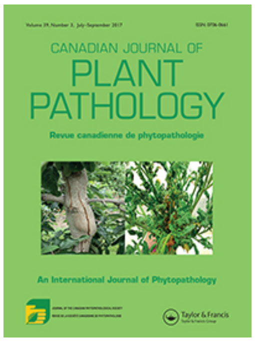

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Effect of soybean vein necrosis on yield and seed quality of soybean

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Abstract: *Soybean vein necrosis virus* (SVNV) rapidly became a widespread virus of soybean (*Glycine max* (L.) Merr.) in the USA and Canada within a few years of its initial detection in 2008; however, the economic impact of soybean vein necrosis (SVN) symptoms caused by virus infection remains unknown. Field studies were conducted in six states in the USA during 2013, 2014 and 2015 to determine the effect of SVN on soybean yield and seed quality. Quantitative parameters, including seeds per pod, pods per plant, yield and 100-count seed weight, were assessed from plants or seeds collected from research and commercial production fields. Qualitative parameters, including protein and oil concentration, were also obtained from samples collected in Indiana and Iowa. Results from all states suggest that yield is not impacted by SVN; however, seed quality was affected in four of seven location-years. In Iowa, oil concentration decreased by 0.11% as disease incidence increased by 1% ($P = 0.04$). In Indiana, SVNV infected plants exhibited decreased total oil content compared with asymptomatic plants (0.16% ($P = 0.04$); 0.67% ($P > 0.01$) in 2014 and 2015, respectively. These results suggest that SVN may change soybean seed quality, which may affect the marketability of soybeans for premium markets, specifically those interested in high oleic soybeans.

Keywords: seed quality, soybean, *Soybean vein necrosis virus*, tospovirus, *Tospovirus*

Résumé: Quelques années après sa détection initiale en 2008, le virus de la nécrose des nervures du soja (VNNS) s'est largement répandu dans les cultures de soja (*Glycine max* [L.] Merr.) américaines et canadiennes. Toutefois, les retombées économiques des symptômes de la nécrose des nervures du soja (NNS), causés par l'infection virale, sont encore inconnues. En 2013, 2014 et 2015, des études en champ ont été menées dans six États américains afin de déterminer les effets de la NNS sur les rendements du soja et sur la qualité de ses fèves. Des paramètres quantitatifs, y compris le nombre de fèves par cosse, le nombre de cosses par plant, le rendement et le poids de 100 fèves, ont été évalués à partir de plants ou de fèves collectés dans des champs utilisés pour la recherche et pour la production commerciale. Des paramètres qualitatifs, y compris la concentration de protéines et d'huile, ont également été obtenus à partir d'échantillons collectés en Indiana et en Iowa. Les résultats provenant de tous les États suggèrent que le rendement n'est pas influencé par la NNS, mais que la qualité des fèves était altérée à quatre des sept sites durant les années qu'ont duré les études. En Iowa, lorsque l'incidence de la maladie augmentait de 1%, la concentration d'huile baissait de 0.11% ($P = 0.04$). En Indiana, les plants infectés par le VNNS ont affiché, en 2014 et 2015, une baisse de la teneur totale en huile comparativement aux plants sains: 0.16% ($P = 0.04$) et 0.67% ($P > 0.01$), respectivement. Ces résultats suggèrent que la NNS peut altérer la qualité des fèves de soya, ce qui peut en influencer la qualité marchande lorsqu'elles sont destinées aux marchés haut de gamme, particulièrement à ceux qui recherchent des fèves à haute teneur en acide oléique.

Mots clés: qualité de la fève, soja, tospovirus, *Tospovirus*, virus de la nécrose des nervures du soja

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Introduction

Soybean (*Glycine max* (L.) Merr) is grown worldwide and soybean seeds are used in livestock feed, for human consumption, oil extraction and as a biofuel. In the USA, 108 million metric tonnes of soybeans were produced in 2014 (USDA 2015), and 6.05 million metric tonnes were produced in Canada in 2015 (Soy Canada 2016). Globally, 281.9 million metric tonnes of soybeans were produced in 2013–14 (McFerron 2014).

