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ARTICLE

Interaction of peanut root-knot susceptible and resistant cultivars with nematicides for managing *Meloidogyne arenaria* and yield response in peanut

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ABSTRACT

Peanut is an important crop in Alabama, where it is vulnerable to damage by root-knot nematodes, particularly peanut root-knot nematodes (PRKN, *Meloidogyne arenaria* Race 1). Peanut cultivars with resistance to this nematode, as well as nematicides, are used for minimizing yield losses due to PRKN. In this study, the efficacy of the nematicides fluopyram and aldicarb, applied in-furrow, along with cultivar resistance, are evaluated for managing PRKN populations and damage attributed to them, as well as impacts on pod yields and non-target effects on other diseases. In 2016, 2017, and 2018 on an irrigated site with a resident PRKN population, each of two nematicides as well as a control were applied to each of three peanut cultivars. Peanut cultivars included the PRKN-susceptible industry standard Georgia-06G along with the PRKN-resistant Tifguard (2016 only), Georgia-14N (all years), and TifNV-High O/L (2017 and 2018). TifNV-High O/L often had superior plant vigor ratings compared with Georgia-06G and to a lesser extent Georgia-14N. Similar plant vigor, pod galling, PRKN junvenile counts, as well as yield were often noted across all nematicide treatments, including the no-nematicide control. While early and late leaf spot diseases, caused by *Passalora arachidicola* and *Nothopassalora personata*, respectively, were low in all study years, these diseases were lower in 2018 on TifNV-High O/L and Georgia-14N than on Georgia-06G. Stem rot, caused by *Agroathelia rolfsii*, occurrence was low in each study year; however, Georgia-06G had greater disease indices than the nematode resistant cultivars with Georgia-14N having the least damage. While resistant cultivars had lower PRKN juvenile counts and negligible pod galling compared with Georgia-06G in each study year, TifNV-High O/L produced significantly greater yield in 2017 and 2018 than Georgia-06G or Georgia-14N. Georgia-14N had greater yield than Georgia-06G only in 2016. Overall, the PRKN-resistant cultivars often produced greater pod yields while suffering less damage from diseases and PRKN when compared with the current susceptible industry standard Georgia-06G, while no yield protection was provided by either nematicide.

INTRODUCTION

Peanut (*Arachis hypogaea* L.), an important agronomic crop in Alabama, was planted on approximately 74,000 ha (183,000 acres) in 33 of 67 counties in 2020. With an estimated yield of 3811 kg/ha (3400 lb/A), Alabama's peanuts had a farm-gate value in 2022 of $144 million (NASS, 2022). In the southeastern United States, yield and quality of peanut is threatened by several diseases including early and late leaf spots (caused by *Passalora arachidicola* and *Nothopassalora personata*, respectively), southern stem rot (caused by *Agroathelia rolfsii*, anamorph of *Sclerotium rolfsii*), and tomato spotted wilt virus (a *Tospovirus*), as well as several plant parasitic nematodes.

In Alabama, Florida, Georgia, and Texas, a widespread and potentially damaging parasite of peanut is the peanut root-knot nematode (PRKN, *Meloidogyne arenaria* race 1 (Neal) Chitwood) (Timper *et al.*, 2018). The host range of *M. arenaria* race 1 also includes pepper (*Capsicum* spp.), tobacco (*Nicotiana* spp.), and tomato (*Solanum* spp.) (Sasser and Carter, 1982). However, corn (*Zea mays*) and cotton (*Gossypii* spp.), which are commonly rotated with peanut, are likely poor hosts (Rodríguez-Kábana and Touchton, 1984). In production fields with heavy infestations of *M. arenaria* race 1, peanut yield may be less than 50% of expectations (Rodríguez-Kábana *et al.,* 1991; Timper *et al.,* 2018). Javanese root-knot nematode races 3 and 4 (*Meloidogyne javanica* Chitwood), which also parasitizes peanut, has not been reported in Alabama but was identified on peanut in Florida (Cetintas *et al.,* 2003) and Georgia (Minton *et al.,* 1969). In addition, compared to sound, undamaged pods, nematode damaged pods may be more readily colonized by fungi such as *Aspergillus flavus*, with subsequent aflatoxin production occurring under favorable conditions (Timper *et al.,* 2004; Timper *et al.*, 2013; Bowen, 2009).

The primary options available to peanut producers for managing *M. arenaria* are crop rotation, resistant cultivars, and nematicides (Rodríguez-Kábana and Canullo, 1992; Majumdar *et al.,* 2023). Crop rotation is the most sustainable means for suppressing *M. arenaria* populations below damage thresholds and for maximizing yield; however, economic considerations, such as low commodity prices for rotation crops and modest yield projections for rainfed corn and cotton, often limit cropping options for southeastern peanut producers (McSorley *et al.,* 1992; Rodríguez-Kábana and Canullo, 1992). The cultivars COAN and NemaTAM, which are introgressive backcrosses between a PRKN-resistant, interspecific amphiploid hybrid and the cultivar Florunner, were the first PRKN-resistant runner market-type cultivars released by the Texas Agricultural Experiment Station (Simpson and Starr, 2001; Simpson *et al.,* 2003). However, COAN and NemaTAM, like their Florunner parent, proved highly susceptible to the *Tomato spotted wilt orthotospovirus* (TSWV), the causal virus of tomato spotted wilt, an endemic and potentially damaging disease across the southeastern United States. In addition, these PRKN-resistant cultivars failed to match the yield of contemporary TSWV-resistant commercial cultivars (Holbrook *et al.,* 2008). Tifguard (now an obsolete cultivar) not only demonstrated PRKN and TSWV resistance but also superior yield when exposed to both pathogen systems compared with the obsolete commercial standard Georgia Green (Holbrook *et al.,* 2008).

