Variety Trials

Cauliflower Yield and Susceptibility to Alternaria Leaf Spot under New York Field Conditions

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Summary. **Twelve commercial cauliflower (*Brassica oleracea* var. *botrytis*) varieties were evaluated for horticultural traits and susceptibility to alternaria leaf spot (*Alternaria brassicicola*) at the New York State Agricultural Experiment Station in Geneva, NY, in 2014 and 2015. Data including total yield, curd weight, curd width, plant height, days to maturity, and length of harvest were collected for each variety. A duplicate trial was planted in each year and inoculated with *A. brassicicola*, the causal agent of alternaria leaf spot, and the percentage of disease was assessed for each commercial cauliflower variety. Most of the commercial varieties were similar in susceptibility to disease and yield. 'Artica' and 'Apex' were ranked among the highest yielding varieties each year of the trial. The varieties 'Graffiti' and 'Violet Queen', both of which produce purple curds, had significantly less alternaria leaf spot compared with other varieties. Differences were seen between the 2 years of the trial in performance of individual varieties as influenced by temperatures during the growing season. This study demonstrates that some cauliflower varieties perform better than others under New York State growing conditions.**

In New York, cauliflower production was estimated at a value of $2.6 million on a total of 470 acres in 2014 [U.S. Department of Agriculture (USDA), 2015a]. Although the majority of cauliflower production occurs in California and Arizona, there is still strong interest in cauliflower production in New York State especially with the local food movement and consumers' interest in locally grown produce (USDA, 2015b). Cauliflower is an excellent cool season crop for New York vegetable growers and has recently increased in popularity. The consumption of cauliflower increased to 1.9 lb per capita for 2014 from 1.7 lb per capita in 2013 (USDA, 2015c). Little is known about how different cauliflower varieties perform in New York State, as each growing region has unique factors such as disease pressure and climate conditions that influence how varieties perform.

One of the main foliar diseases affecting cauliflower and other brassica crops such as cabbage (*Brassica oleracea* var. *capitata*), brussels sprout (*B. oleracea* var. *gemmifera*), and kale (*B. oleracea* var. *acephala*) is alternaria leaf spot caused by the fungus *Alternaria brassicicola*. The disease causes lesions on the leaves and curd resulting in a damaged and unmarketable crop. *Alternaria brassicicola* thrives under cool, moist conditions which typically occur in the fall during the primary cauliflower growing season for New York State. Optimal conditions for sporulation of *A. brassicicola* include a relative humidity of at least 87% and temperatures between 20 and 30 °C (Humpherson-Jones and Phelps, 1989). Alternaria leaf spot starts as pinpoint brown or black specks on the leaves, which enlarge to form circular lesions with concentric rings creating a distinct bull's eye lesion or target spot as seen in Fig. 1A. The black specks can also appear on the cauliflower curds and can enlarge over time as seen in Fig. 1B. These unsightly black specks can greatly reduce the quality and marketability of the curd.

For a cauliflower curd to be considered the highest grade (USDA No. 1), spots, "when added together cannot exceed that of a circle three-eighths of an inch in diameter" (USDA, 1968). Cauliflower curds must not only be free from disease but also from abnormalities known as

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha^{-1}	0.8922
0.0254	mil	mm	39.3701
33.9057	oz/yard^2	g·m^{-2}	0.0295
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

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Fig. 1. Disease and abnormalities of cauliflower: (A) alternaria leaf spot lesion on a cauliflower leaf, (B) alternaria leaf spot on a cauliflower curd, (C) fuzziness (bracting) seen on 'Candid Charm' cauliflower during the 2015 growing season.

fuzziness and riciness, with a minimum diameter of 4 inches (USDA, 1968). Some abnormalities seen in cauliflower are the result of temperature changes after curd initiation.

