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Susceptibility and Yield of Kale Horticultural Types and Cultivars Affected with Black Spot Caused by *Alternaria brassicicola* and *Alternaria japonica*

Anthony P. Keinath
Clemson University, Coastal Research and Education Center, 2700 Savannah Highway, Charleston, SC 29414-5329, USA

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Abstract. **Curly kale (*Brassica oleracea* var. *sabellica*), lacinato kale (*B. oleracea* var. *palmifolia*), Portuguese kale (*B. oleracea* var. *costata*), and Siberian kale (*Brassica napus* var. *pabularia*) are produced with conventional and organic practices in the southeastern United States. The foliar disease black spot, caused by the fungi *Alternaria brassicicola* and *Alternaria japonica*, may reduce yields of curly kale, but its effects on other kale types are unknown. The objectives of this study were to determine which kale cultivars had the lowest percentage of symptomatic leaves (disease incidence) and greatest yield of healthy leaves when grown with conventional and organic practices in fall and spring. Single-row plots of 14 kale cultivars were inoculated on the ends with one *Alternaria* sp., which then spread to noninoculated plants in the center of the plot. Season, production, pathogen species, harvest, and inoculation affected cultivar performance; season had the largest effect. In general, Portuguese kale was the most susceptible kale type, followed by curly kale. Black spot incidence was greater at the second harvest of cropped plants than at the first harvest. Siberian kales yielded more than curly and lacinato kales, although green curly kale cultivar Winterbor had yields similar to the best-yielding Siberian kales.**

Host plant resistance, when available, is a key component of integrated pest management for vegetable diseases (Lefebvre et al. 2020). Resistant cultivars are one of the most cost-effective disease management techniques, because, in most cases, there is no additional seed cost compared with planting susceptible cultivars, or the cost difference is a negligible part of the input costs (Keinath 2019). In many vegetable crops, however, cultivars resistant to common diseases are not available (Kemble et al. 2024). Tolerant cultivars (i.e., those that yield acceptably despite susceptibility to disease) may provide an alternative to cultivars with specific resistance genes (Pagán and García-Arenal 2018; Schafer 1971). For example, ‘Hansel’ eggplant is tolerant to Phomopsis blight, because, although it had moderately severe foliar symptoms and defoliation, it was the best yielding of seven cultivars evaluated (Keinath 2022).

Kale is an Old World vegetable with multiple centers of origin. The four different morphotypes of kale included in this study represent two species, *B. napus* var. *pabularia* (Siberian kale) and *B. oleracea* var. *sabellica* (curly kale), var. *palmifolia* (lacinato kale), and var. *costata* (Portuguese kale) (Cai et al. 2022; Dias 1995; Hahn et al. 2022; Wiersema 2019) (Table 1, Fig. 1). In the United States, curly kale is the most commonly produced type, followed by lacinato or Tuscan kale, and Siberian kale, primarily the cultivar Red Russian (Reda et al. 2021). Portuguese kale is rarely grown in the United States.

Black spot or Alternaria leaf spot is a common disease on all brassica vegetables throughout the world (Tewari and Buchwaldt 2007). A South Carolina producer of conventional and organic kale named black spot as the most important fungal disease in their operation (Keinath and Silva, unpublished). In the eastern United States, *A. brassicicola* (Schwein.) Wiltshire is the most common *Alternaria* spp. on leafy brassica vegetables (Nieto-Lopez et al. 2023). *A. japonica* Yoshii is another species found more recently in South Carolina, Georgia, and California (Keinath et al. 2021; Nieto-Lopez et al. 2023; Tidwell et al. 2014). A third species, *A. brassicae* (Berk.) Sacc., was recently documented on broccoli in the mountains of North Carolina (Hinchliffe et al. 2024). Japanese isolates of the three brassica-infecting species had similar severities on 10 vegetable brassica hosts, although only *A. brassicicola* was inoculated onto *B. oleracea* var. *sabellica* (common name not reported) (Nishikawa and Nakashima 2020). In a recent field study, virulence of *A. japonica* and *A. brassicicola* did not differ on three kale cultivars, two curly and one lacinato (Keinath 2024). If these two species differ on lacinato or Siberian kale cultivars is unknown. Because kale types have different centers of origin, they also may differ in reaction to foliar diseases, such as black spot.

Consumers in South Carolina and six other southeastern states prefer locally sourced kale (54.9% of respondents) and are willing to pay a premium for organic kale grown in the southeastern United States (49.9%) (Behler et al. 2024). Thus, there is strong market demand for organic kale throughout this region. One reason for this preference may be because the target site for pesticide applications, the leaves, is also the portion of the crop that is consumed.

The objectives of this study were to 1) compare cultivars representing four horticultural types of kale for susceptibility to black spot and its effects on yield; 2) compare the effects of *A. brassicicola* and *A. japonica* on yields of kale cultivars; and 3) determine if cultivars performed consistently in different seasons and under conventional or organic production.

Materials and Methods

Four experiments were done at the Clemson Coastal Research and Education Center in Charleston, SC. Two experiments in Fall 2021 and Spring 2022 were done, one each season in a conventional field and one in a certified organic field. The soil type in all fields was Yonges loamy fine sand, and the soil pH in the organic and conventional fields was 6.5 and 6.8, respectively, in the fall and 6.7 and 6.9 in the spring. Previous crops in the organic fields were ‘Regal Graze’ ladino white clover (*Trifolium repens*) for 2 years before the Fall 2021 experiment and ‘Regal Graze’ followed by a mixture of rye and Austrian winter pea before the Spring 2022 experiment. Previous crops in the conventional fields were rye, sorghum-Sudan grass hybrid ‘Sudex’, and rye before the Fall 2021 experiment and rye, sorghum-Sudan grass hybrid ‘Sudex’, and balansa clover (*Trifolium michelianum*) before the Spring 2022 experiment.

In the organic fields, nitrogen [Naturesafe 10-2-8 (Irving, TX), 111 and 185 $kg{\cdot}ha^{-1}$ in Fall 2021 and Spring 2022, respectively], potassium (potassium sulfate 0-0-22, 68 and 126 $kg{\cdot}ha^{-1}$), phosphorus (bonemeal 0 to 10-0,

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A.P.K. is the corresponding author. E-mail: TKNTH@clemson.edu.

Table 1. Cultivars of four kale horticultural types tested under organic and conventional production in Fall 2021 and Spring 2022.