Branch *et al.* (2014) noted that the PRKN-resistant Georgia-14N (tested as GA 082522; Branch and Brenneman, 2015) often produced greater yield than the contemporary PRKN-susceptible cultivars, Georgia-07W and Georgia Greener, and statistically matched those for Tifguard. TifNV-High O/L (Holbrook *et al.*, 2017), another PRKN-resistant cultivar, has more recently become commercially available. TifNV-High O/L and Georgia-14N had similarly greater yield than Georgia-06G in *M. arenaria* infested fields (Brenneman *et al.* (2017). Grabau *et al.* (2024) also reported greater yields for TifNV-High O/L than Georgia-06G under severe PRKN pressure. Holbrook *et al.* (2017), Campbell *et al.* (2019), and Strayer-Scherer *et al.* (2021) reported comparable yields for the recently released PRKN-resistant cultivars and current PRKN-susceptible commercial standards in the absence of damaging *M. arenaria* populations. However, adoption of PRKN resistant cultivars is limited by the perception of reduced yield, particularly in the absence of damaging *M. arenaria* populations, and concerns about grades (i.e., proportion of sound mature kernels) compared with current commercial standards (Starr *et al.*, 2002; Grabau *et al.*, 2020). In the absence of this damaging nematode, Starr *et al.* (2002) reported that the yield potential of earlier PRKN-resistant cultivars, i.e., COAN and NemaTAM, did not match that of susceptible commercial cultivars.

Nematicides are a widely used option for nematode management in peanut. Currently, the nematicides 1,3-dichloropropene (1,3-D, Telone II, Teleos Ag Solutions, Pinehurst, NC), along with the nematicides/insecticides AgLogic Aldicarb 15GG (AgLogic Chemical, LLC, Chapel Hill, NC) and oxamyl (Vydate C-LV, Corteva Agriscience United States, Indianapolis, IN), as well as the fungicide/nematicide fluopyram (Bayer CropScience) are recommended for nematode control in Alabama (Majumdar *et al.*, 2023). Of these nematicides, only the latter two (aldicarb and fluopyram) are widely used on Alabama peanuts.

Aldicarb is a carbamate insecticide with efficacy for controlling nematodes and thrips on peanut. When compared with non-treated controls, aldicarb treatments had significantly reduced *M. arenaria* populations along with significantly improved plant vigor and yield on a PRKN-susceptible peanut cultivar have been reported by Rodríguez-Kábana *et al.* (1981, 1985b). The current aldicarb label specifies in-furrow placement at 1.1 kg a.i. ha^{-1} with the costly option of side dressing and incorporating an additional 1.6 kg a.i. ha^{-1} at-pegging in fields with high nematode pressure. Rodríguez-Kábana *et al.* (1981) noted superior yield response with equivalent rates of banded compared with in-furrow applications of aldicarb.

Fluopyram is a broad spectrum, succinate dehydrogenase inhibitor (SDHI) fungicide with nematistatic activity against numerous plant parasitic nematodes (Hungenberg *et al.*, 2011) and fungal plant pathogens in the Ascomycetes and Deuteromycetes, particularly in the family *Sclerotinaceae* (Labourdette *et al.*, 2011). Averaged over seven years, Hagan *et al.* (2024b) reported significant yield gains with aldicarb, fluopyram + imidacloprid, or two applications of fluopyram products on Georgia-06G compared to non-treated controls. Similarly, Grabau *et al.* (2020) had previously noted significant pod yield gains with fluopyram, aldicarb, or 1,3-D treatments compared with the non-treated control, in one of two study years when substantial PRKN pressure was encountered. Wade *et al.* (2016) reported that aldicarb reduced pod and root damage as did 1,3-D and fluopyram (+ imidacloprid).

The objective of this study was to compare the interaction of selected commercial PRKN-resistant peanut cultivars and the nematicides fluopyram (formulated with imidacloprid) and aldicarb on pod yield, *M. arenaria* populations, and root and pod galling. In addition, the differential response of selected cultivars to early and late leaf spots, and stem rot, as well as non-target impacts of nematicides on these diseases in an irrigated production system on a site with a resident population of *M. arenaria* in Southeast Alabama was assessed.

MATERIALS AND METHODS

Production Methods

The study area at the Wiregrass Research and Extension Center, Headland, AL (WGREC; 31° 22" 34' N 85° 18" 54' W), was turned with a moldboard plow and worked to seed bed condition with a disk harrow. Rows were laid off in a Dothan fine sandy loam [fine-loamy, kaolintic, themic plinthic kandiudults; 0-2% slope; < 1% organic matter] with a KMC strip till rig with rolling baskets on a site with an established population of *M. arenaria* race 1. Peanuts were sown at 13 seed/m row and were cropped behind peanut (*Arachis hypogaea* L.) in 2016 and 2017 and following one year of cotton (*Gossypium hirsutum* L.) in 2018. Planting dates are listed in Table 1. Disease, thrips, and weed control recommendations of the Alabama Cooperative Extension System were followed (Majumdar *et al.*, 2023). Soil fertility and pH were adjusted each year according to the results of a soil fertility assay done by the Auburn University Soil, Forage & Water Testing Laboratory. The test area was irrigated as needed with a lateral move irrigation system.

In each year, treatments were arranged in a split plot design, with peanut cultivar as the main plot and nematicide treatment as the split-plot. Individual plots consisted of four 9.1 m (30 ft) rows on 0.9 m (3 ft) centers and were randomized in six complete blocks. The PRKN-susceptible cultivar Georgia-06G (Yuan *et al.*, 2018), along with the PKRN-resistant cultivar Georgia-14N, were included in all study years. Tifguard, planted in 2016, was replaced with TifNV-High O/L in 2017 and 2018. Three treatments were included: a non-treated control, aldicarb, and fluopyram + imidacloprid (fluopyram in manuscript) (product and application rate details in Table 2). Early and late leaf spots as well as stem rot were controlled with a 7-application calendar-based fungicide program that included either two applications of chlorothalonil or trifloxystrobin + tebuconazole followed by four successive applications of prothioconazole + tebuconazole or two applications of prothioconazole + tebuconazole alternated with two applications of azoxystrobin, and a final application of chlorothalonil. Pesticide details are provided in Table 2.