In 2008, a new soybean virus was confirmed in Arkansas and Tennessee, and was described as *Soybean vein necrosis virus* (SVNV) (Tzanetakis et al. 2009; Zhou et al. 2011). Since its first detection, the virus has become widespread across the major soybean producing regions of the USA and Canada (Bloomingdale et al. 2015). Soybean vein necrosis (SVN) symptoms caused by the virus start as interveinal chlorosis originating from the leaf vein, and progress to reddish-brown lesions that eventually become necrotic. Leaf veins can be clear, yellow, or dark brown with symptoms often more severe on the underside of the leaf (Bloomingdale et al. 2015). SVNV belongs to the genus *Tospovirus* in the family *Bunyaviridae*. Tospoviruses are transmitted by thrips (Thysanoptera), a small winged insect. Currently there are three known thrips vectors of SVNV, soybean thrips (*Neohydatothrips variabilis* (Beach)) (Zhou & Tzanetakis 2013), eastern flower thrips (*Frankliniella tritici* (Fetch) and tobacco thrips (*Franklineilla fusca* (Hinds) (Keough et al. 2016). Although tospoviruses can infect over 1000 plant species, SVNV is one of two tospoviruses known to infect soybeans in the USA and Canada, with the other being *Tomato spotted wilt virus* (Sikora et al. 2011).

Although SVNV has become widespread, the potential impacts on yield and seed quality are unknown. Of the 46 viruses known to infect soybean, *Alfalfa mosaic virus* (AMV), *Bean pod mottle virus* (BPMV), *Peanut mottle virus* (PeMoV), *Peanut stunt virus* (PSV), *Soybean dwarf virus* (SbDV), *Soybean mosaic virus* (SMV) and *Tobacco ringspot virus* (TRSV) have a reported impact on yield and seed quality (Demski et al. 1971; Filho et al. 2001; Hill & Whitham 2014). Soybean is an important oilseed crop in North America, and oil content of the seed is economically important, particularly in specialty markets (Herbek & Grabau 2013). Additionally, soybean farmers can receive a premium for seeds that have lower levels of palmitic and linolenic acids as well as higher levels of oleic acid. Linolenic acid gives foods a rancid flavour and processers must go through extra steps to remove this from the soybean seed (Frankel 1980). These fatty acids are the focus of soybean breeding efforts to develop soybean cultivars with naturally occurring fatty acid contents closer to the ideals of the marketplace (Fehr 2007).

The objectives of this study were to (i) evaluate the impact of SVN on yield parameters including seeds per pod, pods per plant, yield, and 100-count seed weight; and (ii) determine the effect of SVN on soybean seed quality parameters including protein, oil and fatty acid concentration of seed.

Materials and methods

Collection of SVN data on symptomatic and asymptomatic soybean in the field

Data were collected in 2013, 2014 and 2015 from six states: Alabama, Delaware, Illinois, Indiana, Iowa and Wisconsin. Although data collection protocols differed slightly across states due to variations in disease levels, for all location-years, fields were targeted based on symptoms of SVNV infection, with the goal of comparing symptomatic and asymptomatic plants within a location (Table 1). Trials located in Delaware and Iowa in 2014 and Indiana in 2015 were in commercial production fields and trials located in Illinois and Wisconsin in 2013, and Alabama, Indiana and Wisconsin in 2014, were located in small-plot research trials. Multiple varieties were sampled in trials located in Alabama, Indiana, Iowa and Wisconsin. Once SVN symptoms were first visible and identified, trials were established. In all states, trial establishment occurred around growth stage R4–R5 (Fehr et al. 1971).

