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ARTICLE

Impact of Pesticides on Crop Injury, Yield, Market Quality, and Chemical Composition of Peanut (*Arachis hypogaea* L.)

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ABSTRACT

Producing peanut with limited pest management options creates challenges in maintaining yield, market grade quality, acceptable flavor, and nutritional value of peanut (*Arachis hypogaea* L.) compared with conventional production systems where synthetic pesticides can be used. It is well known that limited or no inputs of synthetic pesticides leads to higher disease and arthropod incidence and weed interference. However, the impact of reduced or no-pesticides on nutritional composition of peanut has not been investigated. Field experiments were conducted in 2017 and 2018 in North Carolina to determine the impact of varying levels of pesticide inputs on crop injury associated with pests, pod yield, market grade characteristics, and nutritional composition of the high-oleic cultivar 'Sullivan.' Treatments included: 1) seed planted at 210 kg/ha without fungicide versus seed treated with commercial fungicide at a seeding rate of 140 kg/ha; 2) peanut treated with acephate within three weeks after peanut emergence and chlorpyrifos applied at pegging versus no insecticides; and 3) no fungicides applied for protection from leaf spot disease versus five sprays of copper salts of fatty acid rosins, and five sprays of diverse commercially-available fungicides. Lower plant population and pod yield were observed when seed was not treated with fungicides even though a higher seeding rate was used. Synthetic fungicides protected peanut from early and late leaf spot disease [caused by *Passalora arachidicola* (syn. *Cercospora arachidicola*) and *Nothopassalora personata*] more effectively than copper salts of fatty acid rosins. Insecticides used to suppress potato leafhopper (*Empoasca fabae*), tobacco thrips (*Frankliniella fusca*), and southern corn rootworm (*Diabrotica undecimpuntata*) did not affect peanut yield compared with non-treated peanut. No difference in the ratio of oleic acid content to linoelic acid content was observed regardless of pest management practices. Total oil content was lower while total tocopherol content was higher when insecticides were applied compared with non-treated peanut. Total oil content increased as yield increased based on fungicide program while sugars decreased as yield increased in presence of less peanut defoliation. While the interaction of fungicide seed treatment and seeding rate and insecticide treatment was significant for total oil content and total sugars, differences among treatment combinations were minor and likely of limited biological significance. Total sugar content was affected by the three-way interaction of pest management inputs. However, no clear trend of treatment effects was noted as related to pesticide treatments and associated yield. Results from this study indicate that lower peanut yield will occur when fungicide is not applied to seed even though higher seeding rates are used compared with fungicide-treated seed when lower seeding rates are used. While more effective fungicides for protection from leaf spot disease resulted in higher yields, acephate applied to suppress tobacco thrips and chlorpyrifos for southern corn rootworm did not affect yield compared with non-treated peanut, possibly due to relatively low insect populations. Though significant effects of pest management on nutritional value were observed, the magnitude may have limited impact to consumers. Lack of difference in the ratio of oleic acid to linoleic acid suggests that differences in the pest management practices reported here will not affect expression of this trait in the high-oleic cultivar Sullivan.

INTRODUCTION

Despite concern from consumers, food systems with residual pesticide content are considered safe (i.e. with acceptable risk) through regulation of Environmental Protection Agency (EPA) and the Food and Drug Administration (FDA) (Weller *et al.*, 2014; Winter *et al.*, 2019). Nevertheless, these concerns from consumers have resulted in demand for food products produced without synthetic pesticides (Greene *et al.*, 2009; Koch *et al.*, 2017; Lee and Yun, 2015; Molinillo *et al.*, 2020). While this approach can limit the use of pesticides that have been proven effective, it creates opportunity for growers to capture new markets (USDA-NASS, 2022). In surveys of peanut farmers (Kaufman *et al.*, 2020) and consumers (Dean *et al.*, 2025), the premium required for peanut production by farmers versus the amount paid by consumers does not create a scenario for widespread production of organic peanut. However, developing strategies that maintain yield with OMRI (Organic Materials Review Institute)-approved approaches (OMRI, 2023) could lead to a greater likelihood of organic production and marketing.

Due to the limitations of approved and available and effective pesticide products in organic production, pests such as tobacco thrips (*Frankliniella fusca* Hinds), southern corn rootworm (*Diabrotica undecimpuntata* Howardi and Barber), early leaf spot [caused by *Passalora arachidicola* (syn. *Cercospora arachidicola* Hori], late leaf spot [*Nothopassalora personata* (Berk. & M.A. Curtis) U. Braun, C. Nakash., Videira & Crous], and southern stem rot (caused by *Sclerotium rolfsii* Sacc.) can lead to economic loss in peanut production systems (Jordan *et al.,* 2020). These pests are not limited to organic systems. In conventional systems, if not controlled throughout the cropping cycle, pests can have significant impacts on yield and quality.

Establishing adequate plant populations is one of the first steps in optimizing peanut yield (Lanier *et al.,* 2004; Mahoney *et al.,* 2019; Oakes *et al.,* 2020). Plant population can be affected by seeding rate and the impact of biotic and abiotic stresses on seed and seedlings (Jordan *et al.,* 2017; Oakes *et al.,* 2020; Ruark and Shew, 2010). Pathogens that can affect seed germination and seedling growth include *Rhizoctonia* spp., *Penicillium* spp., *Fusarium* spp., *Aspergillus niger*, and *A. flavus* (Melouk and Backman, 1995). In organic production systems, the use of synthetic fungicides on seed is prohibited, resulting in fewer options for growers to protect seedlings from death prior to emergence.