Table 1. Dates for planting along with rating dates for plant vigor, disease assessment and nematode assay soil sample collection.

Study year	Planting Date	Subjective plant vigor [Z]	Leaf spot diseases [Y]	Plot inversion [X]	Nematode soil assay
2016	31 May	19 Oct	19 Oct	21 Oct	19 Oct
2017	2 May	15 Sep	15 Sep	18 Sep	25 Aug
2018	03 May	13 Sep	18 Sep	20 Sep	25 Aug

[Z] Subjective visual plant vigor was rated on a 1 to 5 scale.

[Y] Early and late leaf spot intensity (DEF) was assessed together using the 1 to 10 Florida leaf spot scoring system.

[X] Stem rot incidence (SR) along with the level of root and pod damage (RKDam) attributed to M. arenaria were rated immediately after plot inversion.

Plant vigor ratings were taken on a scale where 1 = least vigorous to 5 = most vigorous across each plot as plants approached maturity (Table 1). Along with vigor ratings, early and late leaf spot intensity was assessed together using the Florida leaf spot scoring system on 1 to 10 scale where 1 = no disease, 2 = very few lesions in canopy, 3 = few lesions noticed in lower and upper canopy, 4 = some lesions seen and < 10% defoliation, 5 = lesions noticeable and < 25% defoliation, 6 = lesions numerous and < 50% defoliation, 7 = lesions very numerous and < 75% defoliation, 8 = numerous lesions on few remaining leaves and < 90% defoliation, 9 = very few remaining leaves covered with lesions and < 95% defoliation, and 10 = plants defoliated (Chiteka *et al.*, 1988). Leaf spot severity plus defoliation percentages (LSDEF) were calculated from intensity data using the formula [LSDEF % = 100/(1+*exp*(-(Disease intensity scale-6.0672)/0.7975))] (modified from Li *et al.*, 2012).

Prior to plot inversion (Table 1), soil samples were taken from the center two rows of each plot and consisted of ten subsamples of 2.5 cm diameter cores to a 10 cm depth. Randomly collected soil subsamples from each plot were thoroughly mixed, then 100 cm^3 soil was processed using the centrifugal-flotation method for determining juvenile PRKN densities (Jenkins, 1964). Briefly, soil was mixed with water then screened through several progressively smaller sieves to remove roots and debris. Soil suspensions were centrifuged, and the precipitate was mixed with a sugar solution which was centrifuged again, placed onto a 325-mesh sieve, rinsed, collected in a beaker then quantified using a microscope. Soil samples for nematode assays were stored at 3°C until processed which generally was done within two weeks. Nematode populations are presented as PRKN juveniles per 100 cm^3 of soil.

Stem rot incidence, presented as the number of loci (< 30 cm of consecutive symptomatic plants in row) in each of two center rows (18.2 m), was recorded immediately following plot inversion. In addition, root and pod galling attributed to PRKN (RKDam) was rated on a 1 to 5 scale where 1 = no visible damage, 2 = up to 25% damage, 3 = 25 to 50% damage, 4 = 50 to 75% damage, and 5 = 75 to 100% of roots or pods damaged over the yield rows. Nematode damage was recorded immediately after plot inversion. Inversion dates were determined using the hull scrape method as described by Williams and Drexler (1981) (Table 1).

Table 2. Application rates and source of nematicides and fungicides.

Compound	Application Rate	Product	a.i. conc (%)	Source
aldicarb	1.1 kg a.i./ha	AgLogic 15GG [Z]	15.0	AgLogic, Chapel Hill, NC
fluopyram + imidacloprid	236 g a.i./ha + 341 g a.i./ha	Velum Total 3.87SC [Y]	15.4 22.2	Bayer CropScience, St. Louis, MO
chlorothalonil	130 g a.i./ha	Echo 720 6F [X]	54.0	Sipcam Agro, Durham, NC
trifloxystrobin + tebuconazole	65 g a.i./ha + 65 g a.i./ha	Absolute Maxx 4.36SC [X]	22.63 22.63	Bayer CropScience, St. Louis, MO
prothioconazole + tebuconazole	84 g a.i./ha + 168 g a.i./ha	Provost 433SC [X]	12.9 25.8	Bayer CropScience, St. Louis, MO
azoxystrobin	327 g a.i./ha	Abound 2SC [X]	22.9	Syngenta Crop Protection, Greensboro, NC

[Z] Applied over open seed furrow.
[Y] Applied over open seed furrow in 46.8 L/ha water.
[X] Broadcast over plants in 187 L/ha.

Data analyses.

Plant vigor, LSDEF, stem rot, RKDam, RKpop, and yield, were measured responses analyzed with a generalized linear mixed model approach (PROC GLIMMIX: SAS 9.4 with ddfm=satterthwaite option). For each study year, cultivar, nematicide program, and the two-way interaction of cultivar x nematicide were treated as fixed factors; random effects were block and block × cultivar. Statistical analyses were conducted on rank transformations of vigor, LSDEF, stem rot, RKDam, and RKpop to normalize variances, which were back-transformed for presentation. Means were separated using Fisher's protected least significant difference (LSD) test ($P < 0.05$) unless otherwise indicated.

