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Additive main effects and multiplicative interaction analysis of European linseed (*Linum Ustatissimum* L.) cultivars under South African conditions

Abstract

Flax (Linum ustatissimum L.) is a multipurpose crop cultivated for both the fibre in the stem (fibre flax) or for its oil pressed from the seed (linseed). The natural qualities of flax make it a desirable commodity for manufacturers seeking alternative solutions to chemical and plastic-based products. As there is no production of flax in South Africa, ten linseed cultivars were imported from the Netherlands and the United Kingdom and evaluated for their adaptability under South African conditions. These cultivars were planted during the 2005 to 2009 season at six different localities (environments) in the Western Cape Province under rain fed conditions. The localities were, Bredasdorp, Caledon, Elsenburg, Koringberg, Langgewens and Napier. The Additive Main Effects and Multiplicative Interaction (AMMI) statistical method as well as the PCA (Principal Component Analysis) model were used to describe cultivar environment interaction on grain yield. Results indicated that the cultivars Sunrise, Capricorn, Bilstar, Virgo and Taurus were the most adapted cultivars for high potential environments.

Keywords: flax, AMMI model, ASV, linseed

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Abbreviations: AMMI, additive main effects and multiplicative interaction; ASV, ammi stability value; PCA, principal component analysis; CxE, cultivar x environment interaction

Introduction

Flax (*Linum ustatissimum* L.) is a multipurpose crop cultivated for both the fibre in the stem (fibre flax) or for its oil pressed from the seed (linseed). The natural qualities of flax make it a desirable commodity for manufacturers seeking alternative solutions to chemical and plastic-based products. Linseed grains, which are either brown or yellow, contain 35-45% oil and 18-26% protein. Linseed oil is the most widely available botanical source of Omega-3 fatty acids. Alpha-linolenic acid (ALA) is the important Omega-3 fatty acid in linseed, which is of considerable benefit to humans and animals. Linseed cultivars vary in their ALA content, from cultivars with an ALA content of 2%, which makes them unsuitable for the Omega-3 market, to ALA-rich cultivars (60% ALA) which are extremely suitable for the Omega-3 human food and animal feed markets. Cultivars with an ALA content of 2% compete with sunflowers for processing into margarine and cooking oil.[1]

Practically, all linseed and linseed products used in South Africa are currently being imported from countries such as Canada, Germany, Denmark and the Netherlands. Canada is the world's leading producer of linseed oil and according to Statistics Canada the current production is running 13% below demand.[2] Thus, here is a high demand for this commodity which can potentially be exploited by local farmers. Linseed is an excellent rotational crop with wheat and barley. Flax has great potential to be planted commercially under South African conditions.[3] The current study was undertaken to interpret Cultivar x Environment (CE) interaction obtained by AMMI analysis of yield performance of 10 linseed cultivars over 6 environments, to visually assess how yield performances vary across environments on a biplot and to group the cultivars having similar response patterns across varying environments together.

Materials and methods

Description of the study area

Five linseed cultivars (Bilton, Biltstar, Capricorn, Taurus and Virgo -imported from the Netherlands) and another five cultivars imported from the UK (Gemini, Laser, Linus, Marmalade and Sunrise) were evaluated over a four year period from 2005 to 2009 at six localities (environments) namely Bredasdorp, Caledon, Elsenburg, Koringberg, Langgewens & Napier in the Western Cape Province of South Africa. The trails were planted from mid-May to early June after the first rains and cultivated under rain fed conditions. A seeding rate of 50kg seed ha^{-1} was used. Standard fertilization and weed control practices were implemented throughout the study. 400kg ha^{-1} of 2:3:4 (27) was incorporated in the soil before planting. Two top dressings of 50kg ha^{-1} was done with Limestone ammonium nitrate (LAN). Harvesting of grain was commenced during November. The trial design was a randomized block design with three replications. Plot size was 1mx4m with 6 rows. The inter-row spacing was 25cm with a sowing depth of 2cm. Linseed grain yield data was used to evaluate the different cultivars and localities applying the Additive Main effects and Multiplicative Interaction (AMMI) model.[4] AMMI stability values (ASV) were computed from stability values as derived by Purchase et al.[5]

Results and discussion

Although numerous statistical techniques are available to describe cultivar x environment interaction[6–8] the additive main effects and multiplicative interaction method (AMMI) has been used by various researchers on crops such as bread wheat,[5] cotton,[9] durum wheat,[10] faba bean,[11] lucern,[12] maize,[13] potatoes[14] and tobacco.[15] The graphical version (biplot) of the cultivar means and the first interaction (PCA) Principle component analysis scores eases interpretation and identification of high yielding cultivars. Principal component analysis is a variable reduction procedure and is the most frequently used multivariate method.[6,16] Its aim is to transform the data from one set of coordinate axes to another, which preserves, as much as possible, the original configuration of the set of points and concentrates most of the data structure in the first principal component axis.