Thrips (*Frankliniella* spp.) can reduce peanut yield through feeding and transmission of tomato spotted wilt virus (family Tospoviridae, genus Orthotospovirus) (TSWV) (Reisig, 2025; Srinivasan *et al.*, 2018). However, in some cases, plants are able to recover from insect feeding as the season progresses (Branch and Fletcher, 2001). Adequate plant emergence can reduce incidence of TSWV (Branch and Culbreath, 2008; Branch and Fletcher, 2001; Branch *et al.,* 2003; Brown *et al.,* 2005; Reisig, 2025). Potato leafhopper (*Empoasca fabae* Harris) is a major insect pest in peanut (Reisig, 2025). Chlorosis caused by this insect is often observed after plants have begun to recover from thrips damage (Branch and Culbreath, 2008; Campbell *et al.,* 1976; Reisig, 2025; Smith *et al.,* 1985). Leaf necrosis due to chlorosis limits photosynthesis. Although yield loss does not always occur, Ellis (1984) reported that peanut can withstand some levels of potato leafhopper damage without significant yield reductions. Southern corn rootworm is a soil dwelling pest whose larvae feed on developing peanut pods resulting in yield loss and reduction in pod quality due to pod scarring (Brandenburg and Herbert, 1991) and causing pods to become susceptible to secondary pathogens due to pod damage (Porter and Smith, 1974). Historically, insecticide treatments can be made at pegging (Herbert et al., 1997; Porter and Smith, 1974) or the R2 growth stage (Boote, 1982).

Early and late leaf spot disease and southern stem rot can cause substantial yield loss in peanut in the U.S. (Anco *et al.,* 2020; Standish *et al.,* 2019). Multiple studies have shown a correlation between defoliation caused by disease and peanut yield (Backman and Crawford, 1984; Carley *et al.,* 2009; Chapin *et al.,* 2010). When not treated with fungicide, leaf spot disease can result in a reduction of pod yield over 50% (Knauft *et al.,* 1986, Knauft *et al.*, 1988; Shokes *et al.,* 1982). Early and late leaf spot and southern stem rot in North Carolina are controlled by fungicides applied on a bi-weekly schedule beginning at the R3 stage of peanut development (Boote, 1982; Lux and Shew, 2025). A wide range of effective fungicides is available for growers to control the pathogens causing these diseases in conventional production systems (Lux and Shew, 2025); however, a limited number of effective products is available for organic peanut production (Cantonwine *et al.,* 2011). When evaluating organically-acceptable fungicides, Cantonwine *et al.* (2008) observed treatments such as neem oil lacked the ability to control early or late leaf spot diseases in peanut production systems. Additionally, while copper and sulfur-containing fungicides can be used in OMRI-approved peanut production, they require shorter intervals between applications and are generally less effective than fungicides used in conventional production (Cantonwine *et al.,* 2008; Culbreath *et al.,* 1992).

Pod and seed size are highly correlated with plant maturity (Williams et al., 1987). As plants mature, mass and size of pods and seeds increase; thus, delayed growth of plants due to insect damage can result in a reduction of seed quality or the need to delay harvest (McNeill and Sanders, 1996; Pattee *et al.,* 1977). Larger kernels have higher commercial value. Fully mature seeds of the high oleic cultivars will also have the highest oleic acid content, and the nutritionally valuable α-tocopherol will be at the optimum content. (Hashim *et al.,* 1993b; Klevorn *et al.,* 2016). Although complex, roasted peanut flavor is partially dependent on the sugar content of the seeds. High sugar levels in immature seeds are associated with "off flavors", suggesting that full maturity seed is needed for optimum flavor (Sanders *et al.,* 1989). The impact of pest damage on nutritional value of peanut is not well established in the literature.

Growers often consider reducing pesticide inputs when the price of peanut at the farm gate is low, although this approach creates risk when pests are more prevalent than expected or occur in fields in an unpredictable manner. Additional research is needed to determine the effectiveness of pest management practices that would be appropriate for organic peanut production and how crop injury affects chemical profiles of peanut. This is especially the case given expression of the high oleic trait can be affected by pod and kernel maturation (Davis *et al.*, 2017; Dean *et al.*, 2020). Immature pods often express a lower level of oleic acid, and abiotic and biotic stress can affect plant development and pod and kernel maturation. This study evaluated the crop injury, pod yield, market quality, and chemical composition of peanuts grown using various levels of insecticide and fungicide inputs. The differences in pest reaction, pod yield, and market grade factors associated with financial value of peanut relative to arthropod and disease management using with limited pesticide use were compared with commercially available pesticides for conventional systems.

MATERIALS AND METHODS

Peanut and Pest Reaction in the Field

Experiments were conducted at the Peanut Belt Research Station located near Lewiston-Woodville, NC (36.1 N, 77.1 W) and the Upper Coastal Plain Research Station located near Rocky Mount, NC (35.9 N, 77.7 W) in 2017 and 2018. Soils at these respective locations included a Norfolk sandy loam (fine loamy, kaolinitic, siliceous, thermic, Aquic Paleudults, Kandiudults) with a pH ranging from 5.9 to 6.3 and a Norfolk loamy sand (fine loamy, siliceous, Aquic Paleudults, thermic Typic Paleaquults) with pH ranging from 5.7 to 6.0. Peanut seed from certified lots of the high-oleic Virginia market type peanut cultivar 'Sullivan' (PVP, 2025) was planted during the last week of May in conventionally prepared raised seedbeds with four rows spaced 91 cm apart and 11 m long. With the exception of experimental treatments, all pest management and production practices were administered uniformly across the test area based on NC State Extension recommendations for the region (Jordan *et al.,* 2025).

Treatments consisted of a factorial arrangement of two levels of seeding rate and fungicide seed treatment, two levels of insecticide treatment, and three levels of fungicide treatment to control leaf spot disease and southern stem rot disease. The seeding rate/fungicide seed treatment included: 1) non-treated peanut seed planted at 210 kg/ha and 2) fungicide-treated seed planted at 140 kg/ha. These respective seeding rates were designed to deliver 17 to 25 seeds/linear foot of row for the cultivar Sullivan in a single row planting pattern. The two levels of insecticide treatment included: 1) no insecticide and 2) acephate applied three weeks after planting to minimize injury caused by tobacco thrips feeding and southern corn rootworm. The three levels of leaf spot/southern stem rot management included: 1) no fungicide, 2) copper salts and fatty acid rosin acids applied bi-weekly beginning in early July at the R3 stage of peanut development (Boote, 1982) through September, and 3) commercially available fungicides applied bi-weekly beginning in early July through September.