Weather

Daily temperature (minimum and maximum) and rainfall amounts were recorded by and collected from the AL Mesonet station at WGREC in each year. Raindays, days with > 0.25 cm precipitation, were counted. Plots were located within 500 m of the weather station. Rainfall variability for the first 120 days after planting was calculated for each year using the Shannon diversity index (SDI; Bronikowski and Webb, 1996).

Table 3. Average maximum, minimum and average temperatures, total rain and rain days, and measure of rainfall uniformity (SDI) from planting to inversion for each study year. Temperature and rainfall data collected by the Alabama Mesonet station at study site.

	Max. temp. (C)	Min. temp. (C)	Ave. temp. (C)	Rain (cm)	Irrigation (cm)	Rain days (>0.25 cm)	SDI[a]
30-year average	30.8	19.4	25.1	64.2			
2016	32.4	20.6	26.5	43.7	6.4	48	0.65
2017	30.1	19.8	25.0	52.9	6.4	51	0.73
2018	30.8	21.4	26.1	39.2	5.1	29	0.52

[a] SDI = Shannon's Diversity Index; reflects the uniformity of rain events, where approaching 1.0 reflects equal amounts of rain on a regular basis. SDI calculated using 20-year average from mid-May.

RESULTS

Overall, weather patterns during the production season did not greatly differ among study years (Table 3). A higher average temperature was seen in 2016 compared to other years, but differences were generally < 2°C. In each year, rainfall was 18 to 40% lower than the 30-year average and irrigation was inadequate to reach that average. Rainfall was particularly lacking in 2018, with only 60% of the historical average and fewer raindays than other years.

Vigor was significantly ($P < 0.01$) affected by nematicide treatment in 2016 and cultivar in 2017; no single factor affected plant vigor in 2018 and the cultivar × nematicide interaction was not significant in any year (Table 4). Averaged over nematicide treatments, in 2017 TifNV-High O/L had significantly greater vigor than the other two cultivars and also had numerically greater vigor in 2018; Tifguard in 2016 also had numerically greater vigor than the other cultivars. In 2016, the fluopyram treatment, averaged over cultivars, had > 12% greater vigor than other nematicides, but this was not a trend seen in other years.

Table 4. Plant vigor and nematode damage ratings for each of three study years.

	Plant Vigor[a]						Nematode galling[b]					
	2016		2017		2018		2016		2017		2018	
	P-values											
Cultivar	0.3829		<0.0001		0.5563		<0.0001		<0.0001		<0.0001	
Nematicide	0.0025		0.7065		0.8027		0.7790		0.5941		0.5358	
Cult × Nemat	0.1181		0.6047		0.4177		0.0612		0.2788		0.6413	
	means											
Georgia-06G	3.93	a[c]	2.67	c	3.39	a	4.5	a	2.5	a	3.4	a
Georgia-14N	4.07	a	3.83	b	3.56	a	1.3	c	1.0	b	1.2	b
Tifguard ('16) TifNV High-O/L	4.20	a	4.50	a	3.89	a	1.6	b	1.1	b	1.2	b
Non-treated	4.00	B	3.56	A	3.56	A	2.4	A	1.6	A	2.1	A
Aldicarb	3.70	B	3.72	A	3.78	A	2.6	A	1.5	A	2.1	A
Fluopyram	4.50	A	3.72	A	3.72	A	2.3	A	1.4	A	2.0	A

[a] Plant vigor was subjectively rated on a scale of 1 to 5 over whole plots, where 5 was most vigorous.

[b] Damage to roots and pods attributable to peanut root-knot nematodes (i.e., galls) was rated immediately after plot inversion on a scale of 1 to 5 where 1 = no visible damage, 2 = up to 25% damage, 3 = 25 to 50% damage, 4 = 50 to 75% damage, and 5 > 75% damage.

[c] Different letters with the same case, following means within each column, indicate a significant difference between values based on Fisher's protected least significant difference with P < 0.05.

In 2016, leaf spot damage, across nematicide treatments, differed significantly ($P = 0.03$) among cultivars with Tifguard having more damage than the other two cultivars; nematicide treatment and the cultivar × nematicide interaction did not affect LSDEF (Table 5). In 2017, averaged over cultivars, the non-treated control had greater ($P = 0.099$) LSDEF than the fluopyram and aldicarb treatments; cultivar and the cultivar × nematicide interaction did not affect LSDEF. All factors significantly ($P < 0.04$) affected LSDEF in 2018. Averaged over nematicide treatments, Georgia-06G had the greatest and Georgia-14N had the lowest LSDEF while TifNV-High O/L had intermediate LSDEF (Table 5). Also in 2018, across cultivars, the fluopyram treatment had lower LSDEF than the non-treated control, while the aldicarb treatment was similar to both. The two-way interaction was significant (P = 0.016) in 2018, likely because Georgia-06G with aldicarb or left untreated had significantly greater LSDEF than all other treatments, but with fluopyram, Georgia-06G had LSDEF similar to other treatments (Fig. 1).