Cultivar	Type	Binomial	Leaf color	Leaf texture	Seed source
Blue Curled Scotch	Curly	*Brassica oleracea* var. *sabellica*	Green	Smooth	Eden Brothers
Curly Roja	Curly	*B. oleracea* var. *sabellica*	Red	Smooth	Peaceful Valley
Darkibor	Curly	*B. oleracea* var. *sabellica*	Green	Smooth	Harris Seeds
Oldenbor	Curly	*B. oleracea* var. *sabellica*	Green	Smooth	Johnny's
Winterbor	Curly	*B. oleracea* var. *sabellica*	Green	Smooth	Seedway
Black Magic	Lacinato	*B. oleracea* var. *palmifolia*	Green	Smooth	Harris
Lacinato	Lacinato	*B. oleracea* var. *palmifolia*	Green	Smooth	Peaceful Valley
Toscano	Lacinato	*B. oleracea* var. *palmifolia*	Green	Smooth	Johnny's
Red Russian	Siberian	*Brassica napus* var. *pabularia*	Red	Smooth	Peaceful Valley
Russian Royale	Siberian	*B. napus* var. *pabularia*	Red	Smooth	Johnny's
Siberian	Siberian	*B. napus* var. *pabularia*	Green	Hairy	Peaceful Valley
Siberian Dwarf	Siberian	*B. napus* var. *pabularia*	Green	Hairy	Seedway
White Russian	Siberian	*B. napus* var. *pabularia*	Green	Smooth	Peaceful Valley
Tronchuda Beira	Portuguese	*B. oleracea* var. *costata*	Green	Smooth	Seedway

147 kg·ha^{-1}) and boron (Solubor, 1.1 kg·ha^{-1} in Fall 2021 and QB-10 granulated, derived from ulexite, 34% B_2O_3, 4.0 kg·ha^{-1} in Spring 2022) were incorporated preplant, whereas in the conventional fields 15-0-15 (74 and 102 kg·ha^{-1} in Fall 2021 and Spring 2022, respectively), potassium (potassium sulfate 0-0-22, 60 and 89 kg·ha^{-1}) and boron (as applied in the organic fields) were incorporated preplant, based on soil tests and fertility recommendations for kale in the southeastern United States (Kemble et al. 2024).

Raised beds 0.9 m wide on 1.8-m centers were covered with white-on-black polyethylene mulch in the fall and black mulch in the spring to manage weeds. Mulches were 0.03-mm thick and 1.5-m wide. A single line of drip irrigation tubing was placed 1 inch below the soil surface in the center of each bed. Plots were single rows, 6.1-m long, separated within rows by 1.5 m of non-planted area. Twenty 5-week-old kale plants of 14 cultivars grown from certified organic seed were transplanted into organic and conventional plots on 8 and 13 Oct 2021 and 15 and 28 Mar 2022, respectively (Table 1, Fig. 1). Plants were spaced 30 cm apart within rows. Plants were fertilized every other week via drip irrigation starting 30 d after transplanting. In both fields in the fall, 2.3 kg sodium nitrate (16N–0P–0K) was applied per week, whereas in the spring, 2.3 kg Allganic 15N–0P–2K was applied per week.

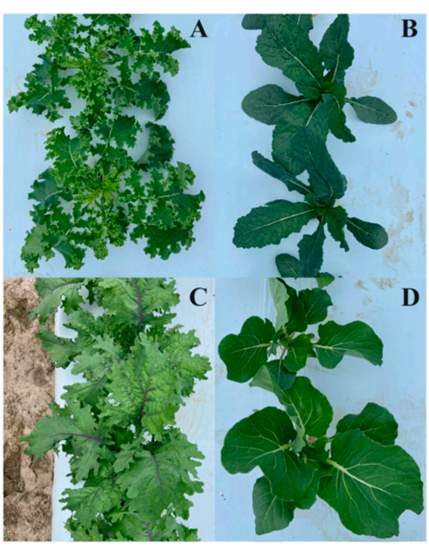

Fig. 1. Representative cultivars of four horticultural types of kale included in this study. (**A**) 'Winterbor' curly kale, (**B**) 'Toscano' lacinato kale, (**C**) 'Red Russian' Siberian kale, and (**D**) 'Tronchuda Beira' Portuguese kale.

In the organic fields, weeds were managed with caprylic acid 45.14% and capric acid 34.76% (Homeplate) in both seasons, with caprylic acid 47% and capric acid 32% (Suppress) added in the spring. Cabbage worms were controlled using *Bacillus thuringiensis* 54.0% (XenTari) in both seasons, as well as pyrethrins 5.0% (Pyganic) in the spring. Azadirachtin 1.2% plus pyrethrins 1.4% (Azera) was applied in the fall to manage whiteflies. Sulfur 90.0% (Yellow Jacket) was applied in the spring to manage powdery mildew. In the conventional fields, S-metolachlor (Dual Magnum) was applied preplant at 1.1 and 2.1 kg·ha^{-1} in fall and spring, respectively, to manage weeds. In the spring, 52 g·ha^{-1} halosulfuron-methyl (Sandea), 0.14 kg·ha^{-1} fomesafen (Reflex), and 4% glyphosate (Credit 41 Extra) were added. In the fall experiment, 2.3 L·ha^{-1} potassium phosphite (Kphite) was applied seven times and 0.54 kg·ha^{-1} ametoctradin 26.9% + dimethomorph 20.2% (Zampro) was applied three times to manage downy mildew during December to February. To manage aphids, 0.18 kg·ha^{-1} flupyradifurone (Sivanto) was applied. In the spring, 73 g·ha^{-1} chlorantraniliprole (Coragen) was applied to manage caterpillars.

All experimental designs were a split-plot with four replications, cultivars as the whole plot, and *Alternaria* spp. as the subplot. Whole plots were divided in half, and *Alternaria* spp. were randomly assigned to subplots. The third and fourth last plants on the outer end of each subplot were inoculated, leaving two noninoculated border plants on the outer end of the subplot and six noninoculated plants on the inner end of the subplot (or 12 noninoculated plants between the inoculated plants) (Fig. 2). Five and 3 weeks after transplanting in fall and spring, respectively, selected plants were inoculated with either *A. japonica* isolate ALT12 or *A. brassicicola* isolate ALT54. Cultures were grown for 2 weeks on unclarified V8 agar under cool-white, fluorescent lights and 18-h photoperiod at an ambient temperature of 23 °C. A suspension of 5 × 10^5 conidia/mL was applied with a handheld sprayer to the lowest two leaves on each inoculated plant. To prolong leaf wetness and promote infection, overhead, low-pressure mini-wobbler sprinklers (Senninger Irrigation, Clermont, FL, USA) were used to produce a mist for 15 min each day at 0800 HR and 2000 HR starting the day after inoculation. The morning mist period was omitted on dates any pesticides were applied.

Harvest date was determined by the length of the largest leaf of curly kale, measured from the tip to the lowest leaflet but excluding the leafless portion of the petiole, because leaves 30 cm long are considered physiologically mature (Reda et al. 2022). Leaves 10 to 30 cm long (based on South Carolina harvest practices) were cut from the two plants inoculated with each isolate and from one plant on each side of the two inoculated plants (Fig. 2). Directly inoculated plants were harvested on 6 to 7 Dec 2021 and 2 Mar 2022 in the organic experiment and 16 to 17 Dec 2021 and 8 Mar 2022 in the conventional experiment (Fig. 2). Leaves on four naturally inoculated plants in the middle of the cultivar plots were harvested on 12 Dec 2021 and 27 Jan 2022 in the organic experiment and 10 Dec 2021 and 13 Jan 2022 in the conventional experiment. In the spring, directly inoculated plants were harvested on 17 and 19 May 2022 in the organic experiment and 2 Jun 2022 in the conventional experiment. (In the conventional experiment, plants were not harvested in one replication due to reduced growth compared with the rest of the field. Directly inoculated plants were not harvested a second time in the spring.) Naturally inoculated plants were harvested on 3 May and 6 Jun 2022 in the organic experiment and 2 and 27 Jun in the conventional experiment. Leaves were sorted as healthy (symptomless) or diseased (one or more lesions of black spot >1 mm diameter), counted, and weighed.

After harvest, two lesions from two leaves on directly inoculated plants and four lesions from naturally inoculated plants were cultured as described previously to determine which *Alternaria* spp. were present (Keinath 2024).

