

# Adaptability of *Phytophthora capsici* Resistant Bell Pepper Cultivars in Southern Georgia

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**KEYWORDS.** *Capsicum annuum*, fruit size, marketable yield, physiological disorder, root rot

**ABSTRACT.** *Phytophthora capsici* (PCap), which causes *Phytophthora* root rot, is the most destructive soilborne pathogen for bell pepper (*Capsicum annuum* L.) production in Georgia, USA. Extensive host range, persistence of inoculum in the soil, and lack of effective chemical control methods make this disease particularly difficult to manage. Resistant cultivars offer a practical solution to manage PCap in affected bell pepper fields. However, most commercial cultivars resistant to PCap are predominantly grown in the northeastern United States. This research aimed to screen commercial bell pepper cultivars for resistance to PCap, marketable yield, fruit size distribution, and overall adaptability for production within the largest growing areas in southern Georgia. Field trials were conducted during Spring 2022 and 2023 in commercial growers' fields with a known history of PCap infestation to evaluate PCap-resistant bell pepper cultivars across four trials conducted in the three counties (Colquitt, Echols, and Lowndes) responsible for ~78% of bell pepper production in Georgia. Eleven cultivars were evaluated: nine that claimed PCap resistance and two widely grown PCap susceptible cultivars included for comparison. *Phytophthora* root rot incidence was very low in these research trials. However, there were significant differences in total yields, marketable yields, fruit size, and unmarketable yields. On the basis of marketable yields for jumbo, extra large, and large-sized fruit, we recommend the PCap-resistant cultivars PS 0994-1819, Paladin, and Mercer for fresh market bell pepper growers. Furthermore, 'Revolution' is recommended for processor growers due to higher jumbo-sized fruit yields and lower quality and higher pancaking for the spring season in southern Georgia, USA. Newer cultivars Tarpon and Nitro have a more desirable disease-resistance package; however, 'Nitro' had small-sized fruit, and 'Tarpon' tended to have lower total yields than current commercial standards.

In 2022, the total fresh market bell pepper (*Capsicum annuum* L.) production in the United States was 10.4 million cwt, with Georgia, USA ranking third for output, accounting for ~10.5% of the total production with 1.09 million cwt [US Department of Agriculture (USDA), National Agricultural Statistics Service (NASS) 2022, 2023a, 2023b]. In 2022, bell peppers ranked third in farm gate revenue for vegetable crops in Georgia. The major production region for bell pepper is in the southern part of the state and the top producing counties are Lake Park, Colquitt, and Lowndes, accounting for 49%, 19%, and 10% of the acres planted in Georgia, respectively [Center for Agribusiness and Economic Development, University of Georgia (UGA) 2024].

*Phytophthora* blight, caused by *Phytophthora capsici* (PCap), is one of the most devastating soilborne diseases in peppers. The meaning of the Greek

name *Phytophthora capsici* is "plant destroyer of capsicum" (Bosland 2008). Significant yield losses due to PCap are widespread and well documented (Dunn et al. 2014; Granke et al. 2012; Krasnow et al. 2017; Sánchez-Chávez et al. 2017; Sujkowski et al. 2000). Excessive rainfall, poor soil drainage, and high air temperatures are the major weather factors that favor the development of this disease (Tompkins and Tucker 1941). The wide host range (Lamour et al. 2012), extremely high soil inoculum persistence (French-Monar et al. 2007), and lack of effective chemical control methods make this pathogen particularly difficult to manage. Commercial vegetable production regions in southern Georgia, United States have a humid subtropical environment and sloping topography with low areas that collect water after rain events. In addition, rotations between PCap host crops in the Solanaceae:

*Capsicum* species, tomato (*Lycopersicon esculentum*), and brinjal (*Solanum melongena*) and Cucurbitaceae: watermelon (*Citrullus lanatus*), *Cucumis* species, and *Cucurbita* species) families frequently occur further exacerbating the development of this disease (Hausbeck and Lamour 2004). PCap is a major problem in watermelon, yellow squash (*Cucurbita pepo*), and bell pepper in Georgia, which accounts for 26.6% total vegetable production value (UGA 2024). Resistant cultivars offer a practical solution to manage PCap in affected bell pepper fields, which is an effective practice to reduce the use of fungicides along with improving yields (Hwang and Kim 1995). The major limiting factor is the availability of suitable bell pepper cultivars with high levels of resistance to PCap suitable for production in southern Georgia (Foster and Hausbeck 2010).

Historically, PCap-resistant fresh market bell peppers have been developed for and produced in the northeastern United States (Wyatt et al. 2013), primarily in New Jersey, USA (Krasnow et al. 2017). Various physiological disorders (or abnormalities with no causal organisms) occur in pepper cultivars that are not well adapted to a specific environment, which ultimately reduces marketable yields (Jauron 1997). The primary reasons for physiological disorders are environmental and nutrient deficiencies (Kathayat and Rawat 2019). Silvering or skin separation reduces the aesthetic quality of bell pepper fruit and makes it less preferable to consumers, but it is still suitable for processing (Wyenandt et al. 2017). Blossom end rot has been linked to a range of environmental conditions that result in calcium deficiencies in developing fruit (Taylor and Locascio 2004). This rot often occurs in the distal part of the bell pepper fruit or blossom end, hence the name (Savvas et al. 2008). Sunburn is a major physiological disorder severely affecting fruit quality, reducing market acceptance and is often found in plants that produce inadequate foliage to protect the fruit from the sun (Racsko and Schrader 2012).

