Exploring Genotype by Environment Interaction in Winter Canola in North Carolina

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Abstract

Farmers in the Southeastern U.S have recently begun growing winter canola to meet a local demand for biodiesel, but optimal varieties for the region are unclear. Winter canola was trialed in North Carolina and the trial data analyzed to obtain estimates of genotype by environment interaction. Yields were found to be similar to the U.S. national average. There was considerable yield variation between varieties, with the minimum yield being 0.1 Mg/ha and the maximum 3.4 Mg/ha. Little genotype by environment interaction was observed. The low genotype by environment interaction indicates that the best performing cultivars are likely to be broadly adapted and that future evaluation can be reasonably restricted to a limited number of sites. The results suggest that if appropriate varieties are selected, winter canola could be an economically viable crop in the Southeastern U.S. It is recommended that winter canola varieties continue to be evaluated in the Southeast.

Keywords: Winter canola, *Brassica napus,* Southeastern United States, Genotype by environment interaction

1. Introduction

Annually, the United States produces over 500 thousand hectares of canola (*Brassica napus* L.) (NASS, 2010), primarily spring canola in North Dakota, with limited commercial production elsewhere (NASS, 2010). There has been long-standing interest in canola in the southeastern United States but a lack of local markets has acted as an obstacle to industry development. At current production costs and seed prices, winter canola can be economically viable, with a break-even yield of approximately 1.5 Mg/ha (George, Tungate, Hobbs, & Atkinson, 2008). Farmers have therefore begun producing a small area of winter canola to meet the demand of the local biodiesel industry. However, growers in the region report mixed success from winter canola plantings.

Since 2000, winter canola has been evaluated in several states of the Southeastern U.S. as part of the Kansas State University Winter Canola Variety Trials. Data from these trials suggest that winter canola can perform well in the Southeast U.S. but, as would be expected, performance is strongly dependent on cultivar and year, with the top-performing varieties varying between sites and seasons. Analyses of genotype by environment interaction have been used to identify high-yielding and broadly-adapted canola genotypes (for example (Cullis, Smith, Beeck, & Cowling, 2010; Gunasekera, Martin, Siddique, & Walton, 2006; Javidfar, Alemkhomaram, Oghan, & Azizinia, 2004; Marjanovic´-Jeromela, et al., 2011)) but to date there has been no attempt to conduct a similar analysis of data for winter canola from the Southeastern U.S. Furthermore, the authors continue to encounter Southeastern farmers who are unwilling to consider adopting canola due to perceived concerns regarding the potential for poor seedling establishment, low winter survival, lodging, and uneven maturity and shattering at harvest.

In this paper we report on the outcome of winter canola trials conducted in North Carolina. The trial data is analyzed to estimate genotype by environment interaction and evaluate the performance of cultivars on a state-wide basis. A general evaluation of the performance of canola in the context of the perceived problems with the crop in the Southeast is provided. The potential of canola in the state is assessed and recommendations regarding future research needs are made.

2. Experimental

2.1 Site Description and Establishment

Over three seasons, between 2007 and 2010, canola was established at seven trial sites North Carolina (Figure 1). All sites were located at research stations managed by either North Carolina States University or the North Carolina Department of Agricultural and Consumer Service: Clayton - Central Crops Research Station (35 40 00 N 78 29 00 W), Fletcher - Mountain Horticultural Crops Research Station (35 24 00 N 82 33 00 W), Jackson Springs - Sandhills Research Station (35 11 00 N 79 40 00 W), Oxford - Oxford Tobacco Research Station (36 18 00 N 78 36 00 W), Plymouth - Tidewater Research Station (35 50 00 N 76 39 00 W), Reidsville - Upper Piedmont Research Station (36 22 00 N 79 41 00 W), Williamsdale - Williamsdale Farm (34 45 00 N 78 06 00 W). Preliminary analysis of the data suggested that genotype by environment interaction was low, so the number of sites was reduced in the final season.