Data analysis. Data were analyzed with a mixed-model maximum likelihood analysis with SAS PROC GLIMMIX (SAS Version

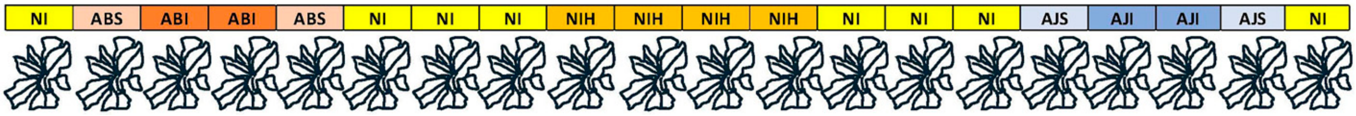

Fig. 2. Sample arrangement of directly inoculated (ABI and AJI) and naturally inoculated (NI and NIH) plants within cultivar plots. The left and right halves of plots (10 plants each) were considered subplots, and *Alternaria brassicicola* and *Alternaria japonica* were assigned randomly to subplots. ABI = plants inoculated with *A. brassicicola*; AJI = plants inoculated with *A. japonica*; ABS = plants indirectly inoculated by splashing of inoculum of *A. brassicicola*; AJS = plants indirectly inoculated by splashing of inoculum of *A. japonica*; NIH = naturally inoculated plants harvested.

9.4; SAS, Inc., Cary, NC, USA). Before analysis of variance (ANOVA), disease incidence (percentage of diseased leaves harvested) was transformed by calculating the arcsine of the square root, and marketable weight for the second harvest was transformed by base-10 logarithm. In the initial ANOVA, season, production type (organic or conventional), cultivar, pathogen species, and harvest were tested as fixed effects in the appropriate split-plot models, and block was tested as a random effect. Season nested within block, season, and production type nested within block, and season, production type, and cultivar nested within block were used as the error terms to test the effects of biofungicides, cultivars, and pathogen species, respectively. Because of significant ($P \leq 0.05$) interactions among many factors, subsequent ANOVAs were done by season and also by production type or pathogen species when interactions of these factors with cultivar also were significant. In addition, combined analyses by inoculation type were done with yields summed over the two harvests, and season, production type, and block considered random variables to be able to make overall conclusions about susceptibility and yield potential of cultivars (Schabenberger and Pierce 2002). Residuals from ANOVAs were plotted against the predicted mean with the RESIDUALPANEL option and examined for normality to judge model goodness of fit. Preplanned, single-degree-of-freedom contrasts were used to compare kale types. Comparisons among least-squares means were based on *t* tests calculated with the PDIFF option at $P = 0.01$. Cultivars were compared only within kale types. Means shown in tables and figures are back-transformed least-squares means.

Results

In all experiments, the main effects of cultivar were highly significant for disease and yield. All factors examined in this study, season, production type, *Alternaria* spp., and harvest, affected the responses of cultivars to disease or yield (Supplemental Table 1). Three-way interactions with cultivar were common, particularly for natural spread of inoculum.

Disease incidence on kale types and cultivars directly inoculated. When directly inoculated plants were harvested the first time in three experiments, organic and conventional production in the fall and organic production in the spring, the experiment-by-cultivar interaction was highly significant (Supplemental Table 1). The cultivar-by-pathogen interaction was significant for disease incidence only in fall conventional production ($P = 0.03$). In this experiment, disease incidence differed between *Alternaria* spp. only for one cultivar, Tronchuda Beira, the Portuguese kale, which had twice as many diseased leaves when inoculated with *A. japonica* as with *A. brassicicola* (Table 2).

Across all three experiments, Portuguese kale had greater disease incidence than lacinato kale ($P \leq 0.01$) (Table 2). In the fall conventional and spring organic experiments, Portuguese kale also had more disease than curly and Siberian kales. In both fall experiments, curly kale had more disease than lacinato kale.

In fall conventional production, only Siberian kale cultivars differed within kale type, and only when inoculated with *A. japonica*. ‘White Russian’ had a greater disease incidence than ‘Russian Royale’, which had disease incidence <1%. In fall organic production, no cultivars differed within kale types. In spring organic production, curly kale cultivars Curly Roja, Darkibor, and Winterbor had lower disease incidence than Oldenbor (Table 2). Siberian kale cultivars separated into two distinct groups: Red Russian and Russian Royale had lower disease incidence than Siberian, Siberian Dwarf, and White Russian.

For organic production, disease incidence was greater in the spring than in the fall for six cultivars: Oldenbor, Toscano, Siberian, Siberian Dwarf, White Russian, and Tronchuda Beira (Table 2).

When regrowth from previously cropped plants that had been directly inoculated was cut at the second harvest in the fall, the maximum disease incidence, 78%, was twice as great as the maximum disease incidence at the first harvest, 34%. All cultivars had disease incidence >20% at the second harvest except Curly Roja, whereas only Tronchuda Beira had this much disease at the first harvest (Tables 2 and 3). Across cultivars and production types, disease incidence was greater on plants inoculated with *A. japonica* 42.7% ± 1.9% (standard error), than with *A. brassicicola*, 36.5% ± 1.8%. Disease incidence on inoculated plants differed between production types (significant production-by-cultivar interaction), but only for two cultivars, Black Magic and Red Russian, which had more disease in conventional than organic production.

Some kale types and cultivars differed from each other. Similar to the first harvest, Portuguese kale had greater disease incidence than the other three kale types in both production systems (Table 3). In addition, Siberian kale had greater disease incidence than lacinato kale. In both production types, Curly Roja had lower disease incidence than all other curly kale cultivars. In organic production, Oldenbor had greater disease incidence than all other curly kale cultivars. Within Siberian kales, cultivar Red Russian had lower disease incidence than White Russian in organic production, and Siberian Dwarf had lower disease incidence than White Russian in conventional production.

Yields of kale types and cultivars directly inoculated. Marketable yield of kale types and cultivars directly inoculated with *A. brassicicola* or *A. japonica* was measured for one harvest of mature leaves in three experiments, organic and conventional production in the fall and organic production in the spring. The main effect of pathogen species was significant ($P = 0.0121$), whereas the cultivar-by-pathogen interaction was not (Table 2). Mean marketable weight was significantly lower for plants inoculated with *A. japonica*, 771 ± 18 cartons/ha, than for plants inoculated with *A. brassicicola*, 814 ± 18 cartons/ha.

The experiment-by-cultivar interaction was highly significant ($P = 0.0001$) (Supplemental Table 1). When the experiments were analyzed separately, pathogen species had no effects on yields, and the cultivar-by-pathogen interactions were not significant ($P \geq 0.07$) (Table 4).

In the fall experiments, Siberian kales and Portuguese kale yielded more than curly and lacinato kales. In the spring organic experiment, however, curly kales yielded more than Siberian kales. In both fall experiments, the hairy Siberian kale cultivars Siberian and Siberian Dwarf yielded more than smooth-leaved cultivars, but in the spring organic experiment, the reverse was observed. However, the smooth-leaved cultivar White Russian yielded as poorly as the two hairy-leaved cultivars. In the fall, cultivars Siberian and Siberian Dwarf yielded more than the other four Siberian kale cultivars in the organic and conventional experiments, respectively, while Red Russian and Russian Royale were among the lowest yielding Siberian cultivars. In the spring, the converse was observed, Red Russian and Russian Royale yielded more than Siberian, Siberian Dwarf, and White Russian.

In the fall experiments, the red curly kale ‘Curly Roja’ had a lower yield than all other curly cultivars in the organic field and a lower yield than ‘Blue Curled Scotch’ in the conventional field. In the spring organic experiment, cultivars Darkibor and Winterbor yielded more than Curly Roja and Oldenbor.