The objective of this study was to screen commercial disease-resistant bell pepper cultivars for adaptability within the main production areas of southern Georgia, and select cultivars with the highest yields, optimal fruit size distribution, and most desirable fruit characteristics.

**Table 1. Sowing, transplant, and harvest dates of 11 bell pepper (*Capsicum annuum*) cultivars across four trials in southern Georgia, USA, during Spring 2022 and 2023.**

Year	Location	Lat./Long.	Sowing date	Transplant date	First harvest date	Second harvest date
2022	Moultrie	31.1392169° N 83.8630920° W	10 Feb 2022	8 Apr 2022	16 Jun 2022	23 Jun 2022
	Valdosta	30.7216862° N 83.1494888° W	10 Feb 2022	4 Apr 2022	10 Jun 2022	17 Jun 2022
2023	Doerun	31.3114336° N 83.9430970° W	10 Feb 2023	21 Mar 2023	22 May 2023	2 Jun 2023
	Lake Park	30.7522370° N 83.4124997° W	10 Feb 2023	29 Mar 2023	31 May 2023	8 Jun 2023

## Materials and methods

### EXPERIMENTAL SITE AND DESIGN.

Research trials were carried out in commercial bell pepper fields at Moultrie, GA, USA and Valdosta, GA, USA in Spring 2022 and at Doerun, GA, USA and Lake Park, GA, USA in Spring 2023. Sowing, transplant, and harvest dates for all trials are shown in Table 1. Plants were managed according to grower standards for the region. Management regimes varied between different farms with 1 to 3 drip irrigation cycles/day of 30 min to 1 h per cycle/irrigation event carried out throughout the season as plants grew bigger and temperature increased. Fertilizer rates

varied between 250 to 400 lbs. N/acre. The bed tops were covered with black plastic mulch, and the field was watered through drip irrigation. All the research trials were carried out in a randomized complete block design with four replications. Planting densities were 14,520 plants/acre configured with raised beds spaced 6 ft apart on center. There was double row of pepper plant on top of the bed and within the rows, plant to plant spacing

was kept at 1 ft. Each plot comprised 20 plants, but only the center 10 plants were harvested for yield assessments.

**EXPERIMENTAL MATERIAL.** Resistance against PCap, bacterial leaf spot (BLS) races 0 to 10, and tomato spotted wilt virus (TSWV) are preferred for cultivation in Georgia, USA because these are all challenging pathogens in southern Georgia. The experiment compared 11 bell pepper cultivars. The PCap-resistant cultivars were compared

**Table 2. Parental seed source and disease resistance in 11 bell pepper (*Capsicum annuum*) cultivars screened across four trials in southern Georgia, USA, during Spring 2022 and 2023.**

Cultivar	Source <sup>i</sup>	Disease resistance
Galileo	Seedway <sup>ii</sup>	R: Xcv 1–3 IR: Pc
Mercer	Sakata <sup>iii</sup>	HR: Tm: 0, Xcv 0–3, 7, 8 IR: Pc
Nitro	Sakata	HR: TMV: 0, Xcv 0–10 IR: Pc, TSWV
Paladin	Syngenta <sup>iv</sup>	HR: TMV, PVY IR: Pc
Playmaker	Seminis <sup>v</sup>	HR: Tm: 0 IR: Pc, Xcv 0–10
PS 0994-1819	Seminis	HR: Tm: 0, Xcv 0–5, 7–9 IR: Pc
Revolution	Harris Moran <sup>vi</sup>	R: Xcv 1, 2, 3, 5 IR: CMV, Pc
Tarpon	Seminis	HR: Tm: 0 IR: Xcv 0–10, Pc
Turnpike	Seminis	HR: Tm: 0, Xcv 0–5, 7–9 IR: Pc
Antebellum	Seminis	HR: Tm: 0 IR: TSWV, Xcv 0–10
Aristotle	Seminis	HR: PVY: 0, Tm: 0, Xcv 0–3, 7–8

<sup>i</sup> Source is representing the original parental breeding company that developed the particular cultivar, though all the cultivars were purchased from Seedway, LLC.

<sup>ii</sup> Seedway, LLC. 1734 Railroad Place, Hall, NY 14463, USA.

<sup>iii</sup> Sakata Seed America, 18095 Serene Drive, Morgan Hill, CA 95037, USA.

<sup>iv</sup> Syngenta Seeds, 2001 Butterfield Rd, Suite 1600, Downers Grove, IL 60515, USA.

<sup>v</sup> Seminis, Inc., St. Louis, MO, USA.