A combination of azoxystrobin plus fludioxonil plus mefenoxam (Dynasty® PD, Syngenta Crop Protection, Greensboro, NC, equivalent to 36 g ai, 22 g ai, and 4.5 g ai/kg formulated product) was applied at a rate of 2.8 g product/110 kg seed prior to planting for the conventional seed treatment. In one fungicide spray program, copper salts and fatty acid rosin acids (Tenn-Cop 5E, Griffin, Corp., Valdosta, GA) at 2.0 kg ai/ha was applied bi-weekly. In a second fungicide program, the fungicide regime (in order of application) consisted of chlorothalonil (Bravo WeatherStik, Syngenta Crop Protection, Greensboro, NC) at 1.3 kg ai/ha, two sequential applications of prothioconazole plus tebuconazole (Provost 433SC, Bayer CropScience, Research Triangle Park, NC) at 0.2 + 0.2 kg ai/ha spaced 14 days apart, tebuconazole (Folicur, Bayer CropScience, Research Triangle Park, NC) at 0.2 kg ai/ha plus chlorothalonil at 1.3 kg/ha, and chlorothalonil at 1.3 kg/ha.

Acephate (Orthene 97, AMVAC Chemical Corporation, Los Angeles, CA) was applied 21 days after planting (DAP) at 0.56 kg ai/ha. Chlorpyrifos (Lorsban 15G, Dow AgroScience, Indianapolis, IN) was applied at 1.2 kg ai/ha on a 45-cm band on each row in early July when peanut was in the R1 to R3 stage of development (Boote, 1982). Acephate and fungicides were applied using a CO_2-pressurized backpack sprayer calibrated to distribute 140 L/ha at a pressure of 275 kPa using 11002 VS nozzles (Spray Systems Co., Wheaton, IL).

Approximately 14 and 21 DAP, peanut emergence was determined from 6 m of length from the center two rows of each plot. The width of the canopy was determined approximately 28 and 56 DAP from three plants from each plot to the nearest cm with the average used as the experimental unit. The number of leaves expressing chlorosis caused by potato leafhopper within three, 0.3 m^2-sections of each plot was determined 56 DAP. Scarring of pods from feeding by southern corn rootworm was determined by collecting 100 pods at harvest and determining the percentage of pods with visible damage. Canopy defoliation caused by leaf spot disease was recorded within one week prior to digging pods and inverting vines using a scale of 0 to 100% was used where 0 = no defoliation and 100 = complete defoliation.

Sample Collection for Composition Analyses

Peanut pods were dug and vines inverted at optimum pod maturity based on pod mesocarp color defined by Williams and Drexler (1981). Peanut pods and vines were allowed to air dry for 4 to 7 days prior to threshing. Pods were removed from vines using a commercial harvester designed for small-plot research. Final yield was adjusted to 8% moisture. Percentages of sound mature kernels (%SMK), sound splits (%SS), total sound mature kernels (%TSMK), other kernels (%OK), extra large kernels (%ELK), and fancy pods (%FP) were determined using USDA grading criteria for peanut (USDA-FIS, 2019). Percentages of SS and OK are not discussed. Market grade samples were handled often during the drying, storing, and processing steps after harvest, and this may have resulted in random differences in %SS and %OK fractions of the sample. The %TSMK, a reflection of %SMK and %SS, and percentages of ELK and FP which reflect pod size, are used in the discussion of market grades relative to yield and pest reaction.

Sample Preparation

Unless otherwise stated, all chemicals utilized in the analyses for this research were obtained from Thermo Fisher (Thermo Fisher, Fairlawn, NJ). In 2017, the SMK fraction of seeds was evaluated for lab analysis. In 2018, there was no exclusion criteria for seed grades, and all sizes were analyzed. The approach in 2017 may have negated possible changes in overall distribution of quality of kernels caused by pest injury during the growing season. Determining chemical composition without segregating kernel fractions would more accurately represent in-shell products that are consumed directly. However, the sampling procedure would be reflective of shelled peanut used in a wide range of products.

Total Moisture Content

Raw peanut samples were weighed into pre-weighed metal tins (Heathrow Scientific LLC, Vernon Hills, IL) in triplicate and were dried at 130° for six hours in an LXD Series Despatch forced air oven (Despatch Industries, Minneapolis, MN). After drying, samples were reweighed and total moisture determined by difference.

Total Oil Content

Total oil content of the raw seeds was determined by time domain nuclear magnetic resonance (NMR), with a Minispec MQ One Seed Analyzer (Bruker Corporation, Billerica, MA) according to ISO10565 (ISOD, 2019). The instrument was calibrated according to the manufacturer's instructions with varying amounts of peanut oil from 0 to 100% to construct a standard curve. Each sample was analyzed in triplicate using 10 to 11 g of whole seeds.

Ratio of Oleic Acid to Linoleic Acid

The oil from the samples was expressed using a Carver Model 3912 hydraulic press (Carver Inc., Wabash, IN). The oils were saponified and fatty acids liberated were methylated using boron trifluoride (14% in methanol, Sigma Chemical Corp., St. Louis, MO) as the catalyst and resulting fatty acid methyl esters were extracted into hexane (AOCS, 2005). The samples of insufficient size for oil expression were ground using a coffee grinder (Cuisinart, East Windsor, NJ) and directly saponified at room temperature overnight prior to methylation and extraction (Zeile *et al.,* 1993). The hexane extracts were analyzed using gas chromatography (GC) with a Perkin Elmer Clarus Model 500 (Perkin Elmer Corp., Shelton, CN) fitted with a 70% cyanopropyl polysilphenylene-siloxane capillary column (SGE BPX70, 30 m length and 0.25-mm i.d., 0.25µ film thickness) (SGE Analytical Science, Austin, TX). The carrier gas was helium (1.85 mL/min, 40 mL/min spit injection flow). The temperature program was 60C with a hold time of 2 min, increased at 10C per min to 180C, then increased at 4C per min to a final temperature of 235C for a total run time of 27.7 min. The detection was by Flame Ionization (FID) at 250C. The injection volume was 1 µL at 220C. A standard mix of fatty acid methyl esters Kel Fim FAME 5, (Matreya, LLC, State College, PA) was used for identification based on run times. Content of oleic and linoleic acids were calculated by normalization according to AOCS Official Method Ce 1h-05 (AOCS, 2005). The ratio of oleic to linoleic acid was then calculated.

