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Seed Treatment Affected Yield and Economic Returns of Nebraska Winter Wheat Genotypes

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ABSTRACT Proper management of insect-pests can reduce winter wheat loss in the Grain Plains of the United States. The objective of this study was to determine the effects of seed treatments (EverGol® Energy; a fungicide, Gaucho®; an insecticide, and both) on grain yield and net economic returns in six Nebraska winter wheat genotypes grown under rainfed conditions (2-sites and 2-years). Treating seeds with EverGol® Energy and Gaucho® combined increased grain yield (up to 770 kg ha^{-1}) and net returns (up to US$ 187.47 ha^{-1}). However, seed treatment did not improve grain protein content. This study showed that combined fungicide and insecticide seed treatment could improve wheat grain yield and economic returns.

INTRODUCTION

Wheat is one of the most cultivated (third ranked crop) and consumed cereals throughout the world that supplies carbohydrates, protein, minerals, fibers, and anti-oxidants in our diet (Poudel and Bhatta 2016). However, grain yield loss due to insect-pest is one of the major wheat production constraints (Bhatta 2015). Insecticide seed treatments are effective in controlling insect pests such as wireworms (*Elateridae spp.*), Hessian fly (*Mayetiola destructor*), and fall season aphids (*Aphidoidea spp.*) in Nebraska (Hein 2007). Gaucho® (Imidacloprid) is a systemic insecticide and acts against a wide range of economically important insect pests (Pike et al.1993) such as aphids, thrips (*Thysanoptera spp.*), leafhoppers (*Cicadellidae spp.*), leaf miners (*Agronmyzidae spp.*), and some beetles (*Coleoptera spp.*). Gourmet et al. (1996) reported that imidacloprid seed treatment decreased barley yellow dwarf virus infection in soft red winter wheat and increased yield upto fourteen percent. Similarly, Royer et al. (2005) reported imidacloprid seed treatment reduced bird cherry-oat aphids (*Rhopalosiphum padi*) and barley yellow dwarf in winter wheat.

Fungicide seed treatments help in controlling seed-borne wheat diseases such as common bunt and loose smut, and soil-borne diseases such as root and crown rots, seedling damping off, and blights. EverGol® Energy is a seed treatment containing the fungicides penflufen, prothioconazole, and metalaxyl and provides seed and seedling protection against a wide range of pathogens and diseases such as *Rhizoctonia solani*, *Fusarium spp.*, *Pythium spp.*, cereal smuts, barley stripe, and common bunt. Hagan (2014) reported that seed treatment with EverGol® Energy had significantly increase yield by 1480 kg ha^{-1} in oat (*Avena sativa*).

Schaafsma and Tamburic-Ilincic (2005) reported increased emergence, winter survival, tillering, spikes m^{-2}, and grain yield of winter wheat due to fungicide seed treatment with Dividend XL (defeconazole + metalaxyl). Pike et al. (1993) reported increased yield when seed was treated with imidacloprid alone or in combination with a fungicide. Ahmed et al. (2001) found ninety percent increase in yield due to the application of imidacloprid + tebuconazole in wheat. In Oklahoma, USA, DeVuyst et al. (2014) similarly reported a 144 kg ha^{-1} increase in wheat grain yield due to seed treatment with imidacloprid + metalaxyl + tebuconazole.

Although seed treatments are used to protect seeds and seedlings from different pathogens and insects, little information is available on economical and effective type of seed treatment combinations and its effects in contrasting agro-climatic regions of Nebraska and the Grain Plains of the United States. In addition,

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previous research needs to be updated as new genotypes and productions systems are developed. Therefore, this research was conducted to determine the effects of three different combinations of seed treatments on grain yield, grain protein content, and net economic returns of winter wheat genotypes grown under two contrasting environments in Nebraska.

METHODOLOGY

Site Description, Treatments and Experimental Design

Two-year (2014 and 2015 growing seasons) field experiment was conducted at the Agronomy Research Farm (ARF) in Lincoln, Nebraska (coordinates: 40°51'15.077" N 96°36'46.828" W, elevation: 360 m) and the High Plains Agricultural Laboratory (HPAL) in Sidney, Nebraska (coordinates: 41°13'47"N 103°0'4"W, elevation: 1314 m) under rainfed conditions (Bhatta et al. 2018). The soil type at the ARF site is Sharpsburg silty clay loam (Fine montmorillonitic, mesic typic Arguidoll) and Keith loam (Fine-silty, mixed, mesic Aridic Argiustolls) at the HPAL site (USDA-NRCS 2015).