<sup>vi</sup> Harris Morran, 355 Paul Rd, 24966, Rochester, NY 14624, USA.

R = resistance; HR = high resistance; IR = intermediate resistance, CMV = cucumber mosaic virus; PVY = potato virus Y; TMV = tobacco mosaic virus; TSWV = tomato spotted wilt virus; Tm = tobamovirus; Xcv = bacterial leaf spot race resistance; Pc = *Phytophthora capsici*.

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with the PCap-susceptible and widely grown check cultivars in southern Georgia: Aristotle, which has no TSWV resistance and partial BLS resistance, and Antebellum, which has TSWV and complete resistance to BLS races 0 to 10. Seeds of all the cultivars were purchased from Seedway, Hall, NY, USA (Table 2).

**HARVESTS.** Two harvests were conducted ~1 week apart, which is typical for this region (Table 1). Ten plants from the center of each plot were harvested and fruit were graded and sized according to USDA (2005) and industry standards. Marketable fruit were sized into four categories: medium, large, extra large, and jumbo. The estimated numbers of fruit per bushel boxes were 30 for jumbo, 40 for extra large, 50 for large, and 60 for medium. A mechanical grader was used to separate fruit by width: 3 inches for medium, 3.5 inches for large, 4 inches for extra large and >4 inches for jumbo. Percentage of marketable fruit was calculated by dividing the total number of marketable fruit per plant by the total (marketable + unmarketable) number of fruit per plant and then multiplying by 100.

**PHYSIOLOGICAL DISORDERS.** A total of six fruit physiological disorders, including silvering (Fig. 1A), misshapen (Fig. 1B), pancaking (Fig. 1C), pointy fruit (Fig. 1D), blossom end rot (BER) (Fig. 2A), and sunburn (Fig. 2B), were encountered in the trials and recorded. Fruit physiological disorders are caused by environmental factors, and they are more prevalent in cultivars that are not well adapted to production at a particular location. Fruit were further sub-categorized into choice/choppers (for consumption) and cull (discarded).

**STATISTICAL ANALYSIS.** Data were analyzed using statistical software (JMP Pro 16; JMP Statistical Discovery LLC, Cary, NC, USA) with analysis of variance to determine significant differences between cultivars. Replication and trial were treated as random variables. Mean separation was performed using Tukey's significant difference test ( $P < 0.05$ ).

## Results

**NUMBER OF MARKETABLE FRUIT PER PLANT.** There was a significant difference between cultivars for all categories of marketable fruit sizes (Table 3). 'Revolution' had the highest number of