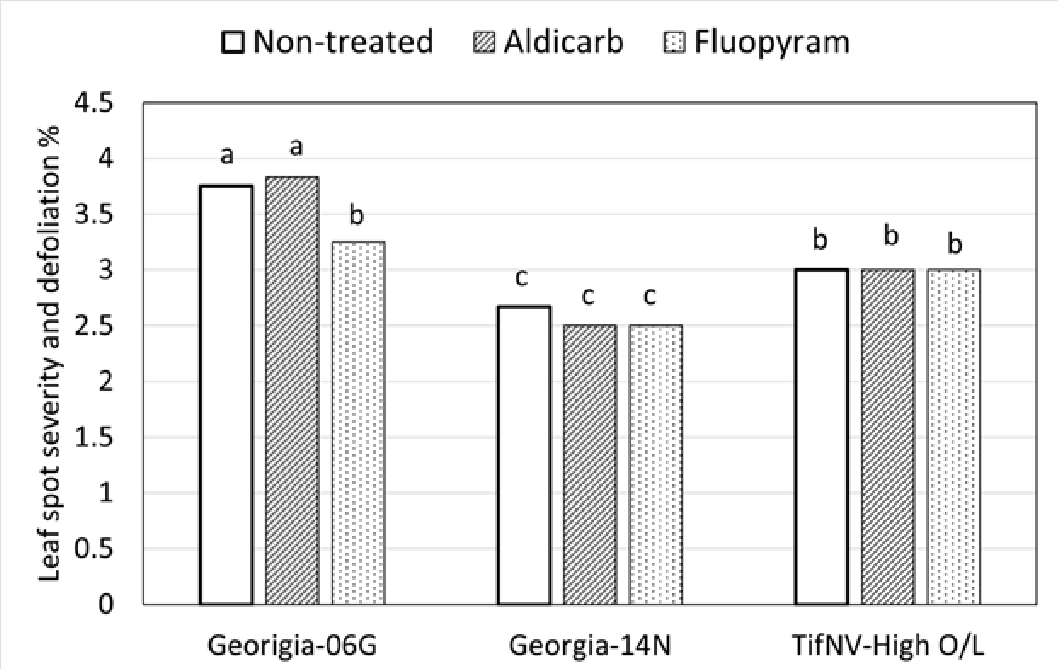

Figure 1. Spot severity on leaves plus proportion of plants that had defoliated due to early and late leaf spots of peanut for each cultivar × nematicide treatment in 2018. Different letters above bars indicate a significant difference between values based on Fisher's protected least significant difference with P < 0.05.

Table 5. Leaf spot severity and defoliation (%) due to early and late leaf spots and numbers of stem rot loci (up to 30 cm symptomatic plants in a row in each of three study years.

	Leaf spot severity and defoliation (%)						Stem rot loci					
	2016		2017		2018		2016		2017		2018	
	- -P-values -											
Cultivar	0.0311		0.9263		<0.0001		0.0004		<0.0001		<0.0001	
Nematicide	1.000		0.0990		0.0350		0.2341		0.8149		0.7193	
Cult × Nemat	1.000		0.6076		0.0163		0.5958		0.9510		0.4134	
	- means -											
Georgia-06G	2.09	b[a]	2.77	a	4.39	a	2.8	a	2.5	a	2.4	a
Georgia-14N	2.09	b	2.68	a	1.22	b	0.1	c	0.2	c	0.1	b
Tifguard ('16) TifNV High-O/L	2.44	a	2.68	a	2.09	c	1.8	b	1.0	b	0.3	b
Non-treated	2.21	A	3.07	A	3.06	A	2.0	A	1.3	A	0.7	A
Aldicarb	2.21	A	2.58	B	3.05	AB	1.4	A	1.3	A	1.1	A
Fluopyram	2.21	A	2.48	B	2.16	B	1.3	A	1.3	A	0.9	A

[a] Different letters with the same case, following means within each column, indicate a significant difference between values based on Fisher's protected least significant difference with P < 0.05, except for defoliation in 2017 with P < 0.10.

Cultivar significantly (P < 0.0005) affected stem rot in each study year, but nematicide and the cultivar × nematicide interaction did not (P > 0.20) (Table 5). Georgia-06G consistently had greater stem rot than Tifguard, TifNV-High O/L or Georgia-14N; the latter nematode-resistant cultivars had > 65% lower stem rot than the former susceptible cultivar (Table 5). Similarly, root and pod galling was significantly (P < 0.0005) impacted by cultivar, but not by nematicide or the cultivar × nematicide interaction ($P > 0.06$) (Table 4). As with stem rot, Georgia-06G consistently had greater RKDam than the PRKN-resistant cultivars (Table 4). The nearly significant ($P = 0.061$) cultivar × nematicide interaction in 2016, was likely due to reduced damage on Georgia-14N with fluopyram compared to aldicarb, while on Tifguard and Georgia-06G, nematode damage was similar for all treatments (data not shown).

In each study year, averaged over nematicide treatments, final PRKN juvenile populations were significantly ($P < 0.0003$) affected by cultivar but not by nematicide or the cultivar × nematicide interaction ($P > 0.05$) (Table 6). Averaged across nematicides, Georgia-06G consistently had greater RKpop than other cultivars—350%, 964%, and 706% greater than populations on Tifguard or TifNV-High O/L in 2016, and 2017 and 2018, respectively, with even lower populations on Georgia-14N. While not statistically compared across years, average RKpop in Georgia-06G was greatest in 2017, somewhat lower in 2016, and considerably lower in 2018 (Table 6). The nearly significant ($P = 0.058$) cultivar × nematicide interaction in 2017 was likely due to numerically greater PRKN juvenile populations with fluopyram on Georgia-14N and TifNV-High O/L while on Georgia-06G this treatment had substantially lower populations than non-treated or aldicarb treatments (data not shown).

Table 6. Peanut root-knot (PRKN) juvenile populations in 100 cm³ soil and yield (kg/ha) in each of three study years.