Treatments were arranged in factorial design with eight replications. Factorial combinations of the six genotypes and the three seed treatments were applied to each block. The six genotypes of hard red winter wheat used in this study were 'Freeman', 'Millennium', 'Overland', 'Pronghorn', 'Robidoux', and 'Settler CL' and described in detail (Poudel et al. 2017). The six cultivars were chosen to represent popular cultivars in Nebraska that differed in their disease and insect reactions (Bhatta et al. 2018). Each plot was 1.8 m x 7.6 m at the HPAL and 1.5 m x6.1 m at ARF. The trials were planted on September 20 at the HPAL and October 2 at the ARF in 2013 whereas on September 15 at the HPAL and on October 17 at the ARF in 2015 (Bhatta et al. 2018).

The three chemical seed treatments were EverGol® Energy (fungicide), Gaucho® 600 (insecticide), and combinations of EverGol® Energy and Gaucho® (EverGol®+Gaucho®). Gaucho® is a seed treatment containing systemic insecticide imidacloprid and acts against a wide range of economically important insect pests (Pike et al. 1993). EverGol® Energy (EverGol®) and Gaucho® were applied in bulk to seed of each wheat genotype with a seed coating of pro-ized red seed colorant at 0.7 ml kg^{-1} of seed (Bhatta 2015).

Data Collection

Grain yield was measured during harvesting with a small plot combine harvester (Bhatta et al. 2017a). Harvesting was done on July 9 at the ARF in 2014 and on July 24 at the HPAL in both years. Near infrared reflectance (NIR) was used to measure grain protein concentration (Bhatta et al. 2017b).

Economic Analysis

Seed treatment cost was taken from Heatherly (2016), and wheat farm price in each year was taken from USDA-ERS (2015). Average seed treatment cost was \$14.83 ha^{-1}, and wheat farm price was \$0.2583 kg^{-1} in 2014 and \$0.2212 kg^{-1} in 2015. Net return from seed treatment was calculated as:

$$NR_{ST} = Yi_{CST}{}^{*}(WFP\text{-}STc)$$

Where, NR_{ST} is the net return from seed treatment cost; Yi is the yield increase due to the treatment obtained by subtracting yield from combined seed treatment (EverGol®+Gaucho®) to either EverGol® or Gaucho® only; WFP is the average wheat farm price, and STc is the seed treatment cost.

Data Analysis

Individual analysis of variance was performed following testing homogeneity of variance across four environments (2 sites by 2 years) to test the effects of seed treatment, genotype and their interactions. Seed treatment, genotype, and their interactions were considered fixed effects whereas replications were considered random effects. The LSMEAN statement was used to calculate treatment means, and mean separation was done using Fisher's protected LSD test at the five percent level of significance. All data were analyzed using PROC MIXED in SAS 9.4 (SAS Institute 2017).

RESULTS AND DISCUSSION

Grain Yield

Analysis of variance on the effect of seed treatment and genotype on grain yield and grain protein content is shown in Table 1. A significant effect of seed treatment and genotype was observed for grain yield. Average grain yield at

ARF was 4.97 mg ha^{-1} in 2014 and 3.28 mg ha^{-1} in 2015. Average grain yield at the HPAL was 5.03 mg ha^{-1} in 2014 and 2.18 mg ha^{-1} in 2015. Lower grain yield was observed in 2015 at both locations due to higher disease severity and relatively higher rainfall from jointing stage to late grain filling stage, suggesting that the growing condition was not favorable for wheat production (Bhatta et al. 2017a; Bhatta et al. 2018). In contrast, higher grain yield was observed in 2014 at both locations due to the favorable growing conditions for wheat production that is, low disease severity and moderate rainfall (Bhatta et al. 2017a; Bhatta et al. 2018).