Curd initiation typically occurs when cauliflower plants reach maturity defined by a critical number of leaves along with an exposure to cooler temperatures or vernalization period (Hand and Atherton, 1987). Wurr et al. (1993) determined that the vernalization period for summer and autumn cauliflower occurs between 9 and 21 °C. Changes in temperatures after curd initiation can result in abnormalities such as fuzziness and riciness. Fuzziness, also referred to as bracting, occurs when small leaves, which can be white in appearance, appear in the curd giving an overall fuzzy appearance to the curd as seen in Fig. 1C. Fuzziness occurs as the result of high temperatures (above 15 °C) just after curd initiation (Grevsen et al., 2003). Riciness, another abnormality, occurs when small flower buds form on the surface of a curd and is the result of high temperatures in combination with low temperatures early in curd development (Grevsen et al., 2003). Grevsen et al. (2003) found that cauliflower plants grown at 20 °C followed by a treatment of 8 °C resulted in 100% riciness. Cauliflower quality and yield is influenced by temperature, and each variety can perform differently under various conditions. Growers need to know how cauliflower performs under various temperatures and disease prevalence to plant the appropriate varieties for their field site. The objective of the present study was to evaluate commercially available cauliflower varieties for yield, quality, and susceptibility to alternaria leaf spot under New York field conditions.

Materials and methods

Field sites. This study was conducted over the course of two growing seasons at Cornell University's New York State Agricultural Experiment Station in Geneva, NY. In 2014, the study was conducted in a field composed of Honeoye loam soil, while in 2015, the study was conducted in a field composed of the Lima loam soil. Each growing season, two identical trials were planted side by side. One trial was inoculated with *A. brassicicola* to examine disease susceptibility among varieties, and the second trial examined the horticultural and harvest traits of each variety. The inoculated trial was located downwind from the uninoculated trial, with a buffer of at least 18 ft between the two trials. Each trial used a randomized complete block design with four replications. Each row was covered with 1.25-mil black polyethylene plastic mulch (Filmtech Corp., Allentown, PA) creating rows 3 ft wide on 6-ft centers. Drip tape (12-inch spacing, 10-mil, 0.45 gal/min per 100 ft flow rate; Torro, Bloomington, MN) was laid under the mulch. Weed cloth (3.5-oz/yard^2 brown groundcover; Dewitt Co., Sikeston, MO) was laid between rows to reduce the number of weeds. When the plastic mulch was laid, a banded application of 30 lb/acre 10N–4.4P–8.3K fertilizer (JR Peters, Allentown, PA) was applied. Fertilizer amounts were applied according to common practices for field studies.

Cauliflower transplants. Twelve commercial cauliflower varieties were selected for the trial based on input from area growers (Table 1). All varieties chosen were hybrids with the exception of 'Amazing' which is an open-pollinated variety. Varieties were chosen to cover a range of harvest dates and colors. Varieties 'Candid Charm' and 'Snow Crown' are advertised as early-season varieties with days to harvest (DTH) ranging from 50 to 65 d, whereas 'Artica' and 'Apex' are advertised as late-season varieties with DTH ranging from 80 to 100 d. The remaining varieties are advertised as main season varieties with DTH ranging from 65 to 90 d. A few colored varieties 'Cheddar' (orange), 'Graffiti' (purple), and 'Violet Queen' (purple) were also included in the trial.

Cauliflower transplants were started on 5 June 2014 and 1 June 2015 and grown in a greenhouse with natural and supplemental lighting. The transplants were fertilized twice with 24N–3.5P–13.3K water-soluble fertilizer (Scotts Miracle-Gro, Marysville, OH) at the labeled rate before being placed in the field. The plants were placed outside in coldframes 1 week before planting. On 17 July 2014 and

Table 1. Area under the disease progress curve (AUDPC) values for disease severity of cauliflower plants growing in the field inoculated with *Alternaria brassicicola* for 2014 and 2015 in Geneva, NY.

	AUDPC[z]	
Variety	2014	2015
Amazing	185.2 bc	140.6 abc
Apex	168.0 abc	149.9 bc
Artica	169.0 abc	142.2 abc
Candid Charm	154.8 abc	146.9 abc
Cassius[y]	218.0 c	—
Cheddar	143.0 abc	132.8 ab
Fremont	218.7 c	153.2 bc
Graffiti	117.2 ab	126.8 ab
Minuteman	199.5 c	188.7 c
Snow Crown	185.6 bc	246.3 d
Violet Queen	101.0 a	92.7 a
White Sails	160.4 abc	160.3 bc

[z]AUDPC values are the means of four replicates. Means followed by the same letter within each experiment are not significantly different using the Tukey–Kramer honestly significant difference ($P \leq 0.05$).
[y]'Cassius' was omitted from the 2015 trial because its seed could not be obtained.

