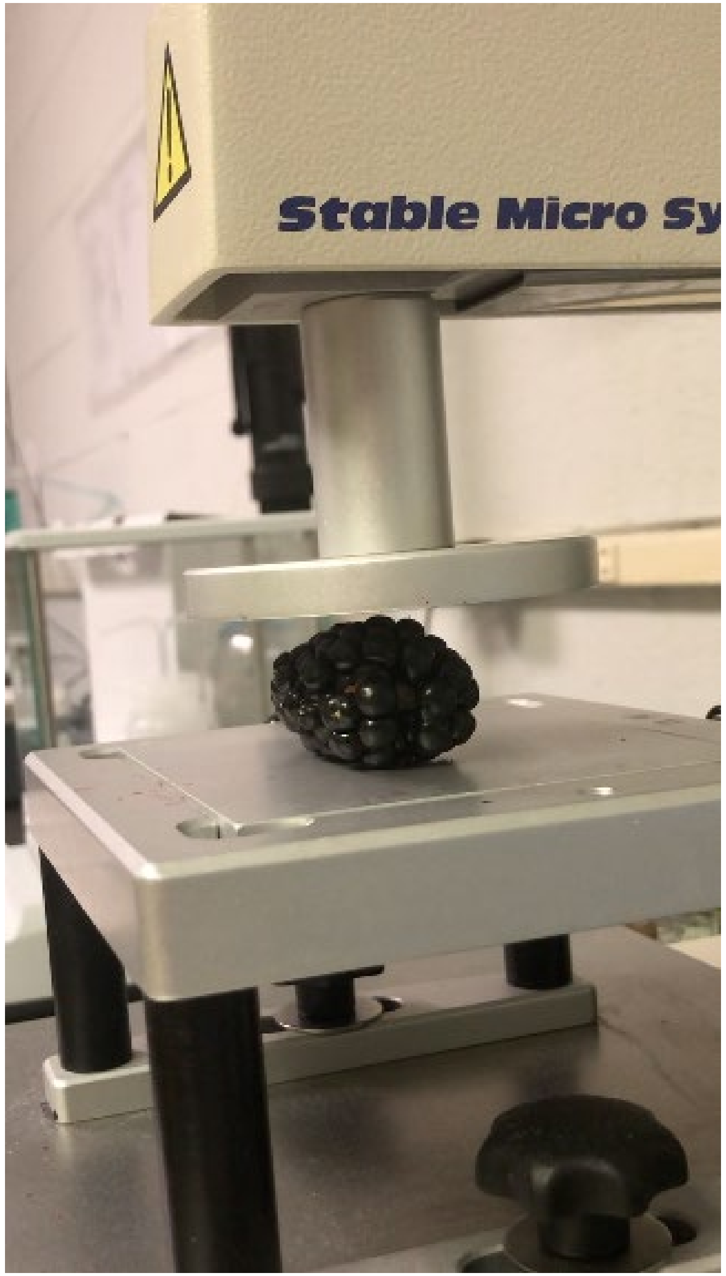
- Blackberries taken to UA System Food Science Department, Fayetteville, AR for analysis
- Physical, composition, and marketability attributes evaluated at harvest
  - Samples frozen (-10 °C) for composition analysis
- Marketability attributes evaluated after storage at 2 °C for 21 days

Physical Analysis

- Weight (g)
- Length (mm)
- Width (mm)
- Firmness (N)

Balance

Calipers

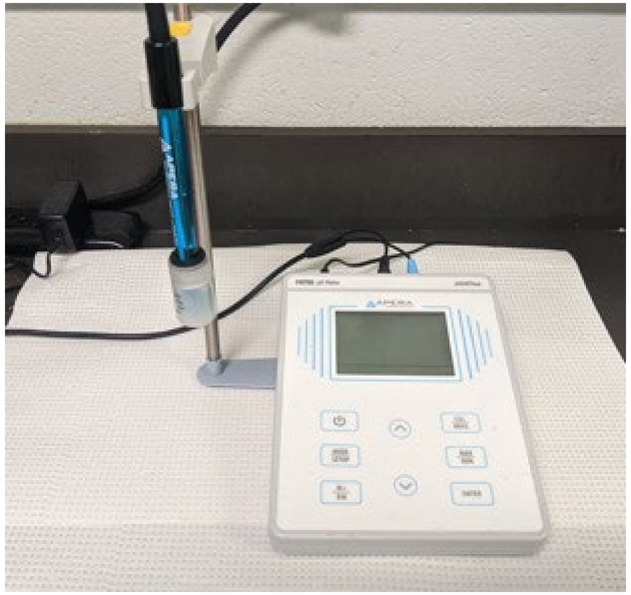


Texture analyzer

Composition Analysis

- Soluble solids (%)
- pH
- Titratable acidity (% citric acid)