Tocopherol Analysis

The oil from the samples was analyzed for tocopherol content after dispersing a weighed amount into 1 mL of hexane containing 1% isopropanol (v/v) as previously described (Hashim *et al*., 1993a 1993b). The samples too small to be expressed were ground as described above and directly extracted with hexane using sonication (Quantrex Model 140H sonicator, L&R Ultrasonics, Kearny, NJ). The extracts were taken to dryness under a nitrogen stream and the residue taken up in 1 mL of hexane containing 1% isopropanol. The resulting solutions were analyzed for tocopherols using normal phase High-performance liquid chromatography (HPLC) with UV detection (Agilent Model 1100, Agilent Technologies, Santa Clara, CA). The system was fitted with a Luna Silica column (250 mm X 4.6 mm, 5 µ, Phenomenex, Torrance, CA) with a mobile phase of 1% isopropanol in hexane at a flow rate of 1.2 mL/min at 30C. The detection wavelength was 294 nm.

Analysis of Sugars

Sugars were analyzed as previously described by Pattee *et al.* (2000). In brief, ground samples were extracted in triplicate into a mixture of methanol, chloroform, and water (60/25/15) (v/v/v) in glass tubes using sonication (Quantrex Model 140H sonicator, L&R Ultrasonics, Kearny, NJ). The tubes were then vortexed and centrifuged at 1,000 rpm using an IEC Model K centrifuge (Block Scientific, Inc., Bellport, NY). The solvent layer was decanted to a small beaker and the pellet was discarded. The solvent was removed under vacuum, and the dried residue was taken up in the internal standard solution (HPLC grade water containing lactose and cellobiose) and further diluted as needed with water.

An aqueous stock standard solution was prepared containing myo-inositol, glucose, raffinose, stachyose (Sigma, St Louis, MO) and fructose and sucrose (Thermo Fisher Scientific, Waltham, MA). Internal standard solution was added to an aliquot of the stock standard solution and diluted to volume to water. The concentration range of the standard solution was 20 to 75 µM. Each sample solution was filtered through Dionex OnGuard-H filter (Dionex, Sunnyvale, CA) and transferred to a screw-capped autosampler vial. The solutions were analyzed for sugars using a Dionex BioLC (Dionex Corp.) fitted with an ion exchange column (Dionex Carbopac PA-1, 250 mm length, 4.7 mm interior diameter). The mobile phase was 200 mM $NaOH$ with a flow rate of 1.0 mL/min at 30 C. The detection was by Pulsed Amperometry using the waveform recommended by the instrument manufacturer.

Statistical Analysis

The experimental design was a randomized complete block with treatments replicated four times in the field. Data for peanut stand, pest reaction, pod yield, market grade factors, sensory analysis, and chemical composition were subjected to analysis of variance (ANOVA) appropriate for the factorial arrangement of treatments using the GLMMIX procedure in SAS version 9.4 (SAS Institute Inc., Cary, NC). Based on the initial ANOVA with the combination of location and year defined as environments for stand establishment, pest reaction, pod yield, and market grade factors, few interactions of environment by treatment factors were significant (data not shown). Therefore, data are pooled over years and locations. However, because the sampling procedure for chemical analysis was different during the two years and sensory data were collected in 2017 only, data for these measurements are presented for each year pooled over locations within a year. Means of significant main effects and interactions were separated using Tukey's HSD test or a t-test for main effects at $p \le 0.05$.

RESULTS AND DISCUSSION

Peanut and Pest Reaction in the Field

Analysis of variance showed main effect differences for fungicide seed treatment/seeding rate, insecticide application, and fungicide programs for leaf spot disease were significant for many of the field variables measured (Table 1 and Table 2). Two-way and three-way interactions were not significant for any of the variables tested, suggesting that decisions to use these practices will result in results independent of other treatment factors.

Plant density was greater and crop canopy wider at both evaluation dates when seed was treated with fungicide with a lower seeding rate compared with non-treated seed with a higher seeding rate (Table 3). Planting peanut using conventional fungicide-treated seed resulted in greater yield compared with yield from the non-treated seed (Table 3). The plant population, plant canopy width, and peanut pod yield were greater when peanut seed was treated with fungicide even though the seeding rate for this treatment was lower (140 kg/ha) compared with the higher seeding rate of 210 kg/ha for non-treated seed. Mahoney *et al.* (2019) reported that peanut populations were often lower when seed was not treated with fungicide compared with fungicide-treated seed when the seeding rate was the same for both treatments The higher seeding rate for non-treated seed was also designed to further maximize potential for peanut seedlings to achieve an adequate stand. These results demonstrate that a higher seeding rate of

Table 1. F-ratio for peanut stand, canopy width, chlorosis caused by potato leafhopper feeding, and canopy defoliation caused by leaf spot disease during 2017 and 2018 at Lewiston-Woodville and Rocky Mount.