Treatments consisted of: (i) SVN-symptomatic and (ii) SVN-asymptomatic plants. Plants of each type were marked at each location for later sampling at growth stage R6. Total numbers of plants sampled were: 170 in Alabama; 175 in Delaware; 40 in Illinois; 870 in Indiana; 104 in Iowa; and 300 in Wisconsin. Since the objective of the trial was to assess the impact of SVN on yield and seed quality parameters, leaves from experimental plants were not sampled to confirm presence or absence of SVNV as removal of infected material from the experimental plants could remove a source of inoculum and also contribute to yield loss by removing green leaf tissue from the plants. However, to confirm that symptoms observed in the SVN-symptomatic treatments were caused by SVNV, a minimum of three trifoliates from both asymptomatic and symptomatic plants were sampled from plants adjacent to marked experimental plants or plots and tested for SVNV using an enzyme-linked immunosorbent assay (ELISA; Agdia, Inc., Elkhart, IN), a nested PCR assay (Khatabi et al. 2012) or sent to Agdia, Inc. to confirm pathogen presence. In all states, symptomatic subsamples were confirmed to have SVNV, and virus was not detected in asymptomatic samples tested (data not shown).

Table 1. Details of field trials investigating yield loss from soybean vein necrosis (SVN) in six US states.

Location	Year	Sampling unit	Number of samples	Type of data collected	Statistical analysis
Alabama	2014	Plant	170	Symptoms[a], yield, 100-seed weight, seeds/pod, pods/plant	ANOVA[b]
Delaware	2014	Plant	175	Disease incidence, yield, 100-seed weight, seeds/pod, pods/plant	Regression
Illinois	2013	Plant	40	Disease incidence, yield, 100-seed weight, seeds/pod, pods/plant	Regression
Indiana	2014	Plant	690	Symptoms, protein, oil, and fatty acids, yield, 100-seed weight, seeds/pod, pods/plant	ANOVA
Indiana (full season)	2015	Plant	50	Symptoms, protein, oil, and fatty acids, yield, 100-seed weight, seeds/pod, pods/plant	ANOVA
Indiana (double crop)	2015	Plant	130	Symptoms, protein, oil, and fatty acids, yield, 100-seed weight, seeds/pod, pods/plant	ANOVA
Iowa (Washington)	2013	Plot	10	Disease incidence, protein, oil, and fatty acids, yield, 100-seed weight, seeds/pod, pods/plant	Regression
Iowa (Ottumwa)	2013	Plot	24	Disease incidence, protein, oil, and fatty acids, yield, 100-seed weight, seeds/pod, pods/plant	Regression
Iowa (Stockport)	2013	Plot	20	Disease incidence, protein, oil, and fatty acids, yield, 100-seed weight, seeds/pod, pods/plant	Regression
Iowa	2014	Plant	50	Symptoms, oil, and fatty acids, yield, 100-seed weight, seeds/pod, pods/plant	ANOVA
Wisconsin	2013	Plant	200	Symptoms, yield, 100-seed weight, seeds/pod, pods/plant	ANOVA
Wisconsin	2014	Plant	100	Symptoms, yield, 100-seed weight, seeds/pod, pods/plant	ANOVA

[a]Plants in treatments were rated as symptomatic for soybean vein necrosis (SVN) or asymptomatic.
[b]Analysis of variance conducted on categorical data.

SVN incidence, calculated as the percentage of leaves exhibiting symptoms, was also collected in Delaware, Illinois and Iowa. In Delaware, disease incidence was determined by counting the number of leaf nodes with symptomatic leaves, dividing by the total number of nodes on the plant, and multiplying by 100. In Illinois, disease incidence was determined by counting the number of symptomatic leaves and dividing by the number of total leaves, and multiplying by 100. In Iowa, incidence was calculated by determining the percentage of symptomatic leaves per plant. To calculate the percentage of leaves infected, the total number of infected leaves was divided by the total number of leaves per plot and multiplied by 100. The total number of leaves was counted on 10 arbitrarily selected plants, averaged, and multiplied by the total number of plants per plot. Per cent disease incidence was visually estimated on 25 arbitrarily selected symptomatic leaves per plot. Because SVN-asymptomatic plants were hard to find in fields sampled in Iowa in 2013, the effect of SVN on yield and seed components was measured from plots with varying levels of SVN. At three locations near the towns of Washington, Ottumwa and Stockport, plots that were two 76 cm rows wide and 3 m long were selected for sampling to provide a range in incidence and severity levels, from low incidence and severity to high severity. Within each plot at the R6 growth stage, the total number of fully expanded leaves with SVN symptoms was recorded on all plants. Incidence of disease was determined using the percentage of SVN symptomatic leaves.