Site characteristics and agronomic information are given in Tables 1 and 2. Sites had a variety of edaphic characteristics. Soil analysis for each site was performed by the North Carolina Department of Agriculture and Consumer Services. Soil-type information for each site was obtained from the USDA Web Soil Survey (USDANRCS, 2010). The climatic conditions at each site were obtained from the State Climate Office of North Carolina (Table 3).

Throughout the study, sixty-five winter canola varieties were evaluated (Table 4). These varieties were selected from the National Winter Canola Variety Trial, which is coordinated by Kansas State University. The winter canola was planted approximately six weeks before the average date for the first killing frost (-4°C) in the respective regions (late September in the western half of the state and early to mid October in the eastern half). Prior to planting, the sites were cultivated and treated with glyphosate for weed control. Seeding rates were approximately 5.5 kg per hectare using a 9-row grain drill with 15 cm row spacing. Individual plot dimensions were 1.2 by 5 m in the first year and 1.5 by 14.5 m in the two subsequent years. A 0.3 m alley between plots and a 0.6 m guard row were planted around the trial. The sites were rolled with a culti-paker before and after planting to provide a firm seedbed. Plots were arranged in a randomized complete block design with three replicates.

2.2 Data Collection and Analysis

Seedling emergence was recorded as plant numbers in two 0.5 m^2 grids per plot. The peak flowering date was recorded as the date when approximately 50% of plots at a site were in flower. Varieties were harvested concurrently when the moisture content of a bulked seed sample taken from the guard row at a site was 10% or less (determined using a Superpro Moisture Analyzer and typically occurring in early- to mid-June). In the first year of the study, varieties were cut and threshed by hand. In subsequent years, a Gleaner R-76 small-plot combine was used. Flowering, lodging, shattering, and seedpod maturity were visually assessed using National Winter Canola Variety Trial protocols (Stamm, et al., 2010).

Yield data was analyzed as a Multi-Environment Trial (MET) using the ASReml-R program (Gilmour, Cullis, Gogel, Welham, & Thompson, 2005), which implements a factor analytic mixed model analysis adjusted for spatial field trends (A. Smith, Cullis, & Gilmour, 2001). This type of analysis uses a two-stage approach, firstly, the data from individual trials from one year are analyzed using spatial techniques, then the variety-by-trial mean data is combined with data from all years for an overall mixed model analysis (A. Smith, Cullis, & Gilmour, 2001; A. B. Smith, Cullis, & Thompson, 2005). This produces an estimate of genotype, and genotype by environment interaction, providing a prediction of the yield of each variety at each environment and across different environments, as well as information about interactions with the environment (A. Smith, Cullis, & Thompson, 2001). In the case of this dataset, a factor analytic model of order FA-1 explained 78% of the variance. For the clustering of environments, an agglomerative (nested) hierarchical clustering algorithm was used that is implemented in the "agnes" package of R (R Development Core Team 2009 (Cullis, et al., 2010)).

3. Results

The peak flowering date varied by site and year but generally occurred in the four-week period between the end of March and the end of April. Observations in late winter over all sites and years revealed close to 100% plant survival. Time to maturation was relatively uniform across all sites and years, and seed matured evenly. In the 2007-08 and 2009-2010 trials, all plots were at least 95% mature at harvest, and in the 2008-2009 trial maturity was at least 85%. Shattering was less than 15% and lodging was less than 5% across all sites and years.

There were few observations of pests and disease. Sclerotinia stem rot was observed at all the sites in the 2007-2008 season. Aphids were also observed on plants in 2007-008, however their occurrence was restricted to areas of only a few square meters and no damage was noted.