8 July 2015, cauliflower seedlings were transplanted in the field in a double row with 18 inches between each plant. Blocks were planted in eight plant plots per variety with an 18-inch buffer between varieties. The insecticide chlorantraniliprole (Coragen; DuPont, Wilmington, DE) was applied as a drench at the labeled rate (0.065 lb/acre a.i.) to the plants the day after planting to control insect pests. In 2014, an application of *Bacillus thuringiensis* (Agree; Certis USA, Columbia, MD) was applied at the labeled rate (1 lb/acre a.i.) on 2 Sept. to provide additional control of insect pests. No further insecticide applications were needed in 2015 due to low insect pressure.

Inoculated trial. New York State isolates of *A. brassicicola* (1138A and 1153C both collected from diseased cabbage) were used to inoculate the plants both years. The isolates were grown on potato dextrose agar under fluorescent lights for 12 h/d for 1–2 weeks. Plates were flooded with distilled water, and conidia were released using an L-shaped sterile spreader. The concentration of conidia was determined using a hemocytometer. Cauliflower plants were inoculated twice per growing season in both 2014 and 2015. The first inoculation was made after plants had been in the field for 1 month and before curds had formed. A conidial suspension (10^5 conidia/mL) was applied until runoff using a 5-gal hand pump backpack sprayer (Solo, Newport News, VA). A second application was made 1 week after the first inoculation using the same method. Plants were evaluated for the presence of alternaria leaf spot twice weekly for 3–4 weeks following inoculation. Disease ratings were taken as percentage of diseased tissue for the entire varietal plot.

Noninoculated trial. The noninoculated trial was planted to compare horticultural traits. Harvest of the noninoculated trial began ≈2 months after transplanting (mid-September) and continued until the end of October. When curds reached ≈5 inches in diameter, inner leaves were tied up with elastic bands around the curds for blanching. Curds remained tied until they reached a harvestable size, typically 4 to 7 d. Curds were harvested either once or twice weekly. Before the curd was harvested, plant height was measured from soil line to the tip of the most mature inner leaf. Cauliflower was harvested by cutting flush at the base of the curd. Weight and width of each curd was collected and recorded at harvest. Length of harvest and days to maturity were also calculated for each variety.

Weather. Weather data were obtained from the Vegetable Crops Farm weather station at the New York State Agricultural Experiment Station. The 2014 average daily maximum temperatures were 76 °F (17–31 July), 76 °F (1–31 Aug.), 72 °F (1–30 Sept.), and 62 °F (1–23 Oct.), while the average daily minimum temperatures for the same periods were 57, 57, 50, and 46 °F, respectively. The 2015 average daily maximum temperatures were 78 °F (8–31 July), 77 °F (1–31 Aug.), 76 °F (1–30 Sept.), and 58 °F (1–23 Oct.), while the average daily minimum temperatures for the same periods were 60, 59, 56, and 40 °F, respectively. Mean daily temperatures were used to calculate growing degree days (GDD) from transplanting until harvest with a base of 50 °F. Total monthly rainfall for 2014 was 5.15, 3.57, 1.33, and 2.19 inches for 17–31 July, 1–31 Aug., 1–30 Sept., and 1–23 Oct., respectively. Total monthly rainfall for 2015 was 3.45, 2.63, 4.84, and 1.98 inches for 8–31 July, 1–31 Aug., 1–30 Sept., and 1–26 Oct., respectively.

Statistical analysis. The R statistical software (version 3.1.3; RStudio Team, 2015) was used to perform all statistical testing. The area under the disease progress curve (AUDPC) for each cauliflower variety was calculated from the disease severity ratings using Excel (Microsoft, Redmond, WA) (Cooke et al., 2006). The lme4 R package (Bates et al., 2015) was used to conduct an analysis of variance (ANOVA) on a mixed effects model on the AUDPC data. Cauliflower varieties were considered fixed effects and replications were considered random effects. Once variety effects were determined to be significant by ANOVA ($P < 0.05$), means were separated with the Tukey–Kramer honestly significant difference method ($\alpha = 0.05$) using the lsmeans R package (Lenth, 2016). Total yield, curd weight, curd width, plant height, GDD, and harvest span were also analyzed using ANOVA and Tukey–Kramer's honestly significant difference as described above. All data were analyzed separately for each year of the trial.