Plants were hand-harvested at maturity, and pods were hand-shelled to determine plant yield in grammes. Seeds per pod and 100-seed weight were also determined. In nine-location years, pods per plant were counted, and seeds per pod were determined in five location-years. All fields were managed using standard management practices based on local university recommendations for fertility, fungal diseases, insects and weeds.

Seed quality testing

Two states, Indiana and Iowa, did additional testing for oil, protein and fatty acid content in seed, totalling seven location-years. In Indiana, 15 seeds from each plant were used to determine levels of oils, proteins, as well as fatty acid profiles using a Perten DA 7250 NIR analyser (Hagersten, Sweden). Measurements for Indiana included relative levels of total oil, fibre, ash, palmitic acid, stearic acid, oleic acid, linoleic acid, linolenic acid, taurine, hydroxyproline, aspartic acid, threonine, serine, glutamic acid, proline, lanthionine, glycine, cysteine, valine, methionine, isoleucine, leucine, tyrosine, phenylalanine, hydroxylysine, ornithine, lysine, histidine, arginine, tryptophan and lysine. In Iowa, five seeds per plant were tested at the Iowa State University W.M. Keck Metabolomics Research Laboratory for levels of palmitic, stearic, oleic, linoleic and linolenic oils using conventional gas chromatography (Jamieson and Reid 1965). Only parameters measured in both Indiana and Iowa were subjected to further statistical analysis.

Data analysis

Analysis of variance (ANOVA) was used to compare categorical data of asymptomatic and symptomatic samples in Alabama, Indiana, Iowa (2014) and Wisconsin. Incidence data from Delaware, Illinois and Iowa (2013) were continuous, and therefore subjected to regression analysis where SVN incidence was the independent variable and each yield or seed quality variable was the dependent variable (Table 1). Slopes and intercepts were calculated and r-squared values determined. All statistical analyses were done using SAS v. 9.3 or JMP v. 11 (SAS Institute, Cary, NC).

Results

Yield parameters

In most location-years, SVN did not significantly affect yield (Tables 2 and 3). However, yield was significantly increased ($P = 0.01$) in SVN-symptomatic plants compared with asymptomatic plants in Indiana in 2014 (Table 2) and there was a significant positive relationship ($P < 0.01$) between SVN incidence and yield in Stockport, Iowa in 2013 (Table 3).

In Alabama, Delaware and Indiana, 100-seed weight was significantly greater for plants that were SVN-symptomatic compared with asymptomatic plants (Tables 2 and 3). In all but one of nine location-years, SVN symptomatic plants did not impact the number of pods per plant. In Alabama, there were significantly more pods per plant on symptomatic plants than asymptomatic ($P = 0.04$; Table 2). There were no significant effects of SVN on seeds per pod at any location (Tables 2 and 3).

Seed quality parameters

Significant changes in oil content were observed in three of six location-years, while significant changes in protein were observed in only one location-year (Tables 4 and 5).

Table 2. Yield and yield component data for Wisconsin in 2013, Alabama, Indiana, Iowa and Wisconsin in 2014, and Indiana in 2015 where soybean vein necrosis (SVN) symptomatic or asymptomatic plants were hand-harvested.

Component	State	Year	Asymptomatic	Symptomatic	P-value
Yield/plant (g)	Wisconsin	2013	20.90	24.40	0.06
	Alabama	2014	17.20	21.70	0.17
	Indiana	2014	21.02	22.42	0.01
	Iowa	2014	20.11	20.42	0.84
	Wisconsin	2014	27.10	30.20	0.26
	Indiana-Full season	2015	20.15	17.87	0.43
	Indiana-Double crop	2015	16.49	16.74	0.92
100-seed weight (g)	Wisconsin	2013	15.83	16.72	0.04
	Alabama	2014	16.10	17.40	0.03
	Indiana	2014	-[a]	-	-
	Iowa	2014	17.24	18.03	0.12
	Wisconsin	2014	-	-	-
	Indiana-Full season	2015	13.78	13.39	0.34
	Indiana-Double crop	2015	15.83	16.72	0.04
Seeds per pod	Wisconsin	2013	2.33	2.27	0.31
	Alabama	2014	-	-	-
	Indiana	2014	-	-	-
	Iowa	2014	2.50	2.50	0.91
	Wisconsin	2014	-	-	-
	Indiana-Full season	2015	2.54	2.48	0.36
	Indiana-Double crop	2015	2.33	2.27	0.31
Pods per plant	Wisconsin	2013	49.70	56.70	0.08
	Alabama	2014	53.40	69.40	0.04
	Indiana	2014	-	-	-
	Iowa	2014	46.93	45.93	0.78
	Wisconsin	2014	57.60	64.20	0.26
	Indiana-Full season	2015	57.40	51.40	0.38
	Indiana-Double crop	2015	45.85	44.50	0.83