Over all sites and varieties, the average yield was 1.6 Mg/ha. There was considerable variation in yield between varieties; across all sites, excluding Jackson Springs, the minimum yield was 0.1 Mg/ha (Jetton, Clayton 07-08) and the maximum 3.4 Mg/ha (Dimension, Williamsdale 08-09) (Table 4). The relative performance of the varieties, excluding Jackson Springs, is shown in Table 5. Varieties yielding in the top tenth percentile would be expected to achieve on average over 1.8 Mg/ha across all sites and seasons. The top varieties were 46W14 2.0 Mg/ha, Dimension 2.0 Mg/ha, Kronos 2.0 mg/ha, Baldur 1.9 Mg/ha, Hybrisurf 1.8 Mg/ha and Visby 1.8 Mg/ha.

The REML analysis showed all sites, with the exception of Jackson Springs, clustered together (Table 6). For this reason, Jackson Springs was excluded from the remainder of the analysis. Table 5 shows the individual performance of lines at each site over years as best linear unbiased predictions (BLUPs) plus the site mean. As the genetic correlations were high it is reasonable to average the BLUPS for all sites, except Jackson Springs, to get a ranking for lines at all sites in the MET (Table 6).

4. Discussion

This work found that the yield of winter canola in North Carolina compares favorably to the national average yield (1.6 Mg/ha) from commercial canola production in the United States (NASS, 2010). It should be noted, however, that much of the canola crop in the United States is spring canola, which would be expected to yield lower than winter canola. The mean yields achieved in this study are also comparable to those obtained in other states in the Southeast (Rife, 2002, 2004; Rife & La Barge, 2005, 2006; Stamm & La Barge, 2007, 2008; Stamm, et al., 2010; Stamm, La Barge, & Roozeboom, 2006). Given current production costs and seed prices, this yield exceeds the minimum yield required for canola to be economically viable in the Southeast, and suggests winter canola should be competitive with winter wheat (Bullen & Weddington, 2010), which is the other common winter crop option in the region.

Clustering in the REML analysis indicates that the ranking of winter canola genotypes in terms of yield across the sites is generally similar. The winter canola varieties in this experiment range from very un-adapted low-yielding material to broadly adapted high-yielding material and the results suggest that the rankings will likely be similar between sites as the un-adapted material will always be un-adapted, and low ranking, and the adapted material will be consistently better. Nevertheless, the high correlation between sites still suggests low genotype by environment interaction across the whole state, even with the diverse variety set in this study.

The finding of low genotype by environment interaction suggests that the best-performing varieties indentified in this study are also broadly adapted and suitable for production across the entire state. The top varieties were 46W14, Dimension, Kronos, Baldur, Hybrisurf and Visby. Given the broad adaption identified here it would be interesting to conduct a similar analysis using yield data from winter canola from other states in the Southeast US to explore the extent of this regional adaptation. The results also suggest that the future evaluation of winter canola in the state can be restricted to one or two sites in the Piedmont, thereby increasing the efficiency of the research efforts. However, if a market for winter canola in the region matures, and more varieties are developed, it is likely that the level of genotype by the environment interaction may increase as adaptation for particular environments improves. Under those circumstances, future evaluation of new germplasm on a more localized basis is advised.

The difference in variety ranking between Jackson Springs and the other sites is thought to be mainly associated with increased soil moisture at this site relative to the other sites. Jackson Springs received substantially more rainfall than the other sites and was also irrigated in spring, amounting to 25 mm per week through April. Additional soil moisture also resulted in increase mean yield across all varieties at the Jackson Springs site. The mean yield was 2.5 Mg/ha, which is higher than the other sites, with the exception of Williamsdale in the 2008-2009 season, which achieved 2.8 Mg/ha. We hypothesize that the high yield at Williamsdale was the result of high phosphorous indices at the site.

As the acceptable yield data indicates, across all the sites and years, the overall performance of winter canola in North Carolina was excellent. No problems were encountered in terms of pests and disease, poor seedling establishment or winter survival, lodging, or uneven maturity and shattering. Given our experience with winter canola in these trials, we believe that if farmers in the region adhere to recommended production guidelines perceived problems are unlikely to be encountered.