From the ANOVA table for AMMI analysis it can be seen that the mean squares for cultivars, environments and C x E interaction were found to be highly significant (Table 1). This suggested that a broad range of diversity existed among cultivars and among environments and that the performance of the cultivars was inconsistent over environments. Of the total treatment variation, the variance due to difference in the environment was the largest (61.2%) as can be expected in diverse production areas in the Cape Province of South Africa. This was followed by the variance due to C x E interactions (16.7%) (Table 2). In contrast, the variance due to cultivar was only 2.0%. The ordinary ANOVA model accounted for 63.2% of the trial sum of squares, concentrating only on the cultivar effects and environment effects. Although it is obvious that cultivars, environments and cultivar x environment interaction exerted a significant effect on yield, it is not clear which cultivars, environments or cultivar x environment interactions were responsible for the differences, or how these responses differ. The ANOVA model was thus found not to be adequate enough for analyzing the linseed grain yield data, as C x E interactions were highly significant. The ANOVA model was, therefore, combined with PCA (Principal Component Analysis) model to further analyze the residuals of the ANOVA model, which contains the C x E interaction (Table 1). Results from the analysis of multiplicative effects showed that the first interaction principal component analysis (IPCA1) captured 54.7% of the interaction sum of squares. The second interaction principal component analysis (IPAC2) explained only 13.3% of the C x E interaction. This is of relative minor magnitude and it would be difficult to draw meaningful conclusions from this principal component factor. Further analysis would, therefore, mostly concentrate on the IPCA1 scores.

The IPCA1 scores and mean performances data (grain yield) for both cultivar and environment that were used to construct an AMMI biplot are presented in Table 3. This was used to identify a specific pattern of the main effect and C x E interactions on both the cultivars and environments simultaneously.[6–8] It is clear from the biplot that the points for environment were more scattered than the points for cultivars (Figure 1). This indicated that variability due to environments was higher than that of cultivar differences. According to the AMMI model, cultivars which are characterized by means greater than grand mean and the IPCA score nearly zero are considered as generally adaptable to all environments (this suggests negligible or no C x E interaction). The cultivars, Laser and Linus meet these requirements. On the other hand, cultivars with high mean performance and with large value of IPCA scores are considered as having specific adaptability to the environments. The cultivars Sunrise, Capricorn, Bilstar, Virgo and Taurus fell into this category. Favourable environments for these cultivars can be characterized as with high mean and large IPCA score with same sign as of cultivar IPCA1 score. The environments in quadrant II of the biplot, i.e. Elsenburg 2007, Caledon 2007, Langgewens 2007; 2009 and Napier 2008, will thus be suitable environments for these cultivars. Similar sign of IPCA1 scores implies positive interaction and as a result will suggest higher yield of related cultivars. Lower potential environments predominating in quadrant I nemely Langgewens 2006, Bredasdorp 2006 and Koringberg 2006 and 2008 are grouped together, because of the low rainfall received.

AMMI analysis generates predicted means which gave greater accuracy, hence greater value for making selections than do the unadjusted or observed means.[4] The observed and AMMI predicted values are demonstrated in Table 2. Based on this predicted yield data, it is evident that Virgo is one of the first five AMMI selections in 16 out of 20 environments, Linus 13 out of 20, Sunrise is 12 out of 20 and Taurus 11 out of 20 environments, but no clear pattern is evident in terms of localities or seasons (Table 3).

Purchase et al.,[5] developed a test based on AMMI model's IPCA1 and IPCA2 values for each cultivar and each environment.[5] It is called the AMMI Stability Value (ASV). An AMMI stability value is the distance from the coordinate point to the origin in a two dimensional scatter gram of ICPA1 scores against ICPA2 scores.). Cultivar Bilton (with the lowest ASV), was ranked as the most stable cultivar but it had a below average yield performance, except for the highest yield at Elsenburg (2006). The environment Napier in the 2007 season was the most stable environment and Langgewens 2008 and Elsenburg 2008 was the least stable environments. The latter two environments received flush floods during the 2008 season which had an effect on the grain yield. Cultivar Bilton was ranked with the lowest ASV, as the most stable cultivar but it had a below average yield performance.