Seed treatment had a significant effect on grain yield in 2014 at both sites. Seed treated with EverGol®+Gaucho® had increased grain yield compared to either EverGol® or Gaucho® in 2014 (Table 2). For instance, in 2014 at the ARF site, seed treated with EverGol®+Gaucho® increased grain yield by 10.5 percent and 7.8 percent, respectively, compared to either EverGol® or Gaucho® only (Table 3). Similarly, in 2014 at the HPAL site, seed treated with EverGol®+ Gaucho® increased grain yield by 4.2 percent and 5.3 percent, respectively, compared to either EverGol® or Gaucho® only. However, grain yield was not significantly affected by seed treatment in 2015 at both sites. This might be due to high disease severity observed in 2015 (Bhatt et al. 2017a; Bhatta et al. 2018), which may have overshadowed the effect of seed treatment. Although no significant effect of seed treatment was observed for grain yield in 2015 at both sites, seed treated with EverGol®+Gaucho® compared to Evergol® resulted in increased yield by 2.8 percent at the ARF site only and increased yield at both sites (1.4% at the HPAL site and 0.3% at the ARF site) when compared to Gaucho®. These results corroborated with the results of DeVuyst et al. (2014) and Ahmed et al. (2001), who found increased yield due to a combination of fungicide and insecticide seed treatment.

Although no significant seed treatment x genotype interaction was observed for grain yield in all sites and years (Table 1), genotype Freeman (2.05 mg ha^{-1} to 5.40 mg ha^{-1}), Overland (2.12 mg ha^{-1} to 5.47 mg ha^{-1}), Robidoux (2.34 mg ha^{-1} to 5.3 mg ha^{-1}), and Settler CL (2.38 mg ha^{-1} to 5.44 mg ha^{-1}) had grain yield higher than average grain yield when seed treated with EverGol®+Gaucho® in 2014 (Table 2). Additionally, Freeman, Overland, Robidoux, and Settler CL had mostly higher yield compared to other genotypes irrespective of seed treatment (Table 2). In 2014 at both sites, grain yield increased from seed treated with EverGol®+Gaucho® compared to either EverGol® or Gacuho® largely varied among genotypes ranging from 0.12 mg ha^{-1} to 0.77 mg ha^{-1} (Table 1). This result suggests that grain yield varied among genotypes and environments (sites and years). Similar results were observed by Bhatta et al. (2017a).

Grain Protein Content

Seed treatment had no significant effect on grain protein content (Table 1). This result was similar to that of Nass et al. (1975) who reported no effect of seed treatment on grain protein content. As expected, genotype had significant effect on the grain protein content (Table 1). Grain protein content was higher than average (121.6 g kg^{-1} in 2014 and 136.2 g kg^{-1} in 2015) for Millennium and Overland in 2014 and Millennium, Robidoux, and Settler CL in 2015 at the ARF site when seed treated with EverGol®+Gaucho® (Table 2). Similarly, grain protein content was high-

Table 1: Analysis of variance with mean squares for grain yield and agronomic characteristics of six genotypes grown at three seed treatments in four environments (2-sites and 2-years) of Nebraska

Source	*Grain yield (mg ha^{-1})*				*Grain protein content (g kg^{-1})*			
	ARF†		*HPAL*		*ARF*		*HPAL*	
	2014	*2015*	*2014*	*2015*	*2014*	*2015*	*2014*	*2015*
Seed treatment (ST)	3.31***	0.11	0.91***	0.08	8.80	0.30	6.20	0.30
Genotype (G)	1.81***	3.12***	2.47***	0.34***	13.0*	97.4***	29**	13.2**
STxG	0.12	0.04	0.04	0.08	8.00	0.90	7.70	3.80

*, **, and ***Significant at the 0.05, 0.01, and 0.001 probability levels respectively
†ARF: Agronomy Research Farm; HPAL: High Plains Agricultural Research Laboratory

Table 2: Mean grain yield and grain protein content for each genotype at each seed treatment in two growing seasons (2014 and 2015) at the Agronomy Research Farm (ARF) in Lincoln and at the High Plains Agricultural Laboratory (HPAL) in Sidney, Nebraska