5. Conclusions and Recommendations

This research establishes that winter canola performs well in North Carolina. Mean yields are comparable to the national average and a number of varieties performed consistently above the mean, suggesting the potential for the commercialization of winter canola within the state given the development of suitable markets. Due to the promising results of this work, it is suggested that winter canola varieties continue to be evaluated in the Southeast region. Finally, given the low GxE detected for sites within North Carolina it would be interesting to conduct a MET analysis of data for study sites elsewhere the Southeast to determine the extent of this regional adaption.

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Table 1. Details of soil analyses for the research sites

Site	Season	Soil Type	Soil P (kg/ha)	Soil K (kg/ha)	Soil S (kg/ha)	Humic matter (g/100 cm3)	Cation exchange capacity (meq/100 cm3)	Soil pH	Previous crop
Clayton	2007-2008	Wagram loamy sand	96	254	28	0.46	2.9	5.8	Small grain
Fletcher	2007-2008	Bradson gravelly loam	170	375	39	0.41	7.3	6.1	Fallow
Jackson Springs	2009-2010	Candor Sand	105	125	19	0.66	4.7	6.9	Small grain
Oxford	2008-2009	Helena Sandy Loam	201	176	44		3.9	5.4	Pasture
Plymouth	2007-2008	Portsmouth fine sandy loam	151	352	99	4.95	11	4.7	Potatoes
Reidsville	2007-2008	Rion sandy loam	216	420	77	0.36	4.9	5.3	Tobacco
Reidsville	2008-2009	Rodhiss Sandy Loam	NA	NA	NA	NA	NA	NA	Pasture
Willamsdale	2008-2009	Goldsboro loamy Sand & Noboco Loamy fine sand	373	101	29	1.49	5.6	5.1	Fallow
Williamsdale	2009-2010	Goldsboro loamy Sand & Noboco Loamy fine sand	320	85	40	0.92	5.4	5.4	Prairie grass

Table 2. Details regarding the management of the research sites

	N applied (kg/ha)	P applied (kg/ha)	K applied (kg/ha)	S applied	Panting date	Emergence Counts	Harvested
Clayton	130-160	55	170	500 L/ha 24S	Oct 4 2007	Dec 2 2007	June 5-6 2008
Fletcher	130-160	0	0	0	Sept 20 2007	Nov 24 2007	June 19-20 2008
Jackson Springs	30 and 90	50	0	26 NH4SO3	Oct 7 2009	Nov 7 2009	June 7 2010
Oxford	100-110	40	40	0	Oct 9 2008	Nov 6 2008	June 11 2009
Plymouth	130-160	0	0	0	Oct 11 2007	Dec 12 2007	June 16-17 2008
Reidsville	130-160	0	0	0	Sept 25 2007	Nov 21 2007	June 11-12 2008
Reidsville	130	0	0	30	Oct 8 2008	Nov 5 2008	Jun 19 2009
Willamsdale	30 and 90	0	0	26 NH4SO3	October 20 2009	Nov 17 2009	June 8 2010
Williamsdale	30 and 90	0	0	26 NH4SO3	Oct 10 2008	Nov 4 2008	June 4 2009

Table 3. Climatic conditions reported for each site throughout the study

	Ave (°C)	Max (°C)	Min (°C)	Rain and irrigation (mm)	Year
Clayton	12.6	29.6	-4.1	504	2007-2008
Fletcher	10.2	25.1	-7.9	640	2007-2008
Jackson Springs	11.7	26.6	-4.2	1294	2009-2010
Oxford	10.7	25.3	-8.2	725	2008-2009
Plymouth	12.9	30.8	-3.3	495	2007-2008
Reidsville	11.9	29.3	-4.7	499	2007-2008
Reidsville	10.7	26.6	-8.4	733	2008-2009
Williamsdale	12.1	26.9	-4.2	555	2008-2009
Williamsdale	13.9	28.5	-3.6	429	2009-2010

Table 4. The estimated per hectare yield of the winter canola varieties at various sites in North Carolina (Mg/ha)