Disease incidence on kale types and cultivars naturally inoculated. At the first harvest of mature leaves, no black spot symptoms

Table 2. Incidence of black spot on 14 kale cultivars at the first harvest of mature leaves from plants inoculated with either *Alternaria brassicicola* or *Alternaria japonica* in Fall 2022 and Spring 2023.

		Fall conventional		Fall organic	Spring organic
Source of variation		*P* value		*P* value	*P* value
Cultivar		0.0001		0.0087	0.0001
Pathogen		0.2505		0.0035	0.0659
Cultivar × pathogen		0.0319		0.3902	0.5930
Contrast[i]					
Curly vs. Siberian		0.0001		0.0330	0.7673
Siberian vs. lacinato		0.9454		0.0169	0.0296
Portuguese vs. Siberian		0.0001		0.1738	0.0001
Curly vs. lacinato		0.0001		0.0001	0.0515
Portuguese vs. curly		0.0102		0.9123	0.0001
Portuguese vs. lacinato		0.0072		0.0061	0.0001
Siberian: hairy vs. smooth		0.0474		0.5383	0.0005
Pathogen		Disease incidence (percentage of diseased leaves by number)			
A. brassicicola				7.2 B[ii]	19.1 A
A. japonica				10.4 A	16.2 A
Cultivar	Type	*A. brassicicola*	*A. japonica*		
Blue Curled Scotch	Curly	9.5 bcdefgh[iii]	20.6 abc	9.8 abcd	17.1 cdef
Curly Roja	Curly	8.1 cdefgh	19.2 abcd	14.8 ab	14.6 defg
Darkibor	Curly	12.9 bcdefg	24.1 ab	11.1 abcd	15.0 defg
Oldenbor	Curly	17.2 abcde	18.2 abcde	8.9 abcd	27.8*[iv] abc
Winterbor	Curly	15.7 bcdef	12.7 bcdefg	17.2 a	12.1 efg
Black Magic	Lacinato	5.9 efghi	2.9 ghi	5.1 bcd	13.7* defg
Lacinato	Lacinato	4.7 fghi	3.1 ghi	3.2 d	9.0 fg
Toscano	Lacinato	6.5 defghi	7.6 cdefgh	4.1 cd	16.4* cdef
Red Russian	Siberian	6.5 defghi	3.1 ghi	7.8 abcd	7.5 fg
Russian Royale	Siberian	1.5 hi	0.6 i	3.5 cd	6.5 g
Siberian	Siberian	10.0 bcdefgh	4.4 fghi	8.0 abcd	23.9* bcde
Siberian Dwarf	Siberian	8.6 cdefgh	5.8 efghi	10.3 abcd	25.0* bcd
White Russian	Siberian	5.8 efghi	9.5 cdefgh	12.8 abc	31.4* ab
Tronchuda Beira	Portuguese	15.8 bcdef	33.7**[v] a	12.6 abcd	39.4* a

[i] The kale type listed first has a greater mean disease incidence than the kale type listed second, based on preplanned single-degree-of-freedom contrasts significant at the indicated *P* value.

[ii] Pathogen means within columns with the same uppercase letter do not differ significantly, Fisher's protected least significant difference tests, $P = 0.01$.

[iii] Cultivar means within columns with the same lowercase letters do not differ significantly, Fisher's protected least significant difference tests, $P = 0.01$.

[iv] Asterisks indicate the mean in spring is significantly greater than the mean in the fall organic experiment, $P = 0.01$. Comparisons of seasons are based on a combined preliminary analysis with both seasons (not shown).

[v] Double asterisks indicate the cultivar mean is significantly greater than the mean with the other pathogen in the fall conventional experiment, $P = 0.01$.

were found on noninoculated plants in either the organic or conventional experiments in Fall 2022. On the regrowth in the fall experiments, very little disease, <2% incidence, developed on naturally inoculated plants in the organic field, so comparisons among kale types and cultivars reflect disease development in the conventional field. Portuguese kale had a greater incidence than the other three kale types and all other cultivars (Table 3). Curly kales had more disease than lacinato kales. Within curly kales, cultivars Curly Roja and Winterbor had lower disease incidence than Oldenbor and Blue Curled Scotch. Within Siberian kales, cultivar Russian Royale had lower incidence than Siberian.

In Spring 2023, the production-by-cultivar interaction was not significant ($P = 0.58$), and disease incidence was slightly greater in conventional production, 10.2%, than in organic production, 6.9% ($P = 0.037$). Portuguese kale was more susceptible than the other three kale types. Cultivars differed only within curly kales, where Curly Roja and Winterbor again had lower disease incidence than Oldenbor (Table 3).

Yields of kale types and cultivars naturally inoculated. In both fall and spring, naturally inoculated plants yielded an overall mean across cultivars of 1.95 kg leaves per 1.3 m, or ∼1075 boxes/ha at the first harvest, and a quarter of that, 0.52 kg/1.3 m or 286 boxes/ha, at the second harvest.

In both seasons, kale types differed in yield at the first harvest when they were exposed to natural spread of inoculum of *Alternaria* spp. In the fall, there was no production type-by-cultivar interaction ($P = 0.83$), but in the spring this interaction was significant ($P = 0.0053$), because two curly kale cultivars and all three lacinato cultivars yielded more in the organic field than in the conventional field (Table 5).

In the fall, Siberian and Portuguese kales yielded more than curly and lacinato kales. Among Siberian kales, hairy cultivars yielded more than smooth-leaved cultivars. Cultivars Siberian, Siberian Dwarf, and White Russian had greater yields than Red Russian and Russian Royale. In addition, 'Red Russian' yielded more than 'Russian Royale'. Curly kales yielded more than lacinato kales. Among curly kales, Curly Roja had a lower yield than all other cultivars, and its yield also did not differ from the yield of any lacinato kale cultivar.

In the spring, Siberian kales yielded more than the other three kale types, which did not differ among each other. In addition, the hairy Siberian cultivars yielded more than the smooth-leaved types. Siberian Dwarf yielded significantly more than the other four Siberian cultivars.

Curly kale cultivars differed in both production types. 'Curly Roja' had low yields in both production types, lower than all other curly kale cultivars in the organic field and lower than cultivars Darkibor and Winterbor in the conventional field. In addition, 'Winterbor' yielded more than 'Oldenbor' in the conventional field.

Regrowth from plants cropped at the first harvest was harvested in the second harvest (Table 6). In the fall, the production type-by-cultivar interaction ($P = 0.0001$) was due to significant differences between production types for four cultivars. Cultivars Curly Roja and Russian Royale yielded more in the conventional field, whereas Siberian Dwarf and Tronchuda Beira yielded more in the organic field. In the spring, the production type main effect was significant but not the interaction. Mean yield in the organic field was 251 cartons/ha, but mean yield was only 89 cartons/ha in the conventional field, where plants appeared smaller than in the conventional field for unknown reasons.

In the fall organic and both spring experiments, Siberian kales yielded more than curly kales. In the fall conventional and both spring

Table 3. Incidence of black spot on regrowth of 14 kale cultivars at the second harvest on plants directly inoculated or naturally inoculated with *Alternaria brassicicola* or *Alternaria japonica* in Fall 2022.