	Stand Count		Canopy Width			
	Days after planting					
Source of variation	14	21	30	60	Potato leafhopper injury	Canopy defoliation
Fungicide seed treatment and seeding rate (Seed)[a]	218.9*	132.6*	68.4*	87.3*	0.1	2.6
Insecticide treatment (Insecticide)[b]	0.4	0.1	25.5*	22.5*	11.0*	5.8*
Fungicide program for leaf spot disease (Foliar Fungicide)[c]	0.9	0.9	0.4	0.7	1.5	322.0*
Seed × Insecticide	0.6	0.2	0.8	0	0.1	0.4
Insecticide × Foliar Fungicide	1	0.9	0.3	0.3	0.6	2.5
Seed × Foliar Fungicide	0.4	0.1	0.2	0.6	0.2	2.4
Seed × Insecticide × Foliar Fungicide	0	0.2	1.2	1.0	0.1	2.2

*Indicates significance at $p < 0.05$. Data are pooled over two locations and two years.

[a] Treatments included: 1) seed treated using a combination of azoxystrobin plus fludioxonil plus mefenoxam and planted at 140 kg/ha and 2) seed not treated with fungicide and planted at 210 kg/ha.

[b] Treatments included: 1) no insecticide and 2) a combination of acephate applied 21 days after planting and chlorpyrifos applied at pegging.

[c] Treatments included: 1) no fungicide after peanut emerged, 2) bi-weekly sprays of copper salts of fatty acid rosins applied bi-weekly, and 3) conventional fungicides applied bi-weekly.

Table 2. F-ratio for pod yield and market grade characteristics for 2017 and 2018 at Lewiston-Woodville and Rocky Mount.

Source of variation	Pod yield	Fancy pods	Extra large kernels	Total sound mature kernels
Fungicide seed treatment and seeding rate (Seed)[a]	46.0*	4.3*	8.8*	13.7*
Insecticide treatment (Insecticide)[b]	2.5	4.0*	4.6*	14.2*
Fungicide program for leaf spot disease (Foliar Fungicide)[c]	51.5*	14.5*	7.5*	4.6*
Seed × Insecticide	0.1	0.5	0.3	0.1
Insecticide × Foliar Fungicide	2.3	0.8	0.8	1.6
Seed × Foliar Fungicide	2.1	0.7	2.8	1.1
Seed × Insecticide × Foliar Fungicide	0.2	1.6	0.5	1.3

*Indicates significance at $p < 0.05$. Data are pooled over two locations and two years.

[a] Treatments included: 1) seed treated using a combination of azoxystrobin plus fludioxonil plus mefenoxam and planted at 140 kg/ha and 2) seed not treated with fungicide and planted at 210 kg/ha.

[b] Treatments included: 1) no insecticide and 2) a combination of acephate applied 21 days after planting and chlorpyrifos applied at pegging.

[c] Treatments included: 1) no fungicide after peanut emerged, 2) bi-weekly sprays of copper salts of fatty acid rosins applied bi-weekly, and 3) conventional fungicides applied bi-weekly.

Table 3. Influence of seed treatment and seeding rate on peanut plant population, plant width, pod yield, and market grade characteristics.

	Peanut population		Canopy width			Market grade characteristics[b]		
	Days after planting				Peanut yield	ELK	TSMK	FP
Fungicide seed treatment[a]	14	21	28	56				
	No./6 m row		----- cm -----		kg/ha	--------- % -----------		
No	42	40	21	62	3410	42	67	83
Yes	70*	62*	26*	70*	4010*	44*	69*	84*

*Indicates significance at $p < 0.05$ based on a t-test. Data are pooled over two year, two locations, insecticide treatments, and fungicide programs for leaf spot disease.

[a] Seed treatments included: 1) seed not treated with fungicides at 210 kg/ha and 2) seed treated with azoxystrobin plus fludioxonil plus mefenoxam planted at 140 kg/ha.

[b] Abbreviations: ELK, extra large kernels; TSMK, total sound mature kernels; and FP, fancy pods.

non-treated seed only partially compensates for challenges with obtaining adequate peanut stands compared with seeding rates in production systems where seed is treated with fungicides. However, it is important to note that higher seeding rates can lead to greater incidence of seedling disease in some cases (Hagan et al., 2015; Sconyers et al., 2005).

Percentages of ELK, TSMK, and FP were higher when seed was treated with fungicide compared with non-treated seed (Table 3). It is possible that pod maturity, which is often reflected in higher percentages of ELK and TSMK (Jordan *et al.,* 2025), may have been more advanced when fungicide was applied to seed. Additionally, it is possible that a greater distribution of development of pods may have occurred when peanut populations were lower and a higher percentage of pods on a plant would have been on lateral vines and not associated with pods around the tap root (Jordan *et al.,* 2025; Lanier *et al.,* 2004). A wider distribution of pod maturity could result in lower percentages of ELK and TSMK.

Potato leafhopper injury was higher in peanut grown without insecticide treatment versus peanut treated with insecticide (Table 4). Canopy defoliation was greater when insecticides were applied regardless of fungicide treatments applied to peanut foliage for protection from leaf spot disease and southern stem rot or fungicide applied to seed for protection from soil-borne pathogens (Table 4). The reason for the lower level of defoliation in absence of insecticide was not documented. It is possible that chlorpyrifos could have caused foliar-feeding caterpillar populations to increase resulting in greater canopy defoliation (Chapin *et al.*, 2001). More detailed scouting than what we report here during the cropping cycle may have enabled determining the cause of this response.

Table 4. Influence of insecticide treatment on potato leafhopper injury, canopy defoliation, and canopy width.

Insecticide[a]	Potato leafhopper injury	Canopy defoliation	Canopy width Days after planting 28	 56
	Leaves/0.3 m^2	%	---------- cm ----------	
No insecticide	27	40	22	64
Acephate and chlorpyrifos[a]	19*	45*	25*	68*

*Indicates significance at $p < 0.05$ based on a t-test. Data are pooled over two years, two locations, fungicide seed treatments, and fungicide programs for leaf spot disease.

[a]Acephate applied 21 days after planting and chlorpyrifos applied at pegging.