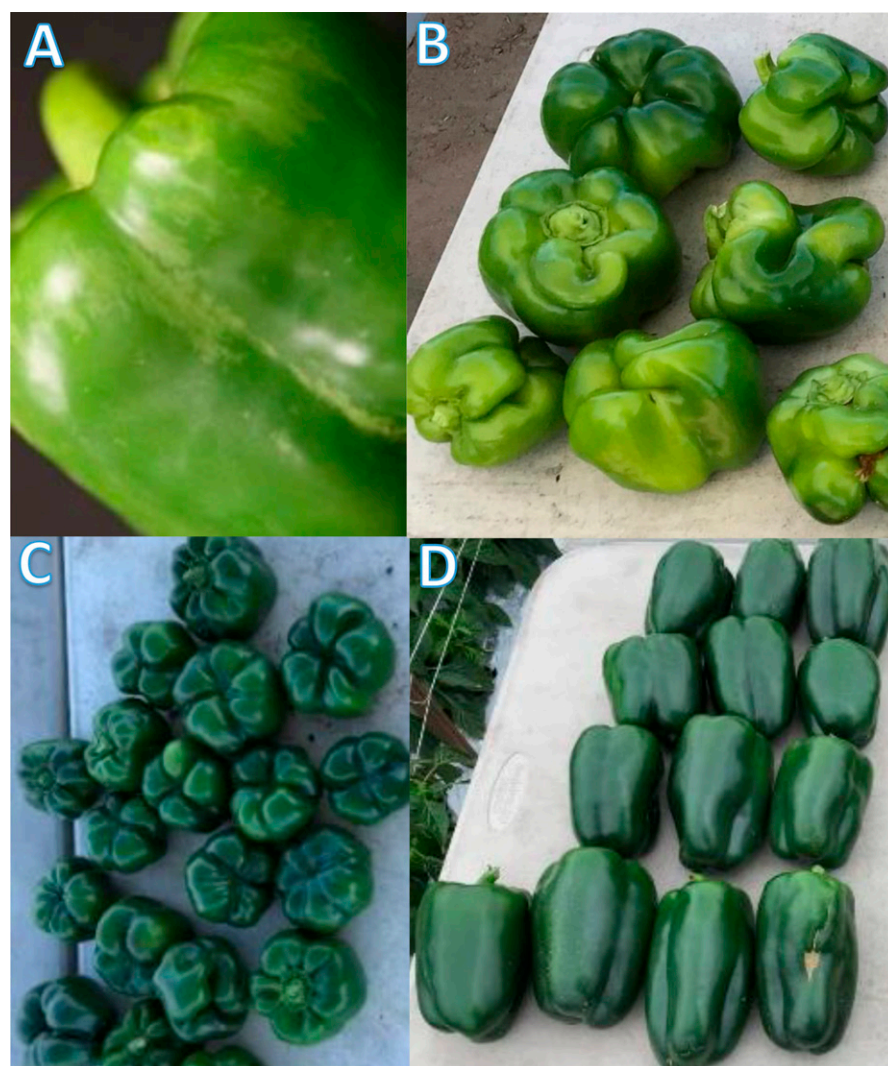


Fig. 1. Images showing choice<sup>i</sup> physiological disorders in bell pepper (*Capsicum annuum*) cultivars: (A) silvering,<sup>ii</sup> (B) misshapen,<sup>iii</sup> (C) pancaking,<sup>iv</sup> and (D) pointy<sup>v</sup>.

<sup>i</sup> Choice fruit is generally not preferred by consumers, which makes it unmarketable for fresh market, but it can be used for processing purposes. <sup>ii</sup> Silvering or skin separation are stripes on the fruit. It is the visual symptom of epidermal or skin separation and generically defined as a "silvery white discoloration." <sup>iii</sup> Misshapen are poorly formed fruit that result from crowding, when the crown fruit develops in the crotch of the first branching node and develops indentations where it grows into the stems. <sup>iv</sup> Pancaking is an atypically flat fruit shape, thought to be caused by improper pollination and is more prevalent when temperatures are extremely hot. <sup>v</sup> Pointy fruit taper from the shoulder, usually with three lobes.

jumbo-size fruit (1.03 fruit per plant), which was similar to 'PS 0994-1819' (0.71 fruit per plant) and significantly higher than all the other cultivars, including the PCap susceptible Antebellum (0.62 fruit per plant) and Aristotle (0.52 fruit per plant). 'PS 0994-1819' had the most extra large fruit (1.06 fruit per plant), whereas all the other cultivars except Revolution (0.64 fruit per plant) performed moderately (ranged from 0.72 to 1.01 fruit per plant). 'Mercer' yielded the highest number of large-size fruit (1.90 fruit per plant),

which is similar to 'Paladin' (1.50 fruit per plant) and 'Antebellum' (1.41 fruit per plant); all three had significantly more fruit than all the other cultivars (1.01 to 1.33 fruit per plant). Medium-sized fruit per plant were the greatest in 'Nitro' (an average of 1.91 fruit per plant), which was similar to 'Mercer' (1.56 fruit per plant) and 'Antebellum' (1.41 fruit per plant) while being significantly higher than cultivars Revolution (0.74 fruit per plant) and Turnpike (1.27 fruit per plant). Although medium fruit are marketable, they are considered





Fig. 2. Images showing cull<sup>i</sup> physiological disorders in bell pepper (*Capsicum annuum*) cultivars: (A) sunburn<sup>ii</sup> and (B) blossom end rot<sup>iii</sup> (McAvoy et al. 2024). <sup>i</sup> Cull fruit is completely unmarketable and discarded. <sup>ii</sup> Sunburn is the burning of pepper skin from direct sunlight. <sup>iii</sup> A disorder resulting in necrosis at the blossom end of pepper fruit. It is a symptom of a localized calcium deficiency that occurs early in the fruit development.

small, undesirable, and bring less money per bushel boxes compared with the most desirable sizes, large and extra large. Jumbo and medium-sized fruit typically bring the same money per bushel boxes to the grower; however, jumbo is more desirable because it takes less fruit to fill a bushel boxes.

**PHYSIOLOGICAL DISORDERS.** Physiological disorders were subcategorized into two types, which are choice

(silvering, misshapen, pancaking, and pointy) and cull (BER and sunburn). Choice fruit may not be preferred by consumers but can be used for processing purposes, while the cull fruit is completely unmarketable and discarded.

**CHOICE.** ‘Revolution’, and ‘Tarpon’ did not display any silvering, whereas the other cultivars had some level of silvering. Pancaking was the largest contributor to total choice fruit. ‘Antebellum’ (0.13 fruit

per plant) had the lowest number of pancaking fruit per plant, which was similar to ‘Tarpon’ (0.30 fruit per plant), ‘Turnpike’ (0.31 fruit per plant), and ‘Aristotle’ (0.31 fruit per plant). The formation of elongated and pointy fruit per plant was lowest in ‘Revolution’ (0.10 fruit per plant) and ‘Nitro’ (0.11 fruit per plant). On the other hand, ‘Paladin’ (0.42 fruit per plant) and ‘Turnpike’ (0.43 fruit per plant) had significantly more fruit with pointy ends per plant (Table 4).