	P value			
Source of variation	Directly inoculated		Naturally inoculated[i]	
Production	0.1161	—	0.0022	—
Cultivar	0.0001	—	0.0001	—
Production × cultivar	0.0113	—	0.0002	—
Pathogen (path)	0.0010	—	—	—
Production × pathogen	0.4481	—	—	—
Cultivar × pathogen	0.2591	—	—	—
Production × cv × path	0.7220	—	—	—
Contrast[ii]	Organic	Conventional	Organic	Conventional
Siberian vs. curly	0.0015	0.0015	0.5892	0.3567
Siberian vs. lacinato	0.0001	0.0104	0.3748	0.0721
Portuguese vs. Siberian	0.0004	0.0001	0.0007	0.0001
Curly vs. lacinato	0.1425	0.8282	0.6723	0.0114
Portuguese vs. curly	0.0001	0.0001	0.0003	0.0001
Portuguese vs. lacinato	0.0001	0.0001	0.0002	0.0001
Siberian: smooth vs. hairy	0.8199	0.0094	0.6119	0.1251
Cultivar	Disease incidence (percentage of diseased leaves by number)			
Blue Curled Scotch	32.4 efgh[iii]	45.5 bcdef	0.0 d	23.8 b
Curly Roja	4.2 i	14.9 hi	0.0 d	0.3 d
Darkibor	37.7 cdefg	34.4 defg	0.0 d	20.1 bc
Oldenbor	62.1 ab	51.9 bcde	0.2 d	21.1 b
Winterbor	20.9 gh	38.5 bcdefg	0.0 d	3.0 cd
Black Magic	21.0 gh	45.7 bcdef	0.0 d	0.3 d
Lacinato	21.7 gh	25.8 fgh	0.0 d	0.5 d
Toscano	29.9 efgh	40.7 bcdefg	0.0 d	5.7 bcd
Red Russian	24.6 fgh	47.7 bcde	0.0 d	8.5 bcd
Russian Royale	42.3 bcdef	50.4 bcde	0.0 d	0.0 d
Siberian	38.5 bcdefg	44.1 bcdef	0.3 d	6.4 bcd
Siberian Dwarf	42.7 bcdef	35.0 defg	0.0 d	20.8 b
White Russian	52.6 bcd	57.9 bc	0.1 d	10.2 bcd
Tronchuda Beira	61.7 ab	77.7 a	1.6 d	58.2 a

[i] Plants were located in the middle of the row between plants directly inoculated with *A. brassicicola* or *A. japonica* and black spot developed from natural spread of conidia.

[ii] The kale type listed first has a greater mean disease incidence than the kale type listed second, based on preplanned single-degree-of-freedom contrasts significant at the indicated *P* value.

[iii] Cultivar means within columns and within rows by inoculation with the same lowercase letters do not differ significantly, Fisher's protected least significant difference tests, $P = 0.01$.

experiments, Siberian and lacinato kales yielded more than Portuguese kale. Among Siberian kales, cultivars Red Russian, White Russian, and Siberian yielded more than Russian Royale in the fall organic experiment. In the spring experiments, 'Siberian' yielded more than 'White Russian'. In fall organic production, 'Toscano' yielded more than 'Black Magic', the only difference between lacinato cultivars observed in the study.

In the fall conventional experiment, curly kale cultivars Darkibor and Curly Roja yielded more than Oldenbor. In both production types in the spring, 'Oldenbor' had a lower yield than the other five curly kale cultivars due to high incidence of black spot. Cultivars Winterbor, Darkibor, and Blue Curled Scotch yielded more than Curly Roja.

Overall effects of kale types and cultivars. Because all factors interacted with cultivar (Supplemental Table 1), season, production type, and pathogen species were considered random effects in a final analysis to make conclusions about susceptibility and yield potential of cultivars affected with black spot. (Disease incidence and yield were summed across the two harvests for this analysis.) Portuguese kale had greater disease incidence than all other kale types and all other kale cultivars with both natural and direct inoculations (Fig. 3). In addition, curly kales had greater disease incidence than lacinato kales. With natural spread of inoculum, curly kale cultivars Curly Roja and Winterbor had lower disease incidence than Darkibor, and Curly Roja also had lower disease incidence than Oldenbor, but curly kale cultivars did not differ when directly inoculated. Similarly, with natural spread of inoculum but not direct inoculation, Siberian kale cultivar Russian Royale had lower disease incidence than the other Siberian cultivars except Red Russian, which had lower disease incidence than White Russian and Siberian Dwarf.

With natural spread of inoculum, 'Winterbor' curly kale and four of the Siberian kale cultivars yielded >1000 cartons/ha at the row spacing used in this study, but no cultivars did with direct inoculation (Fig. 4). Siberian kales yielded more than curly and lacinato kales with both inoculations. Red curly kale cultivar Curly Roja had the lowest yields, significantly lower than green kale cultivars Winterbor and Blue Curled Scotch. With natural spread of inoculum, cultivars Siberian and Siberian Dwarf had greater yields than Russian Royale, but yields of Siberian kale cultivars did not differ with direct inoculation.

Recovery of Alternaria spp. In the fall at the first harvest of inoculated plants in the organic field, both species were recovered at a high percentage, mainly from plants inoculated with that species. *A. brassicicola* and *A. japonica* were recovered from 73% and 86%, respectively, of subplots inoculated with each species, and from 4% and 2%, respectively, of subplots inoculated with the other species. Neither species was recovered from 15% of the subplots. By the second harvest, both species were recovered from most inoculated plants, although *A. japonica* was recovered from 71% of subplots inoculated with *A. japonica* and 55% of subplots inoculated with *A. brassicicola*, and *A. brassicicola* was recovered from 45% of subplots inoculated with *A. brassicicola* and 27% of subplots inoculated with *A. japonica*. Neither species was recovered from 12% of the subplots. No diseased leaves were found on naturally inoculated plants at the first harvest, and, because only five diseased leaves were found at the second harvest in the organic field, lesions were not cultured.

In the conventional field in the fall, both species also were recovered primarily from the plants inoculated with that species. *A. brassicicola* and *A. japonica* were recovered from 84% and 90% of subplots, respectively, inoculated with each species, and from 2% and no subplots inoculated with the other

Table 4. Yield of 14 kale cultivars affected with black spot at the first harvest of mature leaves from plants inoculated with either *Alternaria brassicicola* or *Alternaria japonica* in Fall 2022 and Spring 2023.

Source of variation		*P* value		
		Fall conventional	Fall organic	Spring organic
Cultivar		0.0001	0.0001	0.0001
Pathogen		0.2212	0.071	0.4495
Cultivar × pathogen		0.0852	0.9065	0.3724
Contrast[i]				
Curly vs. Siberian		0.0001	0.0001	0.0062
Siberian vs. lacinato		0.0001	0.0001	0.2039
Portuguese vs. Siberian		0.0027	0.7282	0.2054
Curly vs. lacinato		0.1922	0.0157	0.2534
Portuguese vs. curly		0.0474	0.0001	0.7315
Portuguese vs. lacinato		0.0075	0.0001	0.6896
Siberian: hairy vs. smooth		0.0001	0.0001	0.0001
Cultivar	Type	Marketable weight (11.3-kg cartons/ha)		
Blue Curled Scotch	Curly	762 cd[ii]	808 cd	853 bcd
Curly Roja	Curly	556 f	396 g	586 def
Darkibor	Curly	665 def	711 def	1027 ab
Oldenbor	Curly	662 def	730 cde	704 cde
Winterbor	Curly	685 cdef	770 cde	1227 a
Black Magic	Lacinato	664 def	490 fg	890 bc
Lacinato	Lacinato	570 ef	543 efg	867 bc
Toscano	Lacinato	608 def	671 def	697 cdef
Red Russian	Siberian	877 bc	762 cde	1192 a
Russian Royale	Siberian	702 cdef	768 cde	1239 a
Siberian	Siberian	1014 b	1369 a	453 ef
Siberian Dwarf	Siberian	1226 a	1090 b	429 f
White Russian	Siberian	1024 b	951 bc	433 ef
Tronchuda Beira	Portuguese	785 cd	964 bc	852 bcd

[i] The kale type listed first has a greater mean disease incidence than the kale type listed second, based on preplanned single-degree-of-freedom contrasts significant at the indicated *P* value.