Table 1 ANOVA for AMMI model for the cultivar evaluation trials at the different localities in the Western Cape Province over the period 2005 – 2009

Source	df	SS	MS	Prob
Environment	19	107 497 885	5 657 783	<0.001
Block	40	19 175 697	479 392	<0.001
Cultivar	9	3 517 968	390 885	<0.001
C x E Interaction	171	29 286 665	171 267	<0.001
ICPA1	27	16 048 662	594 395	<0.001
ICPA2	25	3 901 523	156 061	<0.001
Residual	119	9 336 479	78 456	<0.001
Error	360	16 098 679	44 719	
Total	599	175 578 894	293 117	

Table 2 AMMI selections per environment

Environment	Year	Mean	IPCA1 Score	AMMI Selection				
Elsenburg	2007	1349	15.2	Linus	Sunrise	Gemini	Laser	Bilton
Caledon	2007	1280	11.1	Sunrise	Marmalade	Taurus	Gemini	Capricorn
Langgewens	2007	1280	9.3	Sunrise	Linus	Laser	Marmalade	Gemini
Langgewens	2006	488	5.7	Sunrise	Laser	Linus	Marmalade	Virgo
Koringberg	2007	567	5.4	Sunrise	Laser	Marmalade	Linus	Taurus
Elsenburg	2006	1953	5.1	Linus	Sunrise	Laser	Biltstar	Virgo
Elsenburg	2009	1286	5.1	Sunrise	Linus	Laser	Virgo	Marmalade
Bredasdorp	2006	574	4.8	Sunrise	Linus	Laser	Virgo	Marmalade
Caledon	2006	1074	4.5	Linus	Sunrise	Laser	Virgo	Biltstar
Caledon	2009	1449	4.5	Sunrise	Laser	Linus	Virgo	Taurus
Koringberg	2008	831	3.2	Linus	Biltstar	Virgo	Laser	Sunrise
Koringberg	2006	471	3.1	Sunrise	Taurus	Virgo	Laser	Linus
Napier	2006	905	0.8	Biltstar	Virgo	Linus	Laser	Taurus
Napier	2007	1017	0.3	Taurus	Sunrise	Virgo	Capricorn	Marmalade
Caledon	2008	1862	-1.5	Biltstar	Virgo	Linus	Bilton	Laser
Bredasdorp	2007	477	-1.9	Taurus	Virgo	Capricorn	Biltstar	Laser
Langgewens	2009	1134	-9.1	Taurus	Virgo	Biltstar	Capricorn	Laser
Napier	2008	1460	-11.5	Taurus	Virgo	Biltstar	Capricorn	Laser
Elsenburg	2008	1211	-26.9	Taurus	Virgo	Biltstar	Capricorn	Laser
Langgewens	2008	967	-26.9	Taurus	Virgo	Capricorn	Biltstar	Laser