Results

Disease severity. The commercial cauliflower varieties tested varied in their susceptibility to alternaria leaf spot after being inoculated twice per growing season with *A. brassicicola*. All varieties inoculated displayed disease symptoms in both 2014 and 2015. During both years, 'Violet Queen' had the least amount of disease, followed by 'Graffiti', 'Artica', 'Candid Charm', and 'Cheddar' (Table 1). These varieties did not differ significantly in either 2014 or 2015. 'Violet Queen' had significantly less disease than 'Snow Crown', 'Fremont', and 'Minuteman' in both 2014 and 2015 (Table 1).

Yield and plant height. There were relatively few statistically significant differences in total yield and individual curd size (Table 2). 'Artica' was the highest yielding variety in 2014 and produced the largest curds both by weight and width in that same year. 'Artica' yielded fewer curds in the 2015 growing season as less than 50% of the plants produced harvestable curds by the end of October. The remaining plants either did not form curds or the curds were at a very immature state even though the plants were fully grown. In 2015, 'Apex' produced the largest curds and had the highest yield; however, it was not statistically different from several other varieties (Table 2). Overall, the total yield and curd size in 2015 was reduced for all varieties compared with the previous year's growing season. In both years of the trial, 'Artica', 'Apex', and 'Fremont' had yields that were significantly greater than the lowest-yielding variety of that year.

Plant height ranged from an average of 47.3 to 57.8 cm in 2014, and in 2015 height ranged from 50.4 to 72.3 cm (Table 3). In both 2014 and 2015, 'Cheddar' produced the shortest plants while 'Violet Queen' produced the tallest plants; however, there were several other varieties that fell into the same statistical category (Table 3).

Maturity and harvest span. In 2014, the average number of GDD from transplant to harvest ranged from 922 to 1115 GDD; whereas, in 2015, the number of GDD ranged from 1345 to 1510 (Table 4). 'Cassius' and 'Snow Crown' were early-producing varieties

Table 2. Yield and size of cauliflower varieties measured by curd weight and curd width for 2014 and 2015 in Geneva, NY.

Variety	Curds harvested/plants (no.)[z]		Total yield (kg/plot)[y]		Mean curd wt (kg)		Mean curd width (cm)[x]	
	2014	2015	2014	2015	2014	2015	2014	2015
Amazing	31/31	32/32	4.83 abc[w]	2.69 abc	0.60 abcd[w]	0.34 de	27.5 bc[w]	21.3 cde
Apex	28/31	24/31	6.55 cd	3.88 c	0.81 def	0.47 f	30.1 cedf	25.5 e
Artica	26/29	11/32	7.78 d	3.68 c	0.96 f	0.40 def	31.9 f	21.2 cde
Candid Charm	31/31	31/31	6.55 cd	1.36 ab	0.81 ef	0.17 ab	31.5 ef	15.6 ab
Cassius[v]	31/31	—	4.20 abc	—	0.52 ab	—	25.1 ab	—
Cheddar	29/29	30/30	5.19 bcd	1.56 ab	0.64 abcde	0.19 abc	28.3 bcde	17.6 bc
Fremont	31/31	30/30	5.92 bcd	3.08 bc	0.74 cdef	0.39 ef	30.7 def	24.6 de
Graffiti	22/27	15/32	4.59 abc	2.51 abc	0.55 abc	0.31 bcdef	27.6 bcd	21.6 cde
Minuteman	30/30	31/31	5.78 bcd	2.42 abc	0.72 bcde	0.30 cde	31.0 def	20.9 cd
Snow Crown	31/31	30/32	3.81 ab	2.00 abc	0.47 a	0.25 bcd	23.9 a	18.4 bc
Violet Queen	4/28	21/30	2.50 a	2.08 abc	0.31 ab	0.26 bcde	22.0 ab	19.7 bc
White Sails	27/27	31/31	6.54 cd	0.96 a	0.81 ef	0.12 a	30.3 cedf	12.8 a
Overall mean[u]			5.35	2.38	0.69	0.28	28.8	19.6