[ii] Cultivar means within columns with the same lowercase letters do not differ significantly, Fisher's protected least significant difference tests, $P = 0.01$.

species. Neither species was recovered from 25% of the subplots. By the second harvest, *A. japonica* was the dominant species on all plants harvested, recovered from 96% and 77% of the subplots inoculated with *A. japonica* and *A. brassicicola*, respectively. *A. brassicicola* was recovered from 34% of the subplots inoculated with *A. brassicicola* and 20% of subplots with *A. japonica*. Only two subplots yielded neither species. On naturally inoculated plants, no leaves had black spot lesions at the first harvest. At the second harvest, *A. japonica* also was the dominant species, recovered from 55% of the subplots, whereas *A. brassicicola* was recovered from 27% of the subplots, and 41% of the subplots yielded neither species.

In the spring, recovery was low from plants in the organic field directly inoculated, as only 39% and 21% of the subplots yielded *A. brassicicola* and *A. japonica*, respectively, when inoculated with these species. *A. brassicicola* and *A. japonica* were also recovered from 7% and 11%, respectively, of the subplots inoculated with the other species. Neither species was recovered from 52% of the subplots. Recovery also was low from naturally inoculated plants in this field, as each species was recovered from only 13% of the subplots, and only together in one of 132 subplots. Neither species was found in 77% of the subplots. Lesions were not cultured in the conventional field in spring.

Discussion

In all experiments, the main effects of cultivar were highly significant for disease and yield. All factors examined in this study, season, production type, *Alternaria* spp., and harvest, affected the responses of cultivars to disease or yield. Three-way interactions with cultivar were common, particularly for natural spread of inoculum (Supplemental Table 1). As a group, Siberian kales yielded more overall than curly and lacinato kales. The same pattern of differences in yields of kale types was observed in a Colorado study with cultivars Red Russian, Winterbor, and Dinosaur as representatives of the three kale types, respectively (Yoder and Davis 2020). In Kentucky, three of the Siberian kale cultivars tested in the current study, Siberian, White Russian, and Red Russian, also yielded more than curly and lacinato kale cultivars in the absence of foliar diseases (Coolong et al. 2013). In that study, conducted in spring and fall seasons in two years, year and season also interacted with cultivar.

Among the five curly kale cultivars tested in this study, Winterbor was notable for its tendency to have lower incidence of black spot and higher marketable yields. It was the only curly kale cultivar to yield >1000 cartons/ha across two harvests. In all experiments with natural spread of *Alternaria* inoculum, 'Winterbor' had lower incidence and greater yields than 'Darkibor', the most widely grown curly kale cultivar in South Carolina (Fig. 4). 'Winterbor' appears to be a good choice for kale production in South Carolina and other parts of the southeastern United States, as it also was the most productive cultivar of four curly kales evaluated in organic production in Kentucky (Coolong et al. 2013).

In general, red curly kale cultivar Curly Roja yielded the least, not just among curly kale cultivars but across all 14 cultivars. Plants and leaves were shorter than other cultivars, even at low disease incidence. Another red curly kale, 'Redbor', also yielded the least among not only curly kales but among all kale cultivars and types tested in organic production in Kentucky (Coolong et al. 2013). Red curly kale is used in chopped, bagged kale mixes to add color and interest, but other than this specific use, it is unlikely that 'Curly Roja' would yield enough to produce an acceptable net return, even though it was one of the least susceptible cultivars with natural spread of inoculum.

Green curly kale cultivar Oldenbor tended to have greater disease incidence than other curly kale cultivars when cultivar differences were observed. 'Oldenbor' is grown in South Carolina primarily for early fall harvest because it is advertised as having resistance to yellows, which is critical when kale is planted in summer into warm soils infested with *Fusarium oxysporum* f. sp. *conglutinans* (Farnham et al. 2001). Because black spot can be managed with fungicides, whereas yellows cannot, growers will likely continue to plant 'Oldenbor' despite its increased susceptibility to black spot, in part because yields of 'Oldenbor' were at least as good as most other curly kale cultivars (Dutta et al. 2020).

The commonly cultivated Siberian kale, 'Red Russian', showed average to below average disease incidence, even when directly inoculated, and average to above average marketable yields overall. Russian Royale, a morphologically similar cultivar with shiny

Table 5. Yield of healthy leaves at the first harvest of 14 kale cultivars with black spot due to natural spread of inoculum.

		Fall	Spring	
Source of variation		*P* value		
Production		0.1512	0.7192	
Cultivar		0.0001	0.0001	
Production × cultivar		0.8341	0.0053	
Contrast[i]		Combined	Organic	Conventional
Siberian vs. curly		0.0001	0.0001	0.9894
Siberian vs. lacinato		0.0001	0.0001	0.7870
Siberian vs. Portuguese		0.0208	0.0001	0.6642
Curly vs. lacinato		0.0001	0.0145	0.7997
Portuguese vs. curly		0.0031	0.3434	0.6612
Portuguese vs. lacinato		0.0001	0.4827	0.5608
Siberian: hairy vs. smooth		0.0001	0.0001	0.0247
Cultivar	Type	Marketable weight (11.3-kg cartons/ha)		
Blue Curled Scotch	Curly	655 bcd[ii]	754 bcde	689 abc
Curly Roja	Curly	447 f	212 f	394 c*[iii]
Darkibor	Curly	632 bcde	769 bcde	1067 ab
Oldenbor	Curly	695 bcd	729 bcde	446 bc
Winterbor	Curly	716 bc	860 bc	1193 a*
Black Magic	Lacinato	451 f	566 de	848 abc*
Lacinato	Lacinato	474 ef	509 e	779 abc*
Toscano	Lacinato	535 def	500 e	561 bc*
Red Russian	Siberian	802 b	801 bcd	663 abc
Russian Royale	Siberian	625 cde	852 bcd	667 abc
Siberian	Siberian	1030 a	988 b	915 abc
Siberian Dwarf	Siberian	995 a	1345 a	993 ab
White Russian	Siberian	1075 a	919 b	556 bc
Tronchuda Beira	Portuguese	785 bc	586 cde	831 abc

[i] The kale type listed first has a greater mean disease incidence than the kale type listed second, based on preplanned single-degree-of-freedom contrasts significant at the indicated *P* value.

[ii] Means within columns with the same letters do not differ significantly, Fisher's protected least significant difference tests, $P = 0.01$.

[iii] Means with asterisks are significantly greater than the mean in the other production system in the spring, Fisher's protected least significant difference tests, $P = 0.01$.

red leaves, also was less susceptible than many other cultivars but had slightly lower yields than 'Red Russian'. Thus, 'Red Russian' is likely the best Siberian kale for most producers. In organic production in Kentucky, it was among the most productive cultivars overall (Coolong et al. 2013). Because it consistently yielded more than 'Curly Roja', it could be used to provide color in kale salad mixes.