ENTRY	Clayton 07-08	Fletcher 07-08	Plymouth 07-08	Reidsville 07-08	Oxford 08-09	Williams 08-09	Reidsville 08-09	Williams 09-10	Jackson Springs 09- 10
45D03	0.75	1.64	1.24	1.47					
46W14	1.47	1.92	2.04	1.82	1.74	3.2	1.88		
46W99	1.21	1.7	1.61	1.65					
ARC00005-2								2.09	2.45
ARC00024-2								2.1	2.45
ARC2180-1	1.05	1.69	1.49	1.68					
ARC2189-2								2.13	2.44
ARC98015	1	1.74	1.51	1.73					
ARC99009-1								2.12	2.44
Baldur	1.21	1.77	1.75	1.81	1.56	2.98	1.85	2.19	2.41
Ceres	1.09	1.65	1.45	1.64					
CWH081	1	1.71	1.52	1.62					
CWH095	1.21	1.78	1.66	1.62					
CWH111	0.97	1.8	1.53	1.54	1.49	2.76	1.83		
CWH116	0.64	1.42	1.08	1.28					
CWH633	0.84	1.77	1.35	1.55					
Dimension	1.37	1.85	1.93	1.8	1.6	3.4	1.86	2.23	2.4
DKW13-69	0.84	1.66	1.22	1.37					
DKW41-10	0.93	1.49	1.33	1.51					
DKW45-10	0.84	1.58	1.32	1.61					
DKW46-15	0.95	1.55	1.29	1.55					
DKW47-15	0.99	1.8	1.45	1.42					
DSV07100	1.3	1.99	1.78	1.82					
Dynastie								2.05	2.47
Flash	0.67	1.39	1.12	1.15				1.96	2.49
Forza	1.24	1.75	1.77	1.7					
Hornet	0.57	1.33	1.01	1.01					
HPX-501	0.64	1.42	0.96	1.18					
HPX-567	0.7	1.56	1.16	1.33					
Hybrigold	1.23	1.91	1.78	1.7	1.36	2.6	1.81		
Hybristar	1.05	1.75	1.49	1.49	1.44	3	1.83	2.14	2.44
Hybrisurf	1.14	1.72	1.54	1.65	1.58	2.93	1.84	2.17	2.42
HyClass107W	0.7	1.47	1.1	1.38					
HyClass110W	1.05	1.64	1.58	1.76	1.41	2.67	1.82		
HyClass115W	0.93	1.7	1.44	1.51					
HyClass154W	0.86	1.75	1.51	1.52	1.2	2.43	1.79	1.99	2.49
Jetton	0.13	1.05	0.39	0.79					
Kadore	0.94	1.83	1.39	1.51	1.42	2.93	1.82	2.09	2.45
Kiowa	1	1.74	1.45	1.61	1.43	2.7	1.82		
Kronos	1.42	2.04	1.92	1.81	1.65	2.97	1.87		
KS3018	0.84	1.61	1.33	1.43					
KS3074	1.06	1.73	1.56	1.62					
KS3077	1.01	1.92	1.51	1.57	1.57	2.62	1.83		
KS3132	0.93	1.73	1.36	1.49					
KS3254	0.89	1.72	1.42	1.55					
KS3302	1.1	1.83	1.6	1.56	1.43	2.98	1.84		
KS4022	0.85	1.58	1.37	1.44					
KS4085	0.82	1.66	1.18	1.4					
Rally	0.55	1.41	0.97	1.14					
Rapeseed	0.73	1.51	1.26	1.37					
Riley	1.02	1.68	1.51	1.6	1.41	2.67	1.83		
Safran	0.77	1.46	1.23	1.33				2.03	2.47
Satori	1.07	1.66	1.48	1.59					
Sitro	0.79	1.4	1.17	1.21				2.06	2.48
Sumner	0.88	1.55	1.28	1.55					
Taurus	1.18	1.69	1.72	1.87					
Virginia	0.92	1.66	1.42	1.48	1.47	2.98	1.82		
Visby	0.98	1.81	1.53	1.6	1.56	2.77	1.83	2.18	2.43
Wichita	0.91	1.65	1.46	1.55	1.31	2.56	1.82	2.18	2.43