**CULL.** The total number of cull fruit did not differ significantly between cultivars. BER was not significant in all the research trials; ‘Paladin’ (0.02 fruit per plant), ‘PS 0994-1819’ (0.03 fruit per plant), ‘Turnpike’ (0.03 fruit per plant), ‘Aristotle’ (0.05 fruit per plant), and ‘Mercer’ (0.05 fruit per plant) had very low incidence of BER. Sunburn fruit per plant was least in ‘Tarpon’ (0.05 fruit per plant), and ‘Playmaker’ (0.05 fruit per plant). These cultivars had less sunburn per plant, whereas all other cultivars were found to have a moderate level of sunburn incidence, ranging from 0.06 fruit per plant (‘Mercer’) to 0.18 fruit per plant (‘PS 0994-1819’) except ‘Revolution’ (0.28 fruit per plant) (Table 4).

**PERCENTAGE OF MARKETABLE FRUIT.** Marketable fruit are a sum of the number of different sized (jumbo, extra large, large, and medium) fruit per plant, whereas unmarketable fruit indicate the total number of choice and cull fruit per plant. There were statistically significant differences among cultivars for marketable, unmarketable, total, and percentage of marketable fruit per plant (Table 5). ‘Mercer’ had the greatest number of marketable fruit per plant (4.49 fruit per plant), while all the other cultivars performed moderately varying from 3.65 fruit per plant (Turnpike) to 4.20 fruit per plant (Antebellum). These cultivars significantly outperformed Revolution, and Playmaker (an average of 3.43 fruit per plant). ‘Tarpon’ (1.29 fruit per plant) showed the lowest number of unmarketable fruit per plant.

The highest total yield for the number of fruit per plant (marketable + unmarketable) was achieved by ‘PS 0994-1819’, ‘Paladin’, and ‘Mercer’ (an average of 6.62, 6.28, and 6.19 fruit per plant), followed by ‘Antebellum’, ‘Nitro’, and ‘Revolution’ (an average of 5.65, 5.65, and 5.64 fruit per plant).

Table 3. Marketable fruit size distribution per plant of 11 bell pepper (*Capsicum annuum*) cultivars conducted across four trials in southern Georgia, USA, during Spring 2022 and 2023.

Treatment	Marketable fruit <sup>i</sup> (no./plant)			
	Jumbo <sup>ii</sup>	Extra Large <sup>iii</sup>	Large <sup>iv</sup>	Medium <sup>v</sup>
Cultivar				
Antebellum	0.62 bc <sup>vi</sup>	0.78 ab	1.41 ab	1.41 abc
Aristotle	0.52 bcd	1.01 ab	1.28 b	0.97 bcd
Galileo	0.61 bc	0.87 ab	1.32 b	0.95 bcd
Mercer	0.13 e	0.89 ab	1.90 a	1.56 ab
Nitro	0.20 de	0.72 ab	1.27 b	1.91 a
Paladin	0.53 bcd	0.89 ab	1.50 ab	1.24 abcd
Playmaker	0.57 bcd	0.88 ab	1.11 b	0.86 cd
PS 0994-1819	0.71 ab	1.06 a	1.32 b	0.78 cd
Revolution	1.03 a	0.64 b	1.01 b	0.74 d
Tarpon	0.42 bcde	0.81 ab	1.31 b	1.19 bcd
Turnpike	0.29 cde	0.76 ab	1.33 b	1.27 abcd
P value	<0.001	0.038	<0.001	<0.001

<sup>i</sup> Marketable fruit consists all the four bell pepper fruit sizes jumbo, extra large, large, and medium for fresh market consumption.

<sup>ii</sup> Jumbo: bell pepper fruit of width >4 inches.

<sup>iii</sup> Extra large: bell pepper fruit of width 4 inches.

<sup>iv</sup> Large: bell pepper fruit of width 3.5 inches.

<sup>v</sup> Medium: bell pepper fruit of width 3 inches.

<sup>vi</sup> Means followed by the same letter are not significantly different based on Tukey’s honest significant difference test at 95%.

**Table 4.** Statistical analysis of physiological disorders categorized as choice or culls for 11 bell pepper (*Capsicum annuum*) cultivars conducted across four trials in southern Georgia, USA, during Spring 2022 and 2023.