Refractometer



pH meter

Automated titrator

Marketability Analysis

- Marketability attributes evaluated at harvest and after postharvest storage at 2 °C for 21 days on berries from each clamshell
  - Decay (visible mold or rot) calculated as (number decayed berries/number total berries)*100
  - Leakage (berries with juice visible) calculated as (number of leaky berries/number of total berries)*100
  - RDR calculated as (number of berries with red drupelets/number of total berries)*100

Statistical Analysis

- Data analyzed by analysis of variance (ANOVA) using JMP® (version 16.0; SAS Institute Inc., Cary, NC)

- Tukey's Honestly Significant Difference (HSD) or Student's T test used for mean separations (p = 0.05)
  - Means with different letter(s) for each attribute within main effects significantly different

Physical and Composition Attributes at Harvest (2020 and 2021)

Year and Cultivar[z]	Berry weight (g)	Berry length (mm)	Berry width (mm)	Firmness (N)	Soluble solids (%)	pH	Titratable acidity (% citric)
2020							
Natchez	7.51	29.14	22.65	7.81	12.05	3.09	1.36
Osage	3.88	24.80	19.57	6.83	12.08	3.33	1.16
Prime-Ark® Traveler	4.29	21.42	20.70	6.56	12.42	3.33	1.02
Sweet-Ark™ Caddo	8.31	30.14	22.53	9.22	12.10	3.25	1.13
2021							
Natchez	8.39	31.33	21.39	9.80	9.58	3.28	1.17
Osage	5.20	21.51	20.13	6.33	10.63	3.43	1.08
Prime-Ark® Traveler	4.43	19.16	18.87	6.71	11.03	3.24	0.99
Sweet-Ark™ Caddo	6.31	25.55	20.10	7.78	8.48	3.13	1.32

[z]Cultivars were evaluated in triplicate with 240 berries per cultivar and harvest method (total of 1,920 berries).

- **Physical and composition attributes at harvest varied by cultivar**
  - **4-8 g, 19-31 mm long, 19-23 mm wide, and 6-10 N firm**
  - **8-12% soluble solids, 3.1-3.4 pH, and 1.0-1.4% titratable acidity**

Force to Harvest

- Cultivar impacted force to harvest blackberries using a force-sensing apparatus
  - For the thumb and ring finger, Sweet-Ark™ Caddo had the highest force (1.18 N and 0.15 N, respectively) as compared to the other cultivars
  - ‘Natchez’ had the highest force on the index (0.27 N) and middle finger (0.49 N)
  - For the thumb, Prime-Ark® Traveler had the lowest (0.51 N) force
  - Regardless of cultivar, the thumb applied the highest force (0.77 N), followed by the middle finger (0.37 N), index finger (0.16 N), and ring finger (0.06 N)

Cultivar[z]	Thumb	Index	Middle	Ring
Natchez	0.75 b	0.27 a	0.49 a	0.05 b
Osage	0.65 bc	0.09 b	0.31 b	0.03 bc
Prime-Ark® Traveler	0.51 c	0.10 b	0.37 ab	0.01 c
Sweet-Ark™ Caddo	1.18 a	0.17 ab	0.31 b	0.15 a
P-value	<0.0001	<0.0001	0.0136	<0.0001
Average	0.77	0.16	0.37	0.06

[z]Cultivars were evaluated in triplicate with 240 berries per cultivar. Means with different letter(s) for each attribute are significantly different ($p<0.05$) using Tukey’s Honestly Significant Difference test.

Marketability attributes at 21 d at 2° C

	Sensor 2020			Gripper 2021		
Effects[z]	Leakage (%)	Decay (%)	Red drupelet (%)	Leakage (%)	Decay (%)	Red drupelet (%)
Harvest Method[y]						
Hand	1.25 a	0.42 a	3.33 a	23.58 b	16.67 a	1.40 b
Sensor/gripper	6.25 a	0.42 a	5.00 a	37.96 a	17.93 a	8.74 a
P-value	*0.0760*	*0.9999*	*0.3464*	*0.0071*	*0.7478*	*0.0012*
Cultivar						
Natchez	5.00 a	0.00 a	6.67 a	40.07 a	10.95 b	6.15 ab
Osage	2.50 a	1.67 a	0.83 a	8.49 b	12.44 b	0.00 c
Prime-Ark® Traveler	6.67 a	0.00 a	3.33 a	38.19 a	31.82 a	11.63 a
Sweet-Ark™ Caddo	0.83 a	0.00 a	5.83 a	36.33 a	13.99 b	2.50 bc
P-value	*0.4326*	*0.1546*	*0.1106*	*0.0005*	*0.0047*	*0.0027*
Harvest method X Cultivar P-value	*0.6243*	*0.9999*	*0.3787*	*0.3020*	*0.0231*	*0.0119*