Table 5. Overall rank of BLUPS as deviations from the mean (1.6 Mg/ha) for 8 sites tested over 3 years

Variety	Rank	Variety	Rank
46W14	0.35	Virginia	0.01
Kronos	0.3	Arc00024-2	0
NPZ0791RR	0.25	HyClass115W	0
Dimension	0.24	KS3254	-0.01
DSV07100	0.24	Arc00005-2	-0.02
Forza	0.19	HyClass110W	-0.02
Baldur	0.18	KS3132	-0.02
Taurus	0.17	Wichita	-0.02
CWH095	0.15	DKW41-10	-0.04
Hybrisurf	0.14	DKW46-15	-0.04
46W99	0.13	CWH633	-0.04
Hybrisurf	0.1	DKW45-10	-0.05
KS3302	0.1	Hybrigold	-0.05
HyClass117W	0.09	KS4022	-0.05
KS3074	0.08	KS3018	-0.06
Visby	0.07	Sumner	-0.06
ARC2180-1	0.06	Dynastie	-0.07
ARC2189-2	0.06	DKW13-69	-0.09
ARC98015	0.06	45D03	-0.1
KS3077	0.06	Safran	-0.1
Ceres	0.05	KS4085	-0.11
CWH081	0.05	Rapeseed	-0.12
CWH111	0.05	Sitro	-0.15
Hybristar	0.05	HPX-567	-0.16
Satori	0.05	HyClass107W	-0.17
Riley	0.04	CWH116	-0.21
ARC99009-1	0.03	Flash	-0.21
Kiowa	0.03	HPX-501	-0.25
DKW47-15	0.02	Hornet	-0.27
HyClass154W	0.01	Rally	-0.27
Kadore	0.01	Jetton	-0.59

Table 6. The genetic correlation between sites for canola yield tested in North Carolina

	Clayton 2008	Fletcher 2008	Plymouth 2008	Reidsville 2008	Oxford 2009	Reidsville 2009	Williamsdale 2009	JackSprings 2010	Williamsdale 2010
Clayton 2008	1.00								
Fletcher 2008	0.71	1.00							
Plymouth 2008	0.90	0.71	1.00						
Reidsville 2008	0.78	0.62	0.79	1.00					
Oxford 2009	0.80	0.64	0.81	0.70	1.00				
Reidsville 2009	0.94	0.75	0.95	0.83	0.85	1.00			
Williamsdale 2009	0.69	0.55	0.70	0.61	0.62	0.73	1.00		
JackSprings 2010	-0.94	-0.75	-0.95	-0.83	-0.85	-1.00	-0.73	1.00	
Williamsdale 2010	0.80	0.64	0.81	0.71	0.72	0.85	0.63	-0.85	1.00

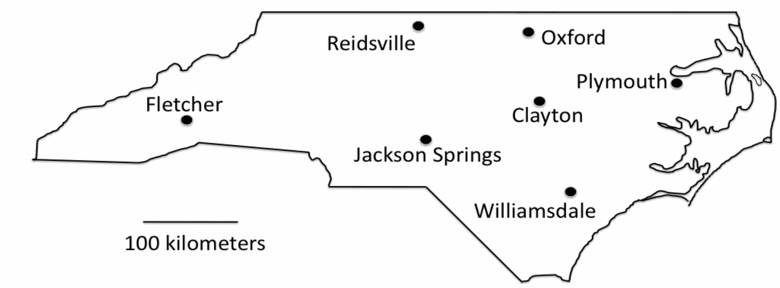

Figure 1. The location of winter canola variety trial sites in North Carolina between 2007 and 2010