[a]A '-' indicates this component was not measured for this state in 2014.

Table 3. Linear regression values for yield and yield components for plants with differing levels of soybean vein necrosis (SVN) in Delaware, Illinois and Iowa in 2013, 2014 and 2015.

Yield component	Year	State (location)	Intercept	Slope	R^2	P-value
Yield[a.]	2014	Delaware	-[b.]	-	-	-
	2013	Illinois	16.64	−0.05	0.02	0.40
	2013	Iowa (Washington)	1804.62	−71.92	0.25	0.14
	2013	Iowa (Ottumwa)	1601.27	−21.55	0.04	0.37
	2013	Iowa (Stockport)	2389.75	+182.00	0.65	<0.01
100-seed weight (g)	2014	Delaware	11.41	+0.09	0.21	<0.01
	2013	Illinois	16.47	−0.01	<0.01	0.66
	2013	Iowa (Washington)	15.24	+0.08	0.07	0.47
	2013	Iowa (Ottumwa)	13.18	−0.10	0.04	0.11
	2013	Iowa (Stockport)	16.31	−0.15	0.08	0.25
Seeds/pod	2014	Delaware	2.59	−0.01	<0.01	0.43
	2013	Illinois	2.54	−0.01	<0.01	0.38
	2013	Iowa (Washington)	-	-	-	-
	2013	Iowa (Ottumwa)	-	-	-	-
	2013	Iowa (Stockport)	-	-	-	-
Pods/plant	2014	Delaware	44.77	0.13	0.01	0.12
	2013	Illinois	40.57	+0.12	0.03	0.27
	2013	Iowa (Washington)	-	-	-	-
	2013	Iowa (Ottumwa)	-	-	-	-
	2013	Iowa (Stockport)	-	-	-	-

[a]Delaware and Illinois yield is measured in grammes per plant and Iowa is measured in kilogrammes per hectare.
[b]A '-' indicates this component was not measured for this state.

Table 4. Linear regression data for protein, oil and palmitic, linolenic, steric, oleic and linoleic fatty acid content of soybean seed hand-harvested from three Iowa locations in 2013 that had differing levels of soybean vein necrosis (SVN).

Iowa Location	Product per cent	Intercept	Slope	R^2	P-value
Washington	Protein	32.51	+0.13	0.29	0.11
	Oil	21.85	−0.09	0.26	0.13
	Palmitic acid	8.78	+0.20	0.52	0.02
	Linolenic acid	5.81	+0.01	<0.01	0.92
	Steric acid	4.47	−0.01	0.02	0.73
	Oleic acid	29.14	−0.40	0.11	0.36
	Linoleic acid	51.69	+0.21	0.05	0.53
Stockport	Protein	36.01	−0.19	0.13	0.13
	Oil	19.86	+0.09	0.05	0.37
	Palmitic acid	10.49	−0.04	0.04	0.43
	Linolenic acid	5.54	+0.01	<0.01	0.87
	Steric acid	5.03	−0.02	0.01	0.65
	Oleic acid	26.29	+0.53	0.15	0.12
	Linoleic acid	52.41	−0.58	0.17	0.08
Ottumwa	Protein	33.91	+0.04	0.02	0.53
	Oil	22.00	−0.11	0.18	0.04
	Palmitic acid	10.51	−0.11	0.16	0.06
	Linolenic acid	5.73	+0.01	<0.01	0.87
	Steric acid	5.92	−0.01	<0.01	0.83
	Oleic acid	25.39	+0.04	<0.01	0.82
	Linoleic acid	52.21	+0.01	<0.01	0.94