[z]The total number of curds harvested across all four replications of the total number of mature healthy plants across all four replications. Some varieties did not produce harvestable curds even though the plants were fully grown.
[y]Total yield is the sum of weights per plot and adjusted for eight plants per plot; 1 kg = 2.2046 lb.
[x]Curd width is the measurement of the curd dome from edge to edge across the widest part of the curd; 1 cm = 0.3937 inch.
[w]Values given are the means of four replicates. Means followed by the same letter within each experiment are not significantly different using the Tukey–Kramer honestly significant difference ($P \leq 0.05$).
[v]'Cassius' was omitted from the 2015 trial because its seed could not be obtained.
[u]Overall mean across all varieties and all replications.

Table 3. Mean plant height across four replications of cauliflower varieties for 2014 and 2015 in Geneva, NY.

Variety	Mean plant ht (cm)[z]	
	2014	2015
Amazing	48.7 ab[y]	56.8 cdef
Apex	53.6 bc	59.4 def
Artica	54.3 c	62.0 f
Candid Charm	56.3 c	52.6 abc
Cassius[x]	56.0 c	—
Cheddar	47.3 a	50.4 a
Fremont	52.7 bc	55.4 bcde
Graffiti	51.2 abc	60.7 ef
Minuteman	55.08 c	51.0 ab
Snow Crown	55.1 c	54.5 abcd
Violet Queen	57.8 abc	72.3 g
White Sails	53.6 bc	51.3 ab

[z]Plant height was measured from the soil line to the tip of the first full sized leaf; 1 cm = 0.3937 inch.
[y]Values given are the means of four replicates. Means followed by the same letter within each experiment are not significantly different using the Tukey–Kramer honestly significant difference ($P \leq 0.05$).
[x]'Cassius' was omitted from the 2015 trial because its seed could not be obtained.

in 2014 and 'Amazing', 'Apex', 'Artica', and 'Graffiti' were late-season varieties that same year. The remaining varieties were all midseason varieties (Table 4). 'Violet Queen' was excluded from the statistical analysis for 2014 since curds were harvested from less than 50% of the plants (Table 2). Similar results were seen in 2015. 'Snow Crown' was an early-season variety and 'Amazing', 'Apex', and 'Violet Queen' were late-season varieties (Table 4). 'Artica' and 'Graffiti' were also late-season varieties but were excluded from statistical analysis since less than 50% of the plants produced harvestable curds (Table 2).

In 2014, the span of harvest varied from 11 to 22 d with 'Cheddar' being harvested over the longest span; however, no significant differences were seen among varieties for harvest span. In 2015, significant differences were seen among varieties. Harvest span ranged from 11 to 30 d, with 'Cheddar' having numerically the longest harvest period, but it was not statistically significant from several other varieties (Table 4).

Discussion

Cauliflower intended for the market place must be free of disease, fuzziness, and riciness. Since the standards for cauliflower are high, it is important that growers choose varieties that are less susceptible to disease and perform well under New York growing conditions. This study revealed that there are cauliflower varieties that perform better than others. In regard to susceptibility to alternaria leaf spot, both the purple varieties, 'Violet Queen' and 'Graffiti', were less susceptible when comparing disease severity on the leaves as compared with the other varieties tested. Colored curds are excellent for niche markets like a farmers market or community-supported agriculture; however, for large-scale, wholesale production, white curds are the most marketable. When comparing the white varieties, 'Artica' and 'Candid Charm', did not have significantly more disease in both 2014 and 2015 than 'Violet Queen'.