	PRKN juvenile populations						Yield					
	2016		2017		2018		2016		2017		2018	
	- -P-values -											
Cultivar	0.0002		<0.0001		0.0001		<0.0001		0.0093		0.0034	
Nematicide	0.1278		0.7052		0.5269		0.0823		0.5999		0.7169	
Cult × Nemat	0.4236		0.0578		0.2768		0.5284		0.6700		0.0164	
	- - - - - - per 100 cm³ - - - - -						- - - - - - - - - kg/ha - - - - - - - - -					
Georgia-06G	262.3	a[a]	328.8	a	24.1	a	3805	b	4548	b	4976	b
Georgia-14N	17.6	c	9.0	b	5.8	b	6063	a	4210	b	4913	b
Tifguard ('16) TifNV High-O/L	73.1	b	34.2	b	3.4	b	4159	b	5127	a	5978	a
Non-treated	120.4	A	161.3	A	9.6	A	4456	B	4536	A	5368	A
Aldicarb	96.5	A	152.8	A	16.1	A	4683	AB	4641	A	5247	A
Fluopyram	136.0	A	57.9	A	7.7	A	4886	A	4708	A	5251	A

[a] Different letters with the same case, following means within each column, indicate a significant difference between values based on Fisher's protected least significant difference with $P < 0.05$, except for yield in 2016 in which means were separated with $P < 0.10$.

Yield was significantly ($P < 0.01$) impacted by cultivar but not by nematicide ($P > 0.10$) in each study year. In 2016, Georgia-14N had significantly greater yield than other cultivars, while in 2017 and 2018, TifNV-High O/L outperformed Georgia-06G and Georgia-14N. The nearly significant ($P = 0.0823$) effect of nematicide treatments in 2016 on yield indicated that non-treated controls, averaged over cultivars, had significantly lower yield than fluopyram. The cultivar × nematicide interaction was not a significant factor ($P > 0.50$) in 2016 or 2017 but was ($P = 0.016$) in 2018 (Table 6) when non-treated Georgia-06G had greater yield than with aldicarb and aldicarb-treated TifNV-High O/L had greater yield than with fluopyram (Fig. 2).

DISCUSSION

This study sought to evaluate the performance of PRKN-resistant peanut cultivars, with and without nematicides, in comparison to the current commercial susceptible standard cultivar, Georgia-06G. In addition, the possible non-target effects of the nematicides, aldicarb and fluopyram, on leaf spot and stem rot diseases were assessed. In fields infested with *M. arenaria* Race 1, in each of three study years, the cultivars, Tifguard, Georgia-14N, and TifNV-High O/L had little or no galling on roots and pods such that nematode damage was consistently and significantly lower than on Georgia-06G. Similarly, significant and consistent reductions in *M. arenaria* juvenile populations were observed on the PRKN-resistant cultivars compared with Georgia-06G. Georgia-06G also had greater leaf spot and defoliation severity in one study year and consistently greater stem rot, but these damages did not appear to consistently detract from its yield.

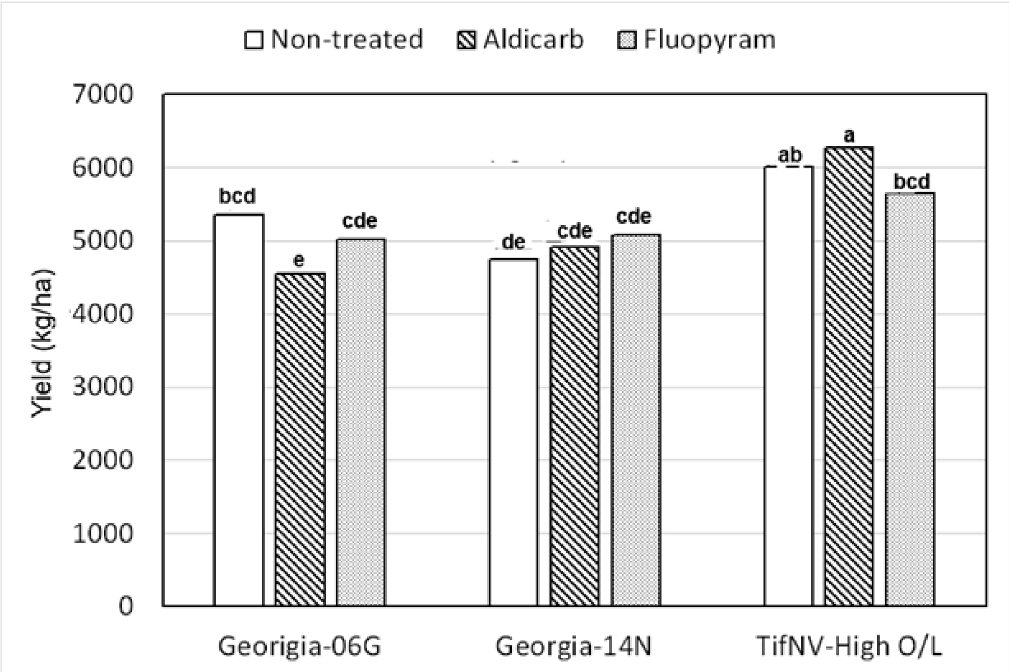

Figure 2. Peanut pod yields (kg/ha) for each cultivar × nematicide treatment in 2018. Different letters above bars indicate a significant difference between values based on Fisher's protected least significant difference with P < 0.05.

The decreased galling and limited *M. arenaria* juvenile counts observed in the current study on PRKN-resistant cultivars aligns with previous work. Branch *et al.* (2014) reported a significant reduction in galling on the roots and pods of Georgia-14N compared with the PRKN-susceptible cultivars Georgia-07W and Georgia Greener. A significant reduction in the egg mass index, which is a measure of *M. arenaria* reproduction, along with a lower root gall index for TifNV-High O/L as compared with the obsolete susceptible cultivars Florida-07, Georgia Green, and FloRun 107 was noted by Holbrook *et al.* (2017). In addition, Brenneman *et al.* (2017) did not observe root galling on either Georgia-14N or TifNV-High O/L, even in fields with high resident *M. arenaria* populations. Holbrook *et al.* (2008) had also noted significantly lower root-gall and egg mass indices along with egg counts with the obsolete resistant cultivars COAN, NemaTAM, and Tifguard compared with the now obsolete susceptible cultivar Georgia Green. Grabau *et al.* (2024) similarly noted significant reductions in root-galling on TifNV-High O/L compared to Georgia-06G. In contrast to the consistent reductions in juvenile populations with the PRKN-resistant cultivars herein, particularly in 2016 and 2017, enhanced plant vigor was observed in only in 2017 for Georgia-14N and TifNV-High O/L compared with the susceptible industry standard Georgia-06G.