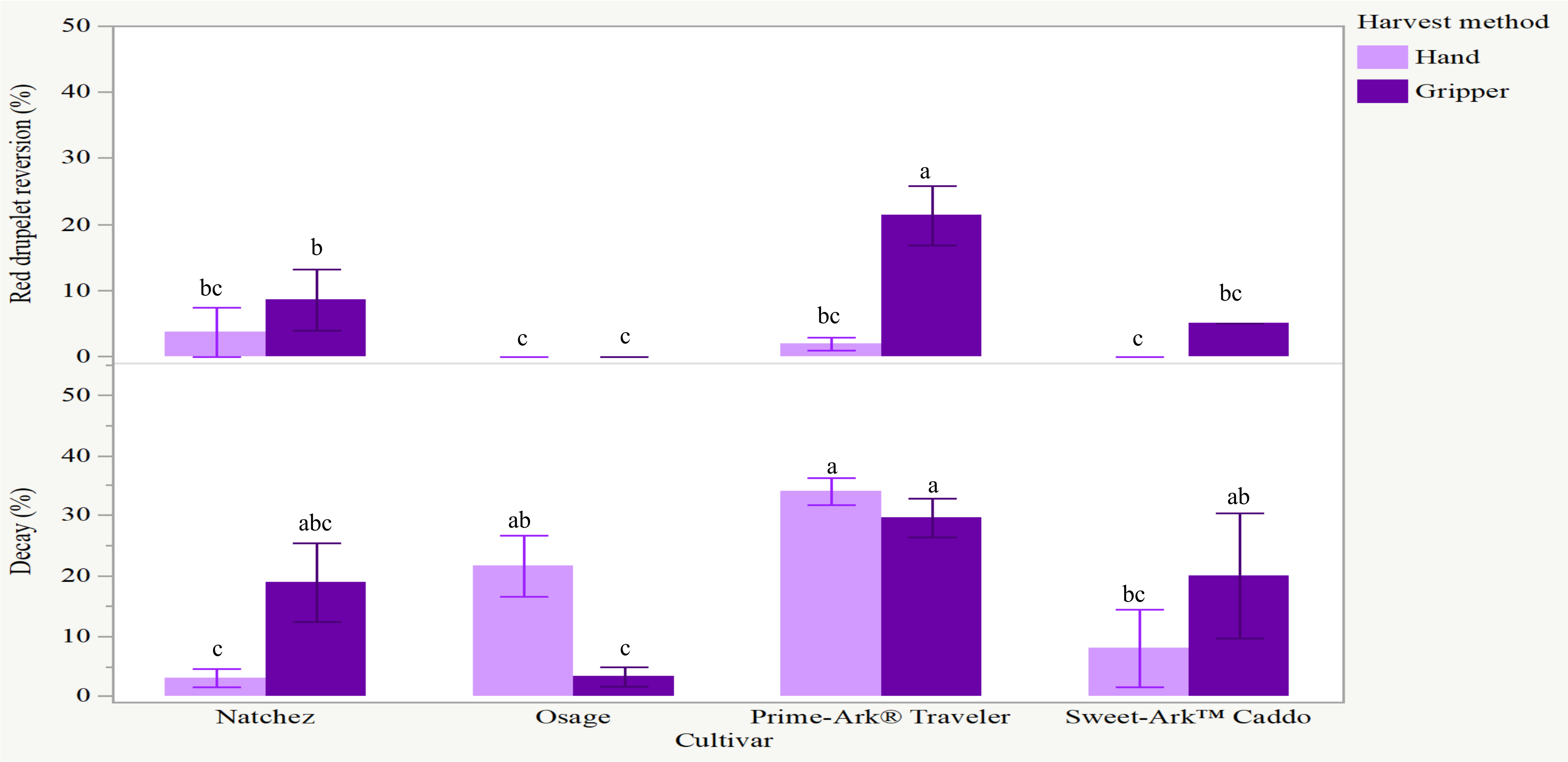
Marketability attributes at 21 d at 2° C (2020)

- Harvest method x cultivar interaction and the main effects were not significant for any marketability attributes
  - Harvest method and cultivar did not impact leakage (3.75%), decay (0.42%), or red drupelet reversion (4.17%).