In Indiana, significantly lower total oil concentration was observed in SVN-symptomatic seed compared with asymptomatic seed in two location-years. In 2015, symptomatic plants from one trial in Indiana had an increase in protein level (Table 5). Total oil levels decreased by 0.11% as percentage of leaves infected increased by 1% ($P = 0.04$) in one Iowa location in 2013 (Table 4). Additionally, protein and oil content had a strong negative linear relationship in all three locations in Iowa in 2013, with oil content decreasing as protein level increased ($P < 0.01$).

Fatty acid profiles of the seed oil differed among location-years. In Indiana in 2014, seed of SVN-symptomatic plants had less palmitic acid ($P = 0.04$) than seed of asymptomatic plants, but an increase in palmitic acid was observed in symptomatic seed from one location in Indiana in 2015 (Table 5). No other significant differences in fatty acid profiles of the oil were identified from other location-years in Indiana. However, one Indiana location in 2015 had a significant decrease in linoleic acid and increase in linolenic acid in SVN-symptomatic plants (Table 5). A significant positive correlation between SVN incidence and palmitic acid ($P = 0.02$) was detected for one location in Iowa in 2013 (Table 4). Significant differences between seed from symptomatic and asymptomatic plants were also observed in Iowa in 2014, where palmitic acid was higher ($P < 0.01$) but stearic acid was lower ($P = 0.01$) and linolenic acid was lower ($P = 0.02$) in symptomatic plants (Table 4). No other significant differences in these fatty acids were found in any location-years in Iowa.

Table 5. Protein, oil and palmitic, linolenic, steric, oleic and linoleic fatty acids content of soybean seed hand-harvested from plants either symptomatic or asymptomatic for soybean vein necrosis (SVN) in Iowa 2014, and Indiana in 2014 and 2015. Protein and oil values presented are percentages of seed composition, while individual oil types are represented as percentage of total oil content.

Location/year/ field	Product	Asymptomatic (%)	Symptomatic (%)	P-value
Iowa 2014	Palmitic	12.51	12.97	<0.01
	Stearic	3.87	3.72	0.01
	Oleic	20.37	19.97	0.36
	Linoleic	55.20	55.68	0.19
	Linolenic	7.97	7.49	0.02
Indiana 2014	Protein	38.94	38.99	0.74
	Oil	21.32	21.16	0.04
	Palmitic	12.19	11.85	0.04
	Stearic	4.41	4.34	0.06
	Oleic	15.82	16.14	0.37
	Linoleic	54.36	54.88	0.16
	Linolenic	11.23	10.89	0.08
Indiana 2015 Full season	Protein	40.21	40.57	0.45
	Oil	40.33	40.36	0.87
	Palmitic	11.91	13.35	0.01
	Stearic	4.60	4.82	0.08
	Oleic	16.34	16.74	0.68
	Linoleic	56.38	53.34	0.01
	Linolenic	8.57	10.17	0.04
Indiana 2015 Double crop	Protein	38.59	39.67	0.01
	Oil	20.46	19.79	<0.01
	Palmitic	12.87	12.43	0.12
	Stearic	4.74	4.64	0.19
	Oleic	16.69	16.68	0.99
	Linoleic	54.39	54.91	0.44
	Linolenic	10.06	9.91	0.69

Discussion

The results from this study indicated that SVN influenced the quality and chemical composition of harvested soybean seed but had little negative effect on overall yield of plants. Seed tested from Indiana and Iowa showed several significant changes to both oil concentration and fatty acid profiles of seed. In three of six location-years, oil concentration decreased significantly in SVN-symptomatic plants. The effects of virus infection on oil concentration in soybean seeds have been reported previously, with oil concentration reduced due to infection by *Cowpea chlorotic mottle virus* (CCMV), *Peanut mottle virus* (PeMoV), *Soybean mosaic virus* (SMV) and *Tobacco ringspot virus* (TRSV) (Demski & Jellum 1975). Similarly, a negative relationship between total oil and protein content was observed in healthy soybean seed, with an increase in protein and decrease in oil (Cartter & Hopper 1942). A negative correlation between oil and protein concentration in seed from infected soybean plants may be related to the higher photosynthate requirements needed to produce oil than protein (Harris et al. 1970). This effect may be increased when the plant is under stress from viral infection, only leaving enough energy available to create protein but not enough to generate oil (Harris et al. 1970).