In 2016 and 2017, juvenile populations of *M. arenaria* on Georgia-06G were in excess of 200 per 100 cm^3 soil while with the PRKN-resistant cultivars juvenile populations were consistently < 80. Given that the damage threshold for *M. arenaria* Race 1 on peanut is 10 juveniles per 100 cm^3 of soil (Jagdale *et al.,* 2013), substantial reductions in yield were expected with Georgia-06G. However, yield differences between nematode resistant cultivars, compared to the susceptible commercial cultivar, were inconsistent. Here, significant yield gains, when compared with the susceptible standard Georgia-06G and averaged over nematicide treatments, were obtained with Georgia-14N in 2016 and with TifNV-High O/L in 2017 and 2018. In 2016, average yield of Tifguard was statistically similar to that of Georgia-06G, despite significantly lower root and pod galling and substantially reduced PRKN juvenile populations on Tifguard. Holbrook *et al.* (2008) noted greater yields for Tifguard compared to the standard check cultivar, Georgia Green, when grown in fields with little to no nematode pressure. Georgia Green, now obsolete, had lower yield potential than Georgia-06G (Branch, 2007), suggesting that Tifguard and Georgia-06G might have similar yield potential as seen herein in 2016. In the two later years of the current study, Georgia-14N had yields that were similar to Georgia-06G while TifNV-High O/L had greater yields than Georgia-06G. On sites with high nematode populations, Brenneman *et al.* (2017) consistently observed yield gains with Georgia-14N and TifNV-High O/L compared with Georgia-06G. Together, these studies suggest that the yield potentials of Georgia-14N and TifNV-HighO/L are comparable to that of Georgia-06G. Yield differences from year-to-year between cultivars observed among these three studies could have arisen from a variety of factors, including soil type, weather, and management practices.

Widespread adoption of PRKN-resistant runner-type cultivars has been limited due to grower perception that yields will be lower than with standard (susceptible) commercial cultivars (Starr *et al.*, 2002; Grabau *et al.*, 2020). In irrigated OVT cultivar trials conducted annually from 2017 to 2022 in Southeast Alabama with minimal stem rot and PRKN pressure, Georgia-14N had greater yield than Georgia-06G in one of six years, while in four of six years TifNV-High O/L had comparable or greater yields than Georgia-06G (Hagan *et al.*, 2024b). Herein, yield of the PRKN-resistant cultivars, under light to moderate PRKN pressure, consistently matched and often exceeded the yield of the PRKN-susceptible Georgia-06G. In a series of concurrent Southwest Alabama trials with minimal root-knot pressure, yields of Georgia-14N and TifNV-High O/L matched or exceeded that of Georgia-06G and many other commercial cultivars (Hagan *et al.*, 2020a; Hagan *et al.* 2020b; Hagan *et al.*, 2021). As noted previously, yield potential of TifNV-High O/L and, to a lesser extent, Georgia-14N is comparable to Georgia-06G under minimal and high PRKN pressure and are suitable replacements for PRKN-susceptible cultivars across the southeastern peanut production region.

In this study in 2016, plant vigor was significantly greater with fluopyram treatment compared with the non-treated control. In the later two study years, both aldicarb and fluopyram numerically, but not significantly, improved vigor. In contrast, Rodríguez-Kábana *et al.* (1982) reported a significant improvement in plant vigor (subjective appearance index) with aldicarb, applied at various rates and with varying methods, compared to the non-treated control; this work was done at two sites in the same year.

Despite low leaf spot (LSDEF) and stem rot pressure during the study period, the PRKN-resistant cultivars evaluated here may display possible tolerance or partial resistance to these diseases. Georgia-14N and TifNV-High O/L had reduced leaf spot damage in 2018 but not in 2017 compared with Georgia-06G. Leaf spot damage on Tifguard in 2016 was greater than on Georgia-06G or Georgia-14N, but, overall, leaf spot pressure was low. Reduced stem rot was also noted for Georgia-14N, Tifguard, and TifNV-High O/L in each year, compared to Georgia-06G, with Georgia-14N having consistently lower stem rot than Tifguard or TifNV-High O/L. Branch *et al.* (2014) had previously noted that Georgia-14N had significantly reduced disease than Tifguard; 'disease' was a combination of tomato spotted wilt and stem rot at digging, expressed as total disease incidence. Under low tomato spotted wilt pressure, stem rot incidence in Alabama studies has continued to be lower on Georgia-14N and TifNV-High O/L compared with Georgia-06G (Hagan *et al.*, 2020a, 2021). In a second 2019 Alabama study, Georgia-14N but not TifNV-High O/L suffered significantly less stem rot damage than Georgia-06G (Hagan *et al.*, 2020b). In the same study, reduced leaf spot-incited defoliation for Georgia-14N compared with Georgia-06G was recorded (Hagan *et al.*, 2020b). Significant differences in leaf spot defoliation and stem rot incidence were not always noted between the above PRKN- susceptible and resistant cultivars herein. However, in uniform peanut OVT trials conducted annually in Alabama from 2017 to 2022, no differences in the occurrence of leafspot diseases or stem rot were noted between Georgia-14N, TifNV-High O/L, and Georgia-06G (Hagan *et al.*, 2024b).