Marketability attributes at 21 d at 2° C (2021)

- Harvest method x cultivar interaction was significant for decay and red drupelet reversion
  - Leakage impacted by harvest method and cultivar
  - Fruit harvested by gripper (37.96%) had higher leakage than hand (23.58%) harvested fruit
  - Osage (8.49%) had less leakage than other cultivars
  - RDR in Prime-Ark® Traveler was lower in fruit harvested by hand (1.91%) as compared to the gripper (21.35%)
  - Decay in Osage higher in fruit harvested by had (21.62%) as compared to the gripper (3.25%)

Marketability attributes at 21 d at 2° C (2021)



Conclusions

- Determined harvest and postharvest parameters to develop a prototype of a soft robotic gripper for the harvest of fresh-market blackberries

- First step to develop a soft robotic gripper for an autonomous harvester for fresh-market blackberries

Acknowledgments

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Publications

- Myers, A., A. Gunderman, R. Threlfall*, and Y. Chen. 2022. **Determining hand-harvest parameters and postharvest marketability impacts of fresh-market blackberries to develop a soft-robotic gripper for robotic harvesting.** HortScience 57(5):592-594, https://doi.org/10.21273/HORTSCI16487-22
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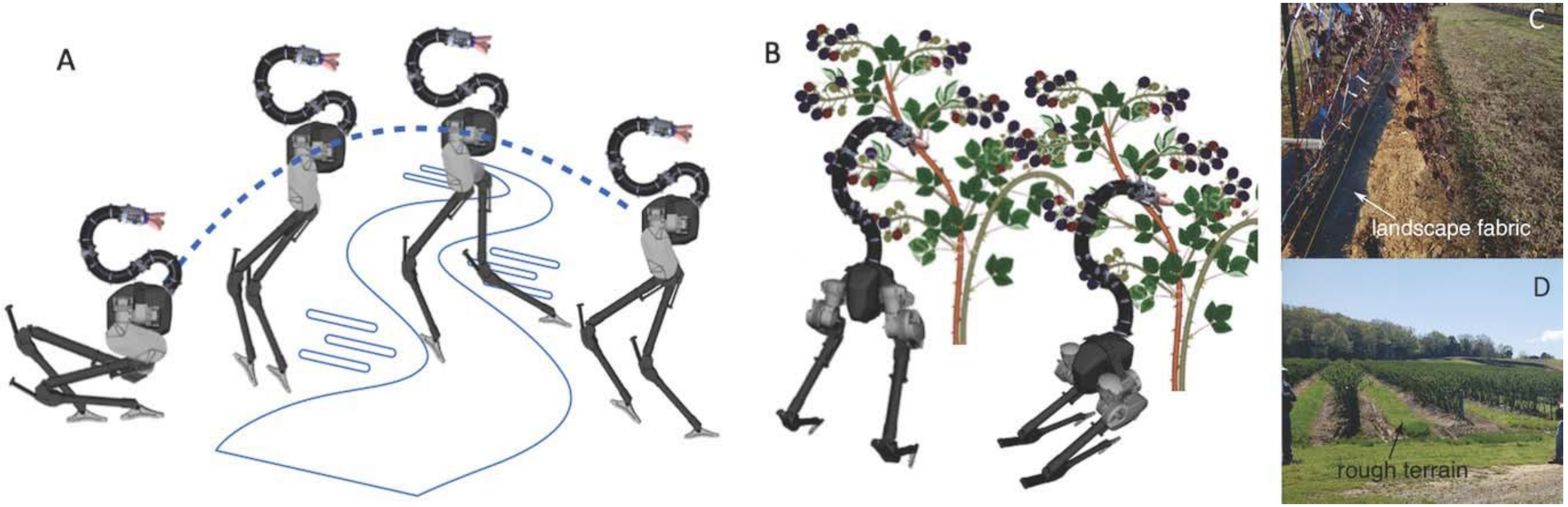
- Zhang, Xin, T. Thayananthan, A.L. McWhirt, R.T. Threlfall; W. Liu, Y. Huang, Y. Zhao, A.L. Gunderman. Y. Chen. 2024. **In-field multi-ripeness blackberry detection for soft robotic harvesting**". Smart Agricultural Technology (In review)

Next Steps

- Engineers from this project currently at Georgia Tech/Emory
- Pursuing other funding to continue the project
  - Harvesting module
  - Robot perception
  - Locomotion planning



Thanks and Questions?

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