Our observation of changes in fatty acid composition in SVN-symptomatic soybean seed is similar to previous studies that found significant changes to fatty acid profiles in soybean infected with CCMV and TRSV, with a decrease in palmitic, linoleic and linolenic and an increase in stearic and oleic acids (Harris et al. 1970; Demski et al. 1971; Demski & Jellum 1975). In our study, seed from four location-years had significant differences in the palmitic, linolenic and stearic fatty acids. A decrease in linolenic acid is desirable since linolenic acid imparts poor flavour to foods and decreases storage life of the oil; thus, linolenic acid is actively removed during processing or reduced through variety development (Howell & Collins 1957; Harris et al. 1970).

Although SVN symptoms were associated with changes in oil and protein content in soybean seed in certain years and locations, yield loss was not associated with SVN in soybean in any of the six states in this study. In contrast, there was a significant yield increase in SVN-symptomatic plants in Indiana and Iowa in two years. Demski et al. (1971) reported that infection by TRSV in soybean resulted in larger, but fewer seeds and this combination produced lower yield overall. Our research also showed this same trend of increased 100-seed weights, suggesting an increase in seed size in SVN symptomatic plants for four location-years.

The goal of our research was to determine if symptom presence impacts yield or seed quality components in soybean, and while our results indicate that SVN may affect soybean seed components, the effects of SVNV on yield require additional research. Confounding factors, such as cultivar yield response and unknown resistance factors to SVNV, may have masked the true effects of SVNV infection on yield and seed composition (Maestri et al. 1998; Filho et al. 2001). Because SVN is a relatively new disease, there is no published information on soybean cultivar response to SVNV infection, which could influence yield or seed composition. More information on cultivar susceptibility to SVNV is needed to understand the effect of SVNV on yield.

Another factor that deserves exploration is the impact of sampling time and disease severity. In this study, treatments were assigned soon after SVN symptoms developed, since infection timing is a significant factor in the interactions between other viruses (*Soybean mosaic virus* and *Bean pod mottle virus*) and soybean yield (Hopkins & Mueller 1984; Ren et al. 1997; Byamukama et al. 2015). Due to this relationship, timing of symptom development was emphasized over disease severity when choosing plants for this study to examine the role of SVN on yield.

Likewise, the impact of SVN on soybean yield components may also be related to the timing of thrips arrival and timing of SVNV infection. Previous research indicates the interaction between timing of infection and incidence levels of SMV was correlated with a reduction in soybean seed size occurring at or before soybean flowering (R1) (Ren et al. 1997). It is possible that yield and seed weight observations may be affected due to the timing of SVNV infection; however, thrips presence and feeding activity were not monitored in the current study. Future research is needed to correlate the onset of thrips feeding and SVN symptom appearance to yield impact. It was previously thought that SVNV was only thrips transmitted and did not move systemically in soybean plants (Zhou & Tzanetakis 2013). However, recent work has shown that SVNV is also seed transmitted, which indicates that the virus can move systemically through the plant (Groves et al. 2016). This observation may confound yield experiments when coupled with infection timing.

While the effect of SVNV on yield may be masked by cultivar and other factors in this study, our findings are similar to previous research on other soybean viruses, which suggests that the decrease in oil content and change in fatty acid composition is not unique to SVN but rather a characteristic of viral infections in soybean. In this study, seed quality parameters were tested only from Indiana and Iowa, and several significant changes were observed to both oil concentration and fatty acid profiles of seed from both states. This research is the first to report significant impacts of SVN on seed quality components, which are important factors in current soybean production systems. These findings provide a foundation for future studies on the impacts of SVN on seed quality.

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