The Siberian kale cultivars Siberian and Siberian Dwarf, which had similar morphology, developed fine hairs on the leaf blades and petioles once leaves matured. Hairy leaves are also typical of wild *B. oleracea* spp. (Cai et al. 2022). Although these two cultivars produced a large marketable biomass in experiments with natural inoculum spread, the hairs may make these cultivars unsuitable for fresh markets. These two cultivars also had relatively high percentages of diseased leaves when plants were directly inoculated.

The Portuguese kale cultivar Tronchuda Beira was included to increase the types of kale represented in this study. Its morphology was decidedly unlike kale and more like collard (*B. oleracea* var. *viridis*) because the wide, flat light green leaves had entire margins (Cai et al. 2022; Hahn et al. 2022). It was uniformly the most susceptible cultivar in this study and, consequently, had low marketable weight. This cultivar, the only Portuguese kale we found, is not recommended where black spot is a risk.

None of the 14 cultivars could be considered tolerant (Pagán and García-Arenal 2018; Schafer 1971). Tolerance in kale could occur, for example, if black spot affected only the lowest leaves on certain cultivars, and more midsized leaves remained healthy. Although some cultivars (e.g., Winterbor) tended to have low disease incidence and high yields in some experiments, there was no overall correlation between disease and yield (data not shown). The concept of tolerance may be more applicable to fruiting vegetables, where disease occurs directly on the consumed portion of the crop, than leafy vegetables.

Main effects of season were significant for incidence of black spot with both direct and indirect inoculations, but season was not a significant source of variation for marketable yield. Black spot was more prevalent in spring than in fall, particularly on directly inoculated plants. The main environmental difference between spring and fall was warmer air temperature in the spring, because misting provided leaf wetness in both seasons.

Main effects of production type were significant with natural spread of inoculum but not with direct inoculation. Apparently, the greater concentration of inoculum when plants were sprayed with a conidial suspension was a more important factor affecting black spot than the indirect effects of production type. When differences between production types were observed, disease incidence was slightly greater in conventional production, and marketable weight was greater in organic production for first and second harvests. In each production type, rates of fertilizers were calculated to deliver 22.7 $kg \cdot ha^{-1}$ nitrogen and 45.4 $kg \cdot ha^{-1}$ potassium (Kemble et al. 2024). The main difference, therefore, between organic and conventional production was the form of nitrogen added preplant. The organic granular fertilizer included nitrogen derived from feather meal, meat and bone meal, and blood meal, which, according to the manufacturer, was slowly available over 7 to 8 weeks. The conventional fertilizer supplied nitrogen as ammonium sulfate, urea, and diammonium phosphate, the ammonium being water-soluble. In previous studies, conventional nitrogen applications reduced severity of Alternaria leaf diseases on field-grown carrot, potato, and cotton (Abuley et al. 2019; Blachinski et al. 1996; Westerveld et al. 2008). Foliar concentrations of nitrogen were not measured in this study. It is possible, though, that the more persistent organic nitrogen sources increased foliar nitrogen content compared with the more readily available but less persistent conventional nitrogen sources. Overall, organic production was less conducive to black spot and had a beneficial effect on marketable yield of kale.

Across three experiments, *Alternaria* spp. differentially affected yield, but disease incidence was similar between *A. brassicicola* and *A. japonica* (Tables 2 and 7). In a previously published study, incidence of black spot caused by *A. brassicicola* or *A. japonica* also did not differ, and only minor effects on yield were observed (Keinath 2024). *A.*

Table 6. Yield of healthy leaves at the second harvest of 14 kale cultivars with black spot due to natural spread of inoculum of *Alternaria* species.

Source of variation	Fall *P* value	Spring *P* value
Production	0.9142	0.0001
Cultivar	0.0001	0.0001
Production × cultivar	0.0001	0.1146

Contrast[i]	Organic	Conventional		Combined	
Siberian vs. curly	0.0019	Siberian vs. curly	0.0647	Siberian vs. curly	0.0001
Siberian vs. lacinato	0.0001	Siberian vs. lacinato	0.1491	Siberian vs. lacinato	0.1306
Siberian vs. Portuguese	0.5496	Siberian vs. Portuguese	0.0003	Siberian vs. Portuguese	0.0001
Curly vs. lacinato	0.0059	Lacinato vs. curly	0.8623	Lacinato vs. curly	0.0052
Portuguese vs. curly	0.0157	Curly vs. Portuguese	0.0068	Curly vs. Portuguese	0.016
Portuguese vs. lacinato	0.0001	Lacinato vs. Portuguese	0.0075	Lacinato vs. Portuguese	0.0001
Siberian: hairy vs. smooth	0.8204	Siberian: smooth vs. hairy	0.0039	Siberian: hairy vs. smooth	0.0261

Cultivar	Type	Marketable weight (11.3-kg cartons/ha)		
Blue Curled Scotch	Curly	172 abc[ii]	149 ab	174 abc
Curly Roja	Curly	128 cd	220* a[iii]	80 cd
Darkibor	Curly	155 bc	134 ab	139 abc
Oldenbor	Curly	146 bc	89 b	26 e
Winterbor	Curly	160 bc	219 a	302 a
Black Magic	Lacinato	96 d	143 ab	199 ab
Lacinato	Lacinato	127 cd	174 a	209 ab
Toscano	Lacinato	157 bc	155 ab	129 bcd
Red Russian	Siberian	239 a	255 a	215 ab
Russian Royale	Siberian	130 cd	230 a	233 ab
Siberian	Siberian	197 ab	225 a	316 a
Siberian Dwarf	Siberian	178* abc	89 b	277 ab
White Russian	Siberian	198 ab	201 a	130 bcd
Tronchuda Beira	Portuguese	197* ab	91 b	60 de

[i] The kale type listed first has a greater mean disease incidence than the kale type listed second, based on preplanned single-degree-of-freedom contrasts significant at the indicated *P* value.

[ii] Means within columns with the same letters do not differ significantly, Fisher's protected least significant difference tests, $P = 0.01$.

[iii] Means with asterisks are significantly greater than the mean in the other production system in the same season, Fisher's protected least significant difference tests, $P = 0.01$.

japonica tolerates lower minimum temperatures than *A. brassicicola* for conidial germination (13 vs. 15 °C, respectively), infection (17 vs. 19 °C), and subsequent sporulation on infected tissue (13 vs. 19 °C) (Degenhardt et al. 1982). This tolerance of lower temperatures may explain why *A. japonica* was recovered from a greater percentage of plots in the fall than *A. brassicicola* was. Temperatures in the fall experiments, however, seem to have been favorable for both species to cause black spot. Thus, the presence of *A.*