Modest but significant reductions in year-end leaf spot severity and defoliation were obtained with in-furrow applications of fluopyram in 2018 on Georgia-06G. Hagan *et al.* (2024a) also reported reduced leaf spot incited defoliation in peanuts with fluopyram compared to aldicarb on Georgia-06G. In addition, in the previous study, enhanced leaf spot control was obtained when the in-furrow application of fluopyram was followed by an at-peg application of fluopyram + prothioconazole compared with fluopyram alone. Extended suppression of early and late leaf spots with in-furrow applications of fluopyram was recently reported by Culbreath *et al.* (2021). As noted by Hagan *et al.* (2024a), yield gains obtained with fluopyram in-furrow followed by fluopyram + prothioconazole at pegging, compared with aldicarb, may be attributed in part to reduced leafspot-incited defoliation.

As was previously noted by Hagan *et al.* (2024a), fluopyram and aldicarb did not impact stem rot incidence. The absence of activity of fluopyram against this disease is not surprising as the causal fungus, *Agroathelia rolfsii*, is a Basidiomycete and this fungicide has not shown significant activity against this class of fungi (Labourdette *et al.*, 2011). In multiple trials on peanut in Alabama, aldicarb, regardless of application placement, timing, and rate, did not significantly impact stem rot incidence on Florunner, a cultivar highly susceptible this disease (e.g., Rodríguez-Kábana *et al.*, 1985a; Rodríguez-Kábana *et al.*, 1991).

When averaged over cultivars, reductions in late-season juvenile PRKN populations were not seen with either fluopyram or aldicarb compared with the non-treated control. In a concurrent study at the same location, similar results were noted on Georgia-06G with these same nematicides along with a fluopyram + imidacloprid followed by an at-peg application of fluopyram + prothioconazole (Hagan *et al.*, 2024a). Similarly, Grabau *et al.* (2024) noted comparable PRKN populations at harvest on Georgia-06G in one of two study years; however, in the preceding year, with greater nematode populations, both aldicarb and fluopyram in-furrow reduced nematode populations compared to non-treated controls. Wade *et al.* (2016) had also noted that final *M. arenaria* juvenile counts were not reduced by 1.1 kg a.i. ha^{-1} aldicarb or fluopyram (+ imidacloprid). While Rodríguez-Kábana *et al.* (1982) failed to record a reduction in final *M. arenaria* juvenile counts with in-furrow applications of 1.1 and 2.2 kg a.i. ha^{-1} aldicarb, significantly lower juvenile counts were noted for banded applications of aldicarb at 1.1 to 4.4 kg a.i. ha^{-1} compared to the non-treated control. Significant reductions in nematode populations with banded compared with in-furrow applications of aldicarb were also observed by Rodríguez-Kábana *et al.* (1981). Overall, nematicides such as fluopyram along with labeled rates of aldicarb are unlikely to give season-end reductions in *M. arenaria* juvenile populations.

In the current study, yields averaged over cultivars were only improved with fluopyram, compared to no treatment, in one study year. In 2017 and 2018, yields were comparable among no nematicide, aldicarb, or fluopyram treatments. Grabau *et al.* (2024) had also noted similar yields among nematicide treatments (non-treated, aldicarb, fluopyram, and two applications of fluopyram products) with Georgia-06G. This contrasts to the significant yield gains with aldicarb, applied according to current label specifications, that were recently reported by Hagan *et al.* (2024a); however, previous research had questioned the efficacy of the now specified in-furrow placement of the 1.1 kg a.i. ha^{-1} of aldicarb for controlling PRKN and providing yield protection. Rodríguez-Kábana *et al.* (1982) noted significantly greater yield gains on peanut with banded compared with in-furrow applications of 1.1 kg a.i. ha^{-1} aldicarb with the latter placement having greater yield than the non-treated control. Enhanced performance of banded compared with in-furrow applications of aldicarb has been attributed to a uniform distribution through the pegging and root zone, which then minimizes phytotoxicity risk along with maximizing product efficacy (Rodríguez-Kábana *et al.*, 1981). Herein, the in-furrow placement is likely the cause for the absence of a significant yield gain with aldicarb. Thrips control with aldicarb is not impacted by product placement, so in-furrow placement is effective for controlling this insect pest on peanut (Majumdar *et al.*, 2023).

Overall, weather patterns during the production season did not differ greatly among study years. While 2016 had an overall higher average temperature than 2018, average minimum daily temperatures were lower in 2016 than 2018. Georgia-14N performed very well in 2016; it may be that this cultivar is tolerant of or is more productive at higher daily temperatures than Georgia-06G or Tifguard. All three years had less than normal rainfall, with 2018 having 40% lower rainfall and fewer raindays compared with the 30-year average. Despite supplemental irrigation, drier weather patterns likely resulted in reduced nematode activity and delayed disease development, which subsequently was reflected in greater yield as was noted in a concurrent nematicide study (Hagan *et al.* 2024a).

Along with crop rotation, resistant cultivars are the preferred method for managing PRKN, while maintaining pod yields and peanut profitability, especially when compared to nematicide use (Rodríguez-Kábana *et al.*,1987). Superior yield gains compared with the PRKN-susceptible cultivar Georgia-06G were consistently observed over the study period with one of the PRKN-resistant cultivars. In addition to sometimes erratic yield gains, the nematicides aldicarb and fluopyram add $33 to $49 ha^{-1} to variable production costs. For fluopyram, added product costs can be partially offset by using the Peanut R_X program (Kemerait *et al.*, 2020) to delete one or possibly more early season fungicide applications. In addition to plant parasitic nematodes, aldicarb has activity against thrips, thereby allowing some savings that are achieved by deleting the insecticide targeting this pest. Overall, nematicides are best adapted for use on susceptible cultivars in fields with light to moderate resident *M. arenaria* populations (Brenneman *et al.*, 2017) as compared with PRKN-resistant cultivars which are best suited to those fields with moderate to high resident PRKN populations.

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