Canopy width was greater when insecticides were applied (Table 4), most likely due to less injury caused by tobacco thrips. Injury caused by this insect pest can slow plant growth (Reisig, 2025). Pod scarring caused by southern corn rootworm feeding was low and unlikely to be of biological significance (Ang et al., 1994; Royals *et al.*, 2020). While peanut yield was not affected by insecticide treatment, percentages of ELK, TSMK, and FP were higher when insecticides were applied (Table 5). These results suggest that healthier plants in absence of tobacco thrips damage and injury caused by potato leafhopper may have resulted in a more rapid pace of plant development and subsequent pod maturation. However, the relatively low level of injury from tobacco thrips (e.g., suggested by a narrower canopy in absence of acephate), potato leafhopper, and southern corn rootworm when comparing insecticide-treated and non-treated peanut was not adequate to affect peanut yield.

Table 5. Influence of insecticide treatments on yield market grade characteristics.

Insecticide[a]	Pod yield	Market grade characteristics Extra large kernels	 Total sound mature kernels	 Fancy pods
	kg/ha	------------------------------------- %	-------------------------------	
No insecticide	3640	42	67	83
Acephate and chlorpyrifos	3780	44*	69*	84*

*Indicates significance at $p < 0.05$ based on a t-test. Data are pooled over two years, two locations, fungicide seed treatments, and fungicide programs for leaf spot disease.

[a]Treatments included: 1) no insecticide and 2) a combination of acephate applied 21 days after planting and chlorpyrifos applied at pegging.

The peanut canopy defoliation was the lowest and pod yield the highest when conventional fungicides were applied (Table 6). Canopy defoliation was greater when copper-based fungicides were applied compared with the conventional fungicide program. The greater canopy defoliation resulted in lower yields when comparing these treatments. The highest canopy defoliation and lowest peanut yield was observed when fungicide was not applied to protect plants from leaf spot disease. It is recommended that copper-based fungicides be applied on ten-day schedule rather than the 14-day schedule we used in our study to be effective (Lux and Shew, 2025). While incidence of southern stem rot disease was low in these experiments and sporadic, the higher yield following conventional fungicide program may have been due in part to suppression of southern stem rot disease by prothioconazole and tebuconazole as copper-based fungicides are not active against this disease (Lux and Shew, 2025). Although %ELK did not differ when comparing fungicide treatments for leaf spot disease, %TSMK and %FP were lower for the conventional fungicide program compared with non-treated peanut or peanut treated with copper-based fungicide (Table 6). This result was surprising, and no plausible explanation for this response is known.

The results from the field portion of this experiment are, in most cases, as expected, although it was anticipated that there would be more frequent interactions of treatment factors. None the less, these data demonstrate that peanut response to inputs including fungicide seed treatment to protect seed and seedlings from pathogens; insecticides to protect peanut from injury caused by tobacco thrips, potato leafhopper, and southern corn rootworm; and fungicides to protect peanut from the effects of pathogens causing canopy defoliation, will likely occur in a manner independent of each other. These results also demonstrate challenges growers attempting to produce peanuts with fewer inputs might experience. Fungicides to protect seed and seedlings from pathogens combined with fungicides used to minimize canopy defoliation caused by leaf spot disease were more effective in protecting peanut yield than insecticides to control thrips, potato leafhopper, and southern corn rootworm. It is important to note that insect pressure was relatively low in our experiments, and caution should be used in extrapolating this response to situations with higher insect pressure. With respect to organic production systems for peanut, these results provide information about yield and possible financial loss with low inputs systems and can inform grower's decisions about growing peanut under organic certification (Kaufman *et al.,* 2020).

Table 6. Influence of fungicide treatment for leaf spot disease on canopy defoliation, peanut yield, and market grade characteristics

			Market grade characteristics[b]		
Fungicide[a]	Canopy defoliation	Peanut yield	ELK	TSMK	FP
	%	kg/ha	----------------	%	----------------
None	75 a	3130 c	41 b	68 a	85 a
Copper salts of fatty acid rosins	43 b	3780 b	44 a	68 a	85 a
Conventional program	11 c	4220 a	44 a	67 b	80 b

*Means followed by the same letter are not significantly different according to Tukey's HSD test at $p < 0.05$. Data are pooled over two years, two locations, insecticide treatments, and fungicide seed treatments.

[a] Treatments included: 1) no fungicide applied to suppress leaf spot disease, 2) bi-weekly sprays of copper salts of fatty acid rosins; and 3) conventional fungicides applied bi-weekly.

[b] Abbreviations: ELK, extra large kernels; TSMK, total sound mature kernels; FP, fancy pods.

Table 7. F-ratio for total peanut oil content, ratio of oleic acid to linoleic acid, total tocopherol content, and sugar content at Lewiston-Woodville and Rocky Mount in 2017 and 2018.

Source of variation	Total oil content	Ratio of oleic acid to linoleic acid	Total tocopherol content	Sugar content
2017	%		%	%
Fungicide seed treatment and seeding rate (Seed)[a]	0.1	0.2	2.8	0.6
Insecticide treatment (Insecticide)[b]	0.8	0.1	0.5	2.5
Fungicide program for leaf spot disease (Foliar Fungicide)[c]	23.0*	0.1	0.5	7.9*
Seed × Insecticide	4.1*	1.0	3.3	4.2*
Insecticide × Foliar Fungicide	0.9	1.4	0.3	0.9
Seed × Foliar Fungicide	1.6	1.2	0.1	0.8
Seed × Insecticide × Foliar Fungicide	1.4	1.2	1.3	0.8
2018				
Fungicide seed treatment and seeding rate (Seed)[a]	3.7	0.8	0	2.0
Insecticide treatment (Insecticide)[b]	4.9*	0.1	4.8*	0.2
Fungicide program for leaf spot disease (Foliar Fungicide)[c]	26.7*	0.6	0.4	2.2
Seed × Insecticide	0.2	1.4	1.1	1.8
Insecticide × Foliar Fungicide	2.1	1.0	0.1	0.7
Seed × Foliar Fungicide	0.6	0.1	0.8	0.4
Seed × Insecticide × Foliar Fungicide	0.1	1.7	0.2	6.3*

*Indicates significance at $p < 0.05$. Data are pooled over two locations within each year. The sound mature kernel fraction was sampled in 2017. The sample in 2018 included all fractions of shelled peanut.