Seed treatment	*Genotype*	*Grain yield (mg ha^{-1})*				*Grain protein content (g kg^{-1})*			
		ARF		*HPAL*		*ARF*		*HPAL*	
		2014	*2015*	*2014*	*2015*	*2014*	*2015*	*2014*	*2015*
EverGol®+ Gaucho®		5.27[a†]	3.31[a]	5.19[a]	2.17[a]	121.6[a]	136.2[a]	139.8[a]	123.5[a]
	Freeman	5.40	3.87	5.57	2.05	117.1	126.8	133.7	119.9
	Millennium	5.08	3.44	5.03	2.10	126.1	138.1	145.4	123.0
	Overland	5.47	3.37	5.33	2.12	122.1	136.2	139.7	127.3
	Pronghorn	4.97	3.14	4.56	2.02	123.7	131.1	145.1	120.9
	Robidoux	5.30	2.76	5.19	2.34	120.0	148.2	137.8	124.6
	Settler CL	5.40	3.26	5.44	2.38	120.9	136.7	137.1	125.3
EverGol®		4.77[b]	3.22[a]	4.98[b]	2.22[a]	121.1[a]	135.7[a]	137.7[a]	123.4[a]
	Freeman	5.03	3.63	5.33	2.24	117.5	127.1	139.3	120.0
	Millennium	4.35	3.37	4.91	2.06	123.3	136.9	140.1	124.7
	Overland	4.91	3.40	5.16	2.45	127.5	137.1	137.5	122.3
	Pronghorn	4.20	3.08	4.35	2.04	115.2	131.7	138.9	124.4
	Robidoux	4.97	2.66	5.05	2.14	122.1	146.2	132.9	125.1
	Settler CL	5.14	3.20	5.08	2.39	121.2	135.1	137.4	124.1
Gaucho®		4.89[b]	3.30[a]	4.93[b]	2.14[a]	123.7[a]	135.9[a]	139.4[a]	123[a]
	Freeman	5.10	3.93	5.19	2.06	123.7	128.4	138.8	118.7
	Millennium	4.74	3.52	4.83	2.09	125.1	137.9	141.7	126.2
	Overland	5.12	3.35	5.01	2.25	123.8	135.8	138.7	122.7
	Pronghorn	4.47	3.06	4.44	2.06	121.8	133.0	145.0	119.5
	Robidoux	4.90	2.80	5.01	2.12	119.8	145.1	129.9	128.6
	Settler CL	5.00	3.16	5.09	2.28	127.8	135.4	142.6	122.5
Overall Mean		4.97	3.28	5.03	2.18	122.1	135.9	138.9	123.3

[†]Means followed by the same letters (a & b) in a given column are not significantly different at $p<0.05$ according to Fisher's LSD test

er than average (139.8 g kg^{-1} in 2014 and 123.5 g kg^{-1} in 2015) for Millennium and Pronghorn in 2014 and Overland, Robidoux, and Settler CL in 2015 at the HPAL (Table 2). Genotype that had higher grain yield (Freeman, Overland, Robidoux, and Settler CL) with grain protein content $\geq$ 120 kg^{-1}, has an acceptable bread quality (Baenziger et al. 2001).

Economic Returns from Seed Treatment

Table 3 shows grain yield increased due to seed treatment and net economic returns associated with different genotypes across sites and years. Net returns from the combined seed treated with EverGol®+Gaucho® compared to EverGol® were $ 121.96 ha^{-1} in 2014 and US$18.61 ha^{-1} in 2015 at the ARF site whereas net returns were $51.22 ha^{-1} in 2014 and -$10.34 ha^{-1} in 2015 at the HPAL site (Table 1). Similarly, net returns from the combined seed treated with EverGol®+ Gaucho® compared to Gaucho® were $95.52 ha^{-1} in 2014 and $2.06 ha^{-1} in 2015 at the ARF site whereas net returns were US$ 63.3 ha^{-1} in 2014 and $6.19 ha^{-1} in 2015 at the HPAL site (Table 1). Net returns in 2014 was higher due to the significant increase in grain yield from the application EverGol®+Gaucho® seed treatment.