According to USDA standards, not only must cauliflower be free of disease, fuzziness, and riciness, but also it must meet the size requirements. The first year of the trial had much higher yields than the second year of the trial (Table 2). The plants themselves were fully grown at the time of harvest given the plant heights of all the varieties were similar (Table 3). Cauliflower initiates curd formation when exposed to cooler temperatures at a certain maturity (Wurr et al., 1988). If the cauliflower is exposed to warm temperatures after exposure to cool temperatures, the curd can revert back to vegetative growth resulting in fuzziness in curds and reduced yields (Grevsen et al., 2003). In 2015, the average temperatures were higher during August and September. Two of the varieties showed very different performances from 2014 to 2015. Both 'Candid Charm' and 'White Sails' had high yields and large curds during 2014, but were low yielding in 2015 and exhibited fuzziness. These varieties were forming curds during warmer temperatures, and may be more sensitive to warm weather than some of the other varieties such as 'Minuteman' and 'Fremont' that were forming curds at the same time (Table 4). Other varieties, although smaller from the

Table 4. Mean growing degree days (GDD) from time of transplant needed for cauliflower varieties to reach maturity, and average span of harvest for cauliflower varieties for 2014 and 2015 in Geneva, NY.

	Mean GDD to harvest[z]		Mean harvest span (d)[y]	
Variety	2014	2015	2014	2015
Amazing	1,081 e[x]	1,499 d	14	29 bc
Apex	1,095 e	1,510 d	18	25 abc
Artica	1,115 e	—[w]	12	—
Candid Charm	996 cd	1,406 c	14	13 a
Cassius[v]	926 a	—	15	—
Cheddar	1,022 d	1,396 c	22	30 c
Fremont	969 bc	1,384 bc	14	20 abc
Graffiti	1,087 e	—	16	—
Minuteman	950 ab	1,370 bc	18	11 a
Snow Crown	922 a	1,321 a	11	15 abc
Violet Queen	—	1,505 d	—	21 abc
White Sails	994 cd	1,345 ab	14	13 ab

[z]The average of GDD from transplanting to harvest. GDD is calculated each day as the average of the maximum and minimum temperature minus base temperature of 50 °F (10.0 °C).
[y]The average of days from the first curd harvested to the last curd harvested by plot.
[x]Values given are the means of four replicates. Means followed by the same letter within each experiment are not significantly different using the Tukey–Kramer honestly significant difference ($P \leq 0.05$); 2014 had no significant differences in the mean harvest span.
[w]Less than 50% of the plants produced harvestable curds. The GDD and harvest span calculated were excluded from the statistical analysis due to the small number harvested.
[v]'Cassius' was omitted from the 2015 trial because its seed could not be obtained.

previous year, were still able to produce sizable curds meeting USDA size standards in 2015. 'Artica', 'Apex', and 'Fremont' produced the largest curds each year of the trial. 'Artica' and 'Apex' produced large compact white curds; however, they were both late-season varieties, and each year of the trial some curds never formed or matured enough to harvest (Table 2). The lack of curd formation could also be related to weather as in some cauliflower varieties curd formation is inhibited by high temperatures (Nieuwhof, 1969). 'Artica' did produce more curds in 2014 than in 2015 (Table 2). The 2015 growing season had warmer temperatures on average throughout August (77 °F) and September (76 °C), and less than 50% of the curds were harvested from 'Artica'. In addition, to the change in yield from 2014 to 2015, differences were seen in the GDD each year of the trial. The GDD indicate the accumulation of warm weather throughout the course of the growing season. Curd formation is dependent on exposure to a vernalization period, and the warm temperatures likely resulted in delaying curd initiation and lower yields in some varieties.

Some of the varieties did show consistent results over the 2 years of this trial. 'Fremont', 'Minuteman', and 'Apex' were consistent each year of the trial. Their yield, curd weight, and curd width were slightly smaller the 2nd year of the trial; however, they were more consistent than some other varieties. They formed compact curds with tight flower clusters, which are desirable traits for market, whereas 'Amazing', 'Snow Crown', and 'Cassius' produced sizeable curds meeting USDA size standards, but they produced less compact curds. In regard to the colored varieties, 'Graffiti' and 'Cheddar' produced compact curds each year and were not as affected by weather. 'Cheddar' also had a longer harvest span as compared with other varieties (Table 4). 'Violet Queen', a purple variety, did not produce large curds either year of the trial, and the curds produced were not compact in nature.

Results of this study indicate the importance of conducting variety trials under the specific conditions for the region of interest for more than 1 year, and will help growers determine which variety best suits their needs. The study also revealed that most varieties are susceptible to alternaria leaf spot disease, and future work could be done to screen additional varieties or breeding lines to identify those that may be less susceptible.

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