Treatment	Choice <sup>i</sup> (no./plant)				Total	Cull <sup>ii</sup> (no./plant)		Total
	Silvering <sup>iii</sup>	Misshapen <sup>iv</sup>	Pancaking <sup>v</sup>	Pointy <sup>vi</sup>		BER <sup>vii</sup>	Sunburn <sup>viii</sup>	
Cultivar								
Antebellum	0.02 ab <sup>ix</sup>	0.65 a	0.13 d	0.36 ab	1.17 a	0.05 a	0.18 ab	0.23 a
Aristotle	0.106 ab	0.62 a	0.31 cd	0.20 ab	1.24 a	0.03 a	0.09 ab	0.12 a
Galileo	0.01 ab	0.73 a	0.41 bcd	0.27 ab	1.44 a	0.06 a	0.16 ab	0.22 a
Mercer	0.03 ab	0.70 a	0.60 bcd	0.25 ab	1.58 a	0.05 a	0.06 ab	0.11 a
Nitro	0.06 ab	0.53 a	0.59 bcd	0.11 b	1.27 a	0.12 a	0.14 ab	0.23 a
Paladin	0.09 ab	0.80 a	0.62 bc	0.42 a	1.91 a	0.02 a	0.14 ab	0.17 a
Playmaker	0.112 a	0.59 a	0.44 bcd	0.19 ab	1.34 a	0.07 a	0.05 b	0.12 a
PS 0994-1819	0.01 ab	1.49 a	0.79 b	0.21 ab	2.51 a	0.03 a	0.18 ab	0.22 a
Revolution	0.00 b	0.46 a	1.28 a	0.10 b	1.85 a	0.06 a	0.28 a	0.35 a
Tarpon	0.00 b	0.57 a	0.30 cd	0.27 ab	1.15 a	0.07 a	0.05 b	0.13 a
Turnpike	0.06 ab	0.71 a	0.31 cd	0.43 a	1.53 a	0.03 a	0.11 ab	0.15 a
P value	0.002	0.605	<0.001	0.001	0.159	0.552	0.042	0.071

<sup>i</sup> Choice fruit is generally not preferred by consumers, which makes it unmarketable for fresh market but can be used for processing purposes.

<sup>ii</sup> Cull fruit is completely unmarketable and discarded.

<sup>iii</sup> Silvering or skin separation are stripes on the fruit. It is the visual symptom of epidermal or skin separation and generically defined as a “silvery white discoloration.”

<sup>iv</sup> Misshapen are poorly formed fruit that results from crowding, when the crown fruit develops in the crotch of the first branching node and develops indentations where it grows into the stems.

<sup>v</sup> Pancaking is an atypically flat fruit shape thought to be caused by improper pollination and is more prevalent when temperatures are extremely hot.

<sup>vi</sup> Pointy fruit taper from the shoulder and usually have three lobes.

<sup>vii</sup> Blossom end rot (BER) is a disorder resulting in necrosis at the blossom end of pepper fruit. It is a symptom of a localized calcium deficiency that occurs early in fruit development.

<sup>viii</sup> Sunburn is the burning of pepper skin from direct sunlight.

<sup>ix</sup> Means followed by the same letter are not significantly different based on Tukey's honest significant difference test at 95%.

The highest percentage of marketable fruit was performed by ‘Antebellum’ (75.68%) and ‘Tarpon’ (75.12%). All the other cultivars varied between 67.46% (Paladin) to 73.76% (Nitro). All these cultivars had a higher percentage

of marketable fruit than Revolution (63.25%).

**NUMBER OF BUSHEL BOXES PER ACRE.** The number of bushel boxes per acre for the fruit sizes jumbo, large, and medium were significantly

different between cultivars (Table 6). Total yield for jumbo fruit bushel boxes per acre varied from 60 to 495 bushel boxes per acre. ‘Revolution’ had the greatest number of jumbo-sized fruit bushel boxes per acre (49 boxes per acre), which was similar to ‘PS 0994-1819’ (342 bushel boxes per acre), ‘Antebellum’ (295 bushel boxes per acre), and ‘Galileo’ (293 bushel boxes per acre). ‘PS 0994-1819’ (371 bushel boxes per acre) had the highest number of extra large bell pepper fruit, which was similar to the other cultivars (218 to 352 bushel boxes per acre). Bushel boxes of large-size bell peppers were highest in ‘Mercer’ (553 bushel boxes per acre), which was significantly higher than other cultivars (291 to 386 bushel boxes per acre) except Paladin and Antebellum (434 and 409 bushel boxes per acre, respectively). Maximum medium-size fruit yields/acre were found in ‘Nitro’ (480 bushel boxes per acre), which was similar to ‘Mercer’ (397 bushel boxes per acre). ‘Antebellum’ (361 bushel boxes per acre), ‘Turnpike’ (325 bushel boxes per acre), and ‘Paladin’ performed moderately higher than ‘Tarpon’, ‘Aristotle’, and ‘Galileo’ (308, 254, and 249 bushel boxes per acre, respectively). ‘Revolution’ (198 bushel boxes per acre) followed by ‘PS 0994-1819’ (207 bushel

**Table 5.** Marketable, unmarketable, and percentage marketable fruit per plant of 11 bell pepper (*Capsicum annuum*) cultivars conducted across four trials in southern Georgia, USA, during Spring 2022 and 2023.

Treatment	Fruit (no./plant)			
	Marketable <sup>i</sup>	Unmarketable <sup>ii</sup>	Total	% Marketable <sup>iii</sup>
Cultivar				
Antebellum	4.2 ab <sup>iv</sup>	1.41 a	5.65 ab	75.68 a
Aristotle	3.78 ab	1.37 a	5.15 ab	73.40 ab
Galileo	3.75 ab	1.67 a	5.41 ab	69.57 ab
Mercer	4.49 a	1.70 a	6.19 ab	73.35 ab
Nitro	4.11 ab	1.51 a	5.65 ab	73.76 ab
Paladin	4.16 ab	2.09 a	6.28 ab	67.46 ab
Playmaker	3.43 b	1.47 a	4.91 b	70.59 ab
PS 0994-1819	3.88 ab	2.75 a	6.62 a	70.34 ab
Revolution	3.43 b	2.21 a	5.64 ab	63.25 b
Tarpon	3.75 ab	1.29 a	5.04 b	75.12 a
Turnpike	3.65 ab	1.68 a	5.34 ab	68.85 ab
P value	0.002	0.095	0.006	0.017

<sup>i</sup> Marketable fruit consist all the four bell pepper fruit sizes—jumbo, extra large, large, and medium—for fresh market consumption.