Positive net returns were observed for all genotypes when seed treatment had significant effect on grain yield such as year 2014 at both sites. However, the amount of net returns varied among genotypes and with change in sites. For instance, in 2014, net returns for Freeman ranged from $73.03 ha^{-1} to $92.52 ha^{-1}, $ 29.22 ha^{-1} to $ 177.73 ha^{-1} for Millennium, $ 41.39 ha^{-1} to $ 136.34 ha^{-1} for Overland, $ 29.22 ha^{-1} to $ 187.47 ha^{-1} for Pronghorn, $ 34.09 ha^{-1} to $ 97.39 ha^{-1} for Robidoux, and $ 63.3 ha^{-1} to $ 97.39 ha^{-1} for Settler CL. Positive net returns were observed in 2015 for few genotypes at both sites even though non-significant effect of seed treatment was observed. For instance, positive net returns were observed in 2015 for Pronghorn ($12.38 ha^{-1} to $16.51 ha^{-1}) and Settler CL ($12.38 ha^{-1} to $20.64 ha^{-1}) at the ARF site and for Millennium ($2.06

Table 3: Mean grain yield increase and net returns to assess economic returns from seed treatment application compared to either EverGol® or Gaucho® seed treatments at four environments (2-sites and 2years) in Nebraska

Treatment	*Genotype*	*Grain yield increase*				*Input Cost*	*Wheat price*†		*Net returns*			
		ARF		*HPAL*					*ARF*		*HPAL*	
		2014	*2015*	*2014*	*2015*		*2014*	*2015*	*2014*	*2015*	*2014*	*2015*
		mg ha^{-1}				*US\$ ha*$^{-1}$	*US\$ mg*$^{-1}$		*US\$ ha*$^{-1}$			
EverGol®+		0.5	0.09	0.21	-0.05	14.83	258.3	221.2	121.96	18.61	51.22	-10.34
Gaucho® *Compared to EverGol*®												
		10.5%‡	2.8%	4.2%	-2.3%							
	Freeman	0.37	0.24	0.24	-0.19	14.83	258.3	221.2	90.08	49.53	58.43	-39.21
	Millennium	0.73	0.07	0.12	0.04	14.83	258.3	221.2	177.73	14.45	29.22	8.25
	Overland	0.56	-0.03	0.17	-0.33	14.83	258.3	221.2	136.34	-6.19	41.39	-68.10
	Pronghorn	0.77	0.06	0.21	-0.02	14.83	258.3	221.2	187.47	12.38	51.13	-4.13
	Robidoux	0.33	0.10	0.14	0.20	14.83	258.3	221.2	80.35	20.64	34.09	41.27
	Settler CL	0.26	0.06	0.36	-0.01	14.83	258.3	221.2	63.3	12.38	87.65	-2.06
EverGol®+*Gaucho*®		0.38	0.01	0.26	0.03	14.83	258.3	221.2	92.52	2.06	63.3	6.19
Compared to Gaucho®												
		7.8%‡	0.3%	5.3%	1.4%							
	Freeman	0.3	-0.06	0.38	-0.01	14.83	258.3	221.2	73.04	-12.38	92.52	-2.06
	Millennium	0.34	-0.08	0.2	0.01	14.83	258.3	221.2	82.78	-16.51	48.69	2.06
	Overland	0.35	0.02	0.32	-0.13	14.83	258.3	221.2	85.21	4.13	77.91	-26.83
	Pronghorn	0.5	0.08	0.12	-0.04	14.83	258.3	221.2	121.74	16.51	29.22	-8.25
	Robidoux	0.4	-0.04	0.18	0.22	14.83	258.3	221.2	97.39	-8.25	43.82	45.4
	Settler CL	0.4	0.1	0.35	0.1	14.83	258.3	221.2	97.39	20.64	85.21	20.64

†USDA-Economic Research Service 2015; ‡Percentage increased in grain yield

ha^{-1} to \$8.25 ha^{-1}) and Robidoux (\$41.27 ha^{-1} to \$45.4 ha^{-1}) at the HPAL site (Table 1).

CONCLUSION

This research showed treating seeds treated with both insecticide and fungicide (EverGol®+ Gaucho®) increased grain yield (upto 0.77 mg ha^{-1} that is, 770 kg ha^{-1}) and net economic returns (up to \$187.47 ha^{-1}) whereas no significant effect of seed treatment was observed on grain protein content. Seed treated with EverGol®+ Gaucho® was beneficial when weather condition for wheat production was favorable. Genotype Freeman, Overland, Robidoux, and Settler CL had high grain yield with acceptable grain protein content for bread making when seeds were treated with EverGol®+Gaucho®. However, the magnitude of increase in yield and economic returns from EverGol®+Gaucho® compared to individual application of either EverGol® or Gaucho® largely varied with genotype and environments (sites and years).

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