[a] Treatments included: 1) seed treated using a combination of azoxystrobin plus fludioxonil plus mefenoxam and planted at 140 kg/ha and 2) seed not treated with fungicide and planted at 210 kg/ha.

[b] Treatments included: 1) no insecticide and 2) a combination of acephate applied 21 days after planting and chlorpyrifos applied at pegging.

[c] Treatments included: 1) no fungicide after peanut emerged, 2) bi-weekly sprays of copper salts of fatty acid rosins applied bi-weekly, and 3) conventional fungicides applied bi-weekly.

Chemical Composition

Total oil content was affected by the main effect of fungicide program for leaf spot disease and the interaction of fungicide seed treatment/seeding rate × insecticide treatment in 2017 (Table 7). Main effects of insecticide and fungicide program for leaf spot disease were significant in 2018. Total oil content was higher in 2017 in absence of insecticides when seed was treated with fungicide and the seeding rate was lower compared with non-treated seed planted at a higher seeding rate (Table 8). The difference was relatively small and likely of no biological significance. When insecticides were applied, no difference in total oil content was observed when comparing fungicide seed treatment/seeding rate. No difference in total oil content was observed when comparing insecticide treatment regardless of fungicide treatment/seeding rate. In 2018, total oil content was not affected by the interaction of fungicide seed treatment/seeding rate × insecticide treatment but was affected by insecticide treatment. A higher total oil content was observed when peanut was not treated by insecticide (47.5%) compared with acephate and chlorpyrifos applications and/or associated protection from insect injury (46.9%) (data not shown in tables). However, the relatively low pressure from insects in our experiment prevents conclusions across other environments relative to effects caused by insects. In 2017, only the sound mature kernel fraction was used to determine chemical composition. In contrast, a composite sample of all shelled components (e.g., sound mature kernels, sound splits, other kernels) was used. Although not conclusive, using one component of the market grade in 2017 compared with the composite sample in 2018 may explain differences in results. Additionally, the magnitude of differences among treatments in both years most likely is of limited biological significance

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Table 8. Influence of fungicide seed treatment and seeding rate and insecticide treatment on total oil content in 2017.

		Total oil content	
		Insecticide treatment[b]	
Fungicide seed treatment[a]	Seeding rate	None	Acephate and chlorpyrifos
	kg/ha	-------------------- %	-------------------
None	210	48.1 b	48.5 ab
Azoxystrobin plus fludioxonil plus mefenoxam	140	48.7 a	48.3 ab

*Means followed by the same letter are not significantly different according to Tukey's HSD test at $p < 0.05$. Data are pooled over two experiments in 2017 and fungicide programs for leaf spot disease.

[a] Azoxystrobin plus fludioxonil plus mefenoxam applied to seed prior to planting (110 g/45 kg seed).

[b] Acephate (0.56 kg/ha) applied 21 days after planting. Chlorpyrifos (1.2 kg ai/ha) applied on a 45-cm band on each row in early July when peanut was in the R1 to R3 stage of development.

Table 9. Influence of fungicide program for leaf spot disease management on total oil content in 2017 and 2018.

	Total oil content	
Disease[a]	2017	2018
	-------------------- %	---------------
None	47.6 c	46.2 c
Copper sulfate only[a]	48.2 b	47.0 b
Conventional program[b]	49.4 a	48.4 a

*Means followed by the same letter are not significantly different according to Tukey's HSD test at $p < 0.05$. Data for total oil content are pooled over two locations during both years, insecticide treatments, and fungicide seed treatments.

[a] Bi-weekly sprays of copper salts of fatty acid rosins (2.0 kg/ha) applied bi-weekly beginning in early July at the R3 stage of peanut development.

[b] Bi-weekly beginning in early July at the R3 stage of peanut development consisting of chlorothalonil (1.3 kg/ha), two sequential applications of prothioconazole plus tebuconazole (110 kg/ha spaced 14 days apart), tebuconazole at (0.2 kg ai/ha) plus chlorothalonil (1.3 kg/ha), and chlorothalonil (1.3 kg/ha).

The ratio of oleic acid to linoleic acid was not affected by any of the treatment factors or their interaction (Table 7). While not conclusive, especially given conventional fertilizers and herbicides were used across the entire test area, our results suggest the approaches to pest management used here likely will not impact oleic acid expression, an important point as the oleic:linoleic ratio has been found to have important impacts on oxidation and rancidity (Braddock *et al.,* 1995). This finding is supported by a study conducted by Samman *et al.* (2008), in which researchers did not find evidence that edible oils derived from an organic production system demonstrated significantly different levels of fatty acids than those derived from a conventional system. While the high oleic trait in peanut is a result of genetic modification through traditional breeding, the degree of expression can be influenced by biotic and abiotic stress.

Total tocopherol content was affected by the main effect of insecticide treatment in 2018 but not by this treatment factor in 2017 or by any of the other treatment factors or their interactions in either year (Table 7). Total tocopherol content was greater when insecticide was applied compared with non-treated peanut (189 vs. 196 mcg/g fresh weight, data not shown in tables).

Total sugar content was affected by main effects of fungicide seed treatment/seeding rate and insecticide treatment in 2017 and the three-way interaction of treatment factors in 2018 (Table 7). In 2017, absence of insecticide and fungicide seed treatment and a higher seeding rate resulted in sugar concentration greater than when acephate and chlorpyrifos were applied or when seed was treated at a lower seeding rate in absence of insecticide (Table 10). Total sugar content was intermediate between these treatments when fungicide was applied to seed and the seeding rate was lower. Similar to results with total oil content, the magnitude of differences is most likely to be of limited biological significance. In 2018, the highest sugar content was observed when pesticide inputs were not included while the lowest content was noted when the most effective pesticides were used for all three treatment factors (Table 11). However, in many cases, sugar content for several combinations of pest management practices and seeding rate was similar to these extremes. The three-way interaction was likely caused by a decrease in total sugar content when fungicides were applied in absence of insecticide compared with response for the no-fungicide control. In this case, no difference across fungicide treatments for leaf spot disease were noted when seed was treated with fungicide and the seeding rate was lower while a lower content was observed when conventional fungicides were applied for leaf spot disease compared with the no-fungicide control when seed was treated with fungicide. A second contribution to this interaction was a lower sugar content when conventional fungicides were applied compared with no fungicide or copper-based fungicide when seed was treated and planted at a lower seeding rate and insecticides were applied. Treated seed with fungicide at a lower seeding rate and applying insecticides resulted in no difference in sugar content across fungicide treatments for leaf spot disease.