<sup>ii</sup> Unmarketable fruit consist choices and culls that are undesirable for fresh market consumption, although choice can be used for processing purpose.

<sup>iii</sup> Percentage marketable is calculated by dividing the total number of marketable fruit per plant by the total (marketable + unmarketable) number of fruit per plant and then multiplying by 100.

<sup>iv</sup> Means followed by the same letter are not significantly different based on Tukey's honest significant difference test at 95%.

**Table 6. Yield and fruit size distribution for number of bushel boxes per acre of 11 bell pepper (*Capsicum annuum*) cultivars conducted across four trials in southern Georgia, USA, during Spring 2022 and 2023.**

Treatment	Bushel boxes <sup>i</sup> (no./acre <sup>ii</sup> )				Total
	Jumbo <sup>iii</sup>	Extra Large <sup>iv</sup>	Large <sup>v</sup>	Medium <sup>vi</sup>	
Cultivar					
Antebellum	295 abc <sup>vii</sup>	268 a	409 ab	361 abc	1338 a
Aristotle	251 bcd	352 a	371 b	254 bc	1229 a
Galileo	293 abc	301 a	383 b	249 bc	1227 a
Mercer	60 d	308 a	553 a	397 ab	1321 a
Nitro	95 cd	246 a	368 b	480 a	1190 a
Paladin	253 bcd	309 a	434 ab	317 abc	1314 a
Playmaker	271 bc	307 a	322 bc	226 c	1131 a
PS 0994-1819	342 ab	371 a	385 bc	207 c	1307 a
Revolution	495 a	218 a	291 c	198 c	1206 a
Tarpon	203 bcd	280 a	378 bc	308 bc	1173 a
Turnpike	138 bcd	259 a	386 bc	325 abc	1112 a
P value	<0.001	0.125	0.001	<0.001	0.522

<sup>i</sup> Bushel box's net weight is 28 lb and estimated numbers of fruit/bushel boxes are 30 for jumbo, 40 for extra-large, 50 for large, and 60 for medium fruit.

<sup>ii</sup> 1 box/acre = 2.4711 boxes/hectare.

<sup>iii</sup> Jumbo: bell pepper fruit of width >4 inches.

<sup>iv</sup> Extra large: bell pepper fruit of width 4 inches.

<sup>v</sup> Large: bell pepper fruit of width 3.5 inches.

<sup>vi</sup> Medium: bell pepper fruit of width 3 inches.

<sup>vii</sup> Means followed by the same letter are not significantly different based on Tukey's honest significant difference test at 95%.

boxes per acre), and 'Playmaker' (226 bushel boxes per acre) had the least number of medium-sized bushel boxes per acre which differed statistically from 'Nitro', and 'Mercer' and other cultivars. Total number of bushel boxes per acre ranged from 1131 to 1338, and there were no significant differences in the total number of bushel boxes per acre. 'Antebellum' (1338 bushel boxes per acre), 'Mercer' (1321 bushel boxes per acre), 'Paladin' (1314 bushel boxes per acre), and 'PS 0994-1819' (1307 bushel boxes per acre), all had average yields that exceeded 1300 bushel boxes per acre. 'Aristotle' (1229 bushel boxes per acre), 'Galileo' (1227 bushel boxes per acre), and 'Revolution' (1206 bushel boxes per acre) performed moderately in the context of yield performance, all having more than 1200 bushel boxes per acre. 'Nitro' (1190 bushel boxes per acre), 'Tarpon' (1173 bushel boxes per acre), 'Playmaker' (1131 bushel boxes per acre), and 'Turnpike' (1112 bushel boxes per acre) performed the worst among all the cultivars.

**PHYTOPHTHORA ROOT ROT.** PCap infection did not occur in three out of four trials, and in the trial that had PCap incidence, it was low and nonuniform. Therefore, we could not quantify

whether there was a difference in resistance levels to naturally occurring local isolates between cultivars in our trials.

## Discussion

Diseases occur when the pathogen and host are present, and the environment is supportive. *Phytophthora* root rot (PCap) disease infestation increases with excessive moisture in the soil or a limited internal drainage system (Tompkins and Tucker 1941). Even susceptible cultivars did not favor the growth of PCap in these trials, so there were no significant results for the particular disease due to unfavorable environmental conditions for disease development. However, we did observe significant differences in adaptability, fruit size, and yields between the cultivars in our trials. The percentage of marketable bell pepper fruit per plant was significant, which indicates differences in the adaptability of PCap-resistant cultivars for cultivation in southern Georgia, USA (Dunn et al. 2013; Krasnow et al. 2017).