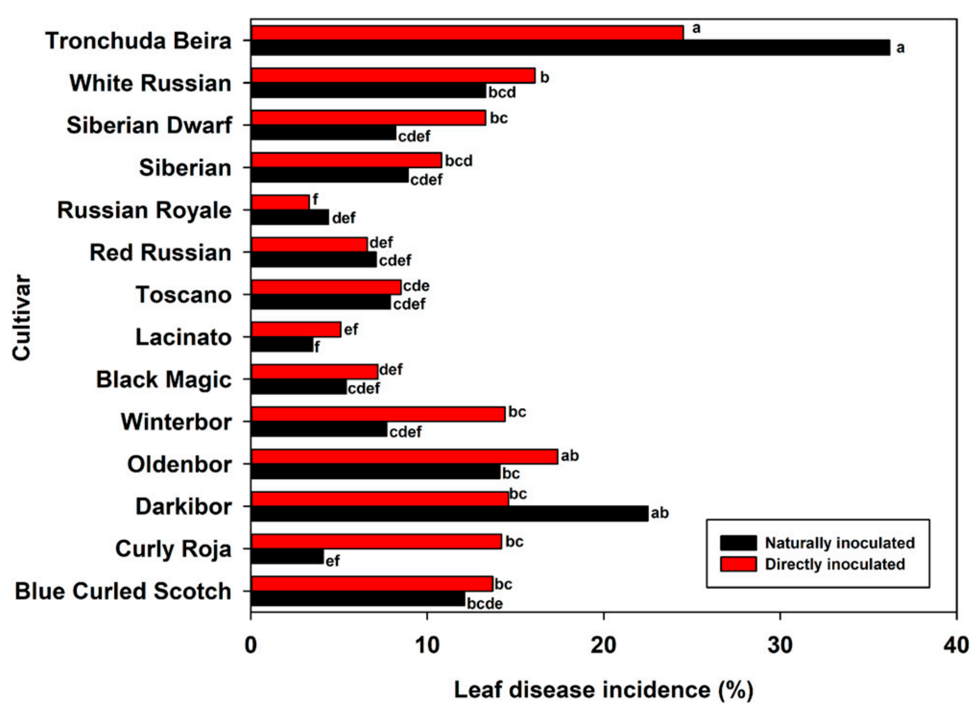

Fig. 3. Overall mean black spot incidence on kale cultivars averaged across both *Alternaria* spp., organic and conventional production, and the Fall 2022 and Spring 2023 experiments. Means with the same letters within inoculation type do not differ significantly, Fisher's protected least significant difference tests, $P = 0.01$.

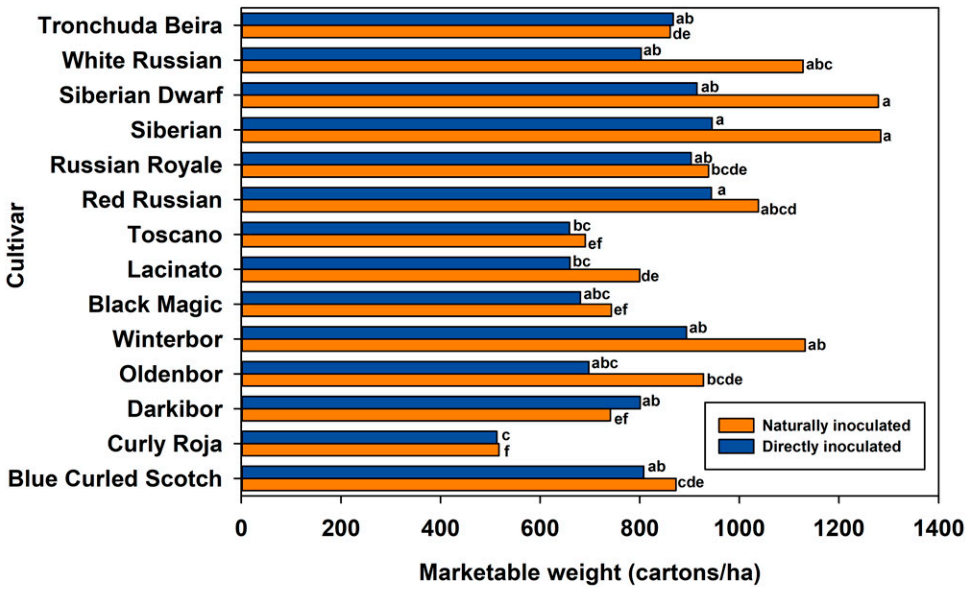

Fig. 4. Overall mean marketable weight of kale cultivars averaged across both *Alternaria* spp., organic and conventional production, and the Fall 2022 and Spring 2023 experiments. Means with the same letters within inoculation type do not differ significantly, Fisher's protected least significant difference tests, $P = 0.01$.

Table 7. Overall mean susceptibility to black spot and overall mean yield of kale cultivars exposed to inoculum of *Alternaria brassicicola* or *Alternaria japonica* and grown with organic and conventional production in Fall 2022 and Spring 2023.[i]

	P value				
	Disease incidence			Marketable wt	
Source of variation	Naturally inoculated	Directly inoculated[ii]		Naturally inoculated	Directly inoculated[ii]
Cultivar	0.0001	0.0001		0.0001	0.0002
Pathogen	–	0.1619		–	0.0152
Cultivar × pathogen	–	0.1393		–	0.2253
Contrast[iii]			Contrast[iii]		
Curly vs. Siberian	0.0626	0.0001	Siberian vs. curly	0.0001	0.0007
Siberian vs. lacinato	0.0992	0.0185	Siberian vs. lacinato	0.0001	0.0001
Portuguese vs. Siberian	0.0001	0.0001	Siberian vs. Portuguese	0.0004	0.6602
Curly vs. lacinato	0.0012	0.0001	Curly vs. lacinato	0.0665	0.1536
Portuguese vs. curly	0.0001	0.0001	Curly vs. Portuguese	0.7606	0.1211
Portuguese vs. lacinato	0.0001	0.0001	Portuguese vs. lacinato	0.1468	0.0183
Siberian: hairy vs. smooth	0.7722	0.0064	Siberian: hairy vs. smooth	0.0001	0.4814
oleracea vs. *napus*	0.0442	0.0006	*napus* vs. *oleracea*	0.0001	0.0001

[i] Season, production type, and block were treated as random variables in the analysis of variance. Marketable weight and numbers of healthy and diseased leaves were summed over two harvests.

[ii] The three experiments from which data were collected were organic and conventional production in fall and organic production in spring.

[iii] The kale type listed first has a greater mean than the kale type listed second, based on preplanned single-degree-of-freedom contrasts significant at the indicated *P* value.

japonica in the southeastern United States does not necessarily mean that black spot will be more problematic in cool growing conditions (i.e., on overwintered crops) than in warm weather.

Strictly grading leaves into symptomless and symptomatic categories was based on the low tolerance for decay in wholesale markets and grocery stores, 1% per USDA standards for kale, and repeated observations that black spot can develop on symptomless leaves when they were stored at high relative humidity at standard postharvest temperatures, ≈4.4 °C (Keinath, Silva, and Turner, unpublished data) (Johnson et al. 2018; US Department of Agriculture, Agricultural Marketing Service 2008). In addition, *A. brassicicola* was recovered from several diseased pieces of commercial chopped, bagged kale stored beyond the recommended interval (Toporek et al. 2024). Yields of some Siberian kale cultivars could have been greater if ≤ % discoloration due to black spot had been considered marketable, as black spot lesions tended to be smaller on Siberian kales than other kale types. Even with strict grading, the yields of Siberian kales often were greater than yields of other kale types, so it is unlikely that a more lenient grading scale would have affected these results.

When plants were harvested a second time, disease incidence was noticeably greater and yields were much lower than at the first harvest, even though the leaves harvested were about the same age as the leaves cropped at the first harvest. It is well known that older leaves of brassicas are more susceptible to *Alternaria* spp. than younger leaves (Keinath 2024; Tewari and Buchwaldt 2007). The regrowth leaves, however, seemed to be physiologically as old as the plants from which they were cut, based on their susceptibility to black spot. Growers should be aware of the increased risk of black spot on leaves produced by cropped plants and adjust their fungicide applications accordingly (e.g., use 7-d application intervals, apply the maximum rate, or choose fungicides that are the most effective) (Dutta et al. 2020).

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