Table 10. Influence of fungicide seed treatment/seeding rate and insecticide treatment on sugar content in 2017.

		Total sugar content	
		Insecticide treatment[b]	
Fungicide seed treatment[a]	Seeding rate	None	Acephate and chlorpyrifos
	kg/ha	---------- mg/g fresh weight --------	
None	210	42.0 a	38.3 b
Azoxystrobin plus fludioxonil plus mefenoxam	140	39.1 b	39.7 ab

*Means followed by the same letter are not significantly different according to Tukey's HSD test at $p < 0.05$. Data are pooled over two experiments in 2017 and fungicide programs of leaf spot disease.

[a] Azoxystrobin plus fludioxonil plus mefenoxam applied to seed prior to planting (110 g/45 kg seed).

[b] Acephate (0.56 kg/ha) applied 21 days after planting. Chlorpyrifos (1.2 kg ai/ha) applied on a 45-cm band on each row in early July when peanut was in the R1 to R3 stage of development (Boote, 1982).

Table 11. Influence of fungicide seed treatment, insecticide treatment, and foliar-applied fungicide program for leaf spot disease on sugar content in 2018.

			Foliar-applied fungicide program		
Fungicide seed treatment[a]	Seeding rate	Insecticide treatment[b]	No fungicide	Copper-based fungicide[c]	Conventional fungicide[d]
	kg/ha		----------------------- mg/g fresh weight ---------------------------		
None	210	None	47.3 a	46.6 ab	39.2 cde
Azoxystrobin plus fludioxonil plus mefenoxam	140	None	38.9 de	40.6 b-e	42.9 a-e
None	210	Acephate and chlorpyrifos	43.8 a-d	39.5 cde	43.0 a-e
Azoxystrobin plus fludioxonil plus mefenoxam	140	Acephate and chlorpyrifos	45.3 abc	43.7 a-d	37.0 e

*Means followed by the same letter are not significantly different according to Tukey's HSD test at $p < 0.05$. Data are pooled over two experiments in 2017 and fungicide seed treatments.

[a] Azoxystrobin plus fludioxonil plus mefenoxam applied to seed prior to planting (110 g/45 kg seed).

[b] Acephate (0.56 kg/ha) applied 21 days after planting. Chlorpyrifos (1.2 kg ai/ha) applied on a 45-cm band on each row in early July when peanut was in the R1 to R3 stage of development (Boote, 1982).

[c] Bi-weekly sprays of copper salts of fatty acid rosins (2.0 kg/ha) applied bi-weekly beginning in early July at the R3 stage of peanut development (Boote, 1982).

[d] Bi-weekly beginning in early July at the R3 stage of peanut development consisting of chlorothalonil (1.3 kg/ha), two sequential applications of prothioconazole plus tebuconazole (110 kg/ha spaced 14 days apart), tebuconazole at (0.2 kg ai/ha) plus chlorothalonil (1.3 kg/ha), and chlorothalonil (1.3 kg/ha).

CONCLUSIONS

Protecting peanut yield from leaf spot disease with fungicides and treating seed with fungicide was more important than protection from insect pests (e.g., potato leaf hopper, southern corn rootworm, and tobacco thrips) at the levels present in these experiments. Of particular note is that peanut population and yield were greater when seed was treated with fungicide even though the seeding rate for non-treated seed was 50% higher. This was the case even though peanut was planted in late May when soils were warmer and more conducive to rapid emergence and avoidance of pathogens that negatively affect seeds and seedlings. These results suggest that increasing the seeding rate for non-treated seed for the Virginia market type cultivar Sullivan, may not result in adequate populations for optimum yield. With respect to insect management, our results suggest that peanuts grown under relatively low levels of pressure will have limited reductions in yield in absence of insecticides.

The total oil content increased with fungicide application with the highest levels found when leaf spot protection was greatest. The fatty acid composition of the oil was not affected by treatments or interactions as evidenced by the oleic to linoleic acid ratio remaining unchanged. The tocopherol content was only found to be affected by insecticide treatment with one year showing a small increase. The levels of the individual sugars present, as well as the total amount of simple sugars, is known to increase with seed growth and then decrease with final seed maturity. In this study, the highest levels were associated with acephate and chlorpyrifos application and lower seeding rates, while fungicide application and lower seeding rates had a lesser effect, but all the levels were not considered different enough to indicate biological significance. This also suggests the applications did not interfere with seed maturity.

Results from this research indicate that OMRI-approved fungicide, in this case copper-based fungicide is less effective than conventional fungicides in terms of protection of peanut yield from leaf spot disease. Planting fungicide-treated seed resulted in higher plant stands and yield than planting non-treated seed at a higher seeding rate. These results were independent of insecticide treatment. Relatively low insect pressure limits conclusions on growing peanut in absence of insecticides.

Production of organic peanuts has been most successful in the southwestern growing areas of the US (Boogades *et al.,* 2023). Organic production in this region is feasible in part due to low rainfall coupled with production under irrigation where unexpected and prolonged rainfall events do not generally occur and weed management can be more effective and consistent and disease incidence is often less intense. However, development of strategies that enable growers in North Carolina to produce peanut with OMRI-approved tools would open up potential for peanut farmers to supply peanut for the in-shell trade.

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