In Georgia, average bell pepper yield is 1143 bushel boxes per acre (USDA, NASS 2024). In our research trials, nine out of 11 cultivars had greater than average yield. Extra large and large-sized fruit are preferred by

consumers and generally provide higher returns for growers (Goldy 2020).

Pepper fruit physiological disorders are often caused by environmental factors, and they can reduce market value, although these choice peppers can be used for processing purpose (Phillips and Schoonmaker 2022). Culls in our trials were mainly caused by sunburn and, to a lesser extent, BER. BER develops in the fruit when calcium concentration cannot be taken up by the plant, and it generally occurs in the spring and summer seasons as the result of increased daylength or light load (Prieto et al. 2007). Sunburn is caused by photooxidative stress resulting in browning and necrosis of bell pepper fruit, which make the fruit unmarketable and eventually affect the profitability of the cultivar (Kabir 2019, 2022; Maughan et al. 2017). In this investigation, pancaking was the most common choice defect, whereas sunburn was the most common cull defect, and they significantly added to the yield loss in specific bell pepper cultivars. Sunburn and BER are always a major concern in spring-grown Georgia peppers.

Silvering disorder is commonly associated with the genotype of a particular cultivar and was historically associated with several PCap-resistant cultivars (Kline et al. 2011; Wyenandt and Kline 2006; Wyenandt et al. 2017). In our trials, silvering incidence was low, and there was no clear pattern between silvering and PCap resistance. Pancaking, pointy and silvering are typically more prevalent in the fall season in our region. Therefore, the best cultivars from this trial should be screened in the fall before mass adoption across seasons.

Several PCap-resistant cultivars performed well in our trials. 'PS 0994-1819' had higher numbers of jumbo and extra large fruit, total yields in bushel boxes per acre, and marketable fruit per plant with lower medium-sized fruit, silvering, pointy, and sunburn fruit. 'PS 0994-1819' had the highest yield (jumbo + extra large + large) bell pepper fruit, which indicates the higher amount of preferable fruit sizes. 'Paladin' and 'Mercer' had larger numbers of extra large and large-sized fruit, marketable fruit, total fruit, and percent marketable fruit. However, 'Paladin' tends to have pointy fruit, and 'Mercer' tends to have smaller, medium-sized fruit. 'Revolution' had no silvering with higher numbers of

jumbo-sized fruit, total fruit per plant, pancaking, and sunburn with fewer medium-sized fruit, marketable, and percent marketable fruit.

The BLS races 0 to 10-resistant and PCap-susceptible check cultivar ‘Antebellum’ performed well, having higher numbers of extra large fruit, total marketable fruit, total bushel boxes per acre, percent marketable fruit with lower numbers of silvering, pancaking, pointy fruit, and sunburned fruit. However, ‘Antebellum’ had large numbers of medium-sized fruit and is susceptible to PCap. ‘Aristotle’, which has limited BLS resistance and does not claim resistance to PCap, had a high number of extra large fruit, marketable fruit, percent marketable fruit, and silvering with low numbers of medium-sized fruit total fruit per plant. These cultivars continue to perform well for growers in the absence of disease or environmental conditions conducive to disease development.

Three cultivars are reported to be resistant to PCap and BLS races 0 to 10: Nitro, Playmaker, and Tarpon. In addition, ‘Nitro’ also had TSWV, which is a disease spread by thrips and is problematic during the spring in southern Georgia. However, these cultivars did not yield as well as others well in our trials. ‘Playmaker’ had lower marketable and total fruit per plant and had the most silvering, which indicates it is not well adapted to southern Georgia in the primary production regions. ‘Nitro’ and ‘Tarpon’ were well adapted, with low numbers of defects and a high percentage of marketable fruit. However, ‘Nitro’ had more medium-size fruit, and ‘Tarpon’ had a relatively low yield. ‘Nitro’ performed well in all categories but had a small fruit size, as indicated by the low number of jumbo fruit and the high number of medium-sized fruit.

## Conclusion

Of the cultivars comprising this research experiment, no statistically significant differences for PCap resistance were observed. However, there were lots of differences between cultivars in fruit size, yield, and defects over multiple trials. Considering adaptability, yield, and fruit size distribution, we would recommend the PCap-resistant cultivars PS 0994-1819, Paladin, and Mercer for fresh market spring production of bell pepper in southern Georgia, USA. ‘Revolution’ would be an adequate

choice for processing bell pepper due to its immense size and lower fruit quality. ‘Antebellum’ continues to be a good choice for growers looking for resistance to BLS races 0 to 10, and ‘Aristotle’, although old and not particularly disease-resistant, continues to perform well. Newer cultivars Tarpon and Nitro have a desirable disease-resistant package and are somewhat promising for Georgia due to their excellent fruit quality, however, Nitro has small-sized fruit, and Tarpon tends to have reduced yields.

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