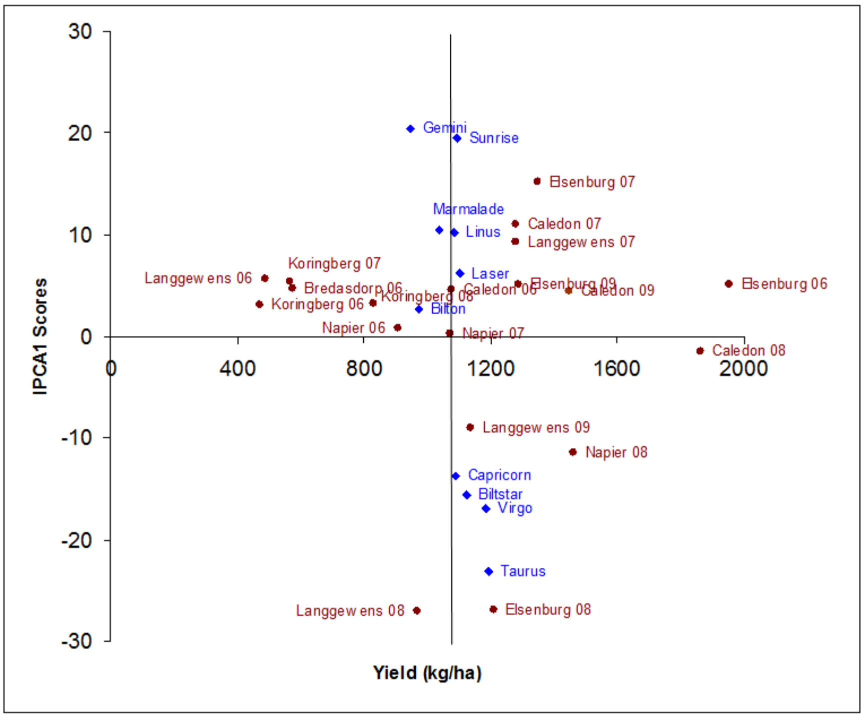

Figure 1 AMMI model biplot for linseed grain yield showing main and interaction effects for both cultivars and environments.

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Table 3 Observed and predicted grain yield (kg^{-1} ha^{-1}) of 10 linseed cultivars evaluated over 6 localities from 2005-2009

Environment	Year	Yield type	Bilton	Bilstar	Capricorn	Gemini	Laser	Linus	Marmalade	Sunrise	Taurus	Virgo
Bredasdorp	**2006**	T	584	643	591	*	546	569	493	702	694	528
		AMMI	495	562	501	530	625	636	569	668	560	597
Bredasdorp	**2007**	T	324	482	427	382	614	455	391	453	747	594
		AMMI	334	523	526	303	478	442	428	467	655	610
Caledon	**2006**	T	1009	1022	1062	*	1255	988	1153	1070	983	1105
		AMMI	1020	1091	988	1022	1128	1149	1052	1148	1044	1102
Caledon	**2007**	T	742	748	1420	1622	1761	1098	1661	1580	1509	1122
		AMMI	767	719	1415	1437	1304	1133	1604	1764	1483	1169
Caledon	**2008**	T	2012	2184	1675	1792	1919	1824	1836	1552	1892	1933
		AMMI	1957	2138	1749	1660	1901	1975	1679	1720	1838	2001
Caledon	**2009**	T	1293	1376	1348	1414	1367	1638	1441	1568	1500	1531
		AMMI	1344	1416	1397	1404	1494	1493	1456	1552	1462	1475
Napier	**2007**	T	855	1066	873	856	993	938	903	763	880	992
		AMMI	887	1027	893	768	940	970	815	878	924	998
Napier	**2008**	T	1005	819	990	447	1014	929	1166	1388	1237	1148
		AMMI	783	932	1098	905	1019	947	1048	1108	1220	1106
Napier	**2009**	T	1052	1906	1510	1820	1328	1576	1381	1381	1823	1812
		AMMI	1366	1730	1592	1080	1414	1373	1268	1220	1799	1760
Elsenburg	**2006**	T	2368	1566	1804	1594	1929	2098	2096	2077	1845	2047
		AMMI	1930	1991	1840	1907	2014	2052	1919	2020	1887	1973
Elsenburg	**2007**	T	1374	1226	912	1746	1581	1643	1191	1433	1163	1227
		AMMI	1431	1306	1045	1498	1484	1599	1375	1568	985	1201
Elsenburg	**2008**	T	1173	1713	1570	586	1146	626	942	701	2003	1655
		AMMI	1010	1656	1600	526	1059	926	896	709	1962	1770
Elsenburg	**2009**	T	1215	1578	1537	1234	1395	1298	1051	1564	1235	1740
		AMMI	1212	1273	1205	1247	1339	1354	1281	1382	1260	1303
Koringberg	**2006**	T	518	471	437	241	516	461	511	823	540	388
		AMMI	334	432	457	401	503	486	480	564	539	519
Koringberg	**2007**	T	388	631	562	630	641	374	491	855	488	616
		AMMI	429	484	526	546	613	598	604	710	588	575
Koringberg	**2009**	T	863	1057	808	808	810	848	750	858	783	690
		AMMI	832	928	725	742	884	928	760	844	786	885
Langgewens	**2006**	T	313	494	508	541	488	457	478	623	491	413
		AMMI	376	426	424	469	539	438	513	620	479	492
Langgewens	**2007**	T	1192	1095	1276	1575	1216	1500	1368	1194	1197	1200
		AMMI	1186	1172	1163	1331	1354	1371	1337	1476	1184	1225
Langgewens	**2008**	T	626	1258	1449	556	677	823	464	401	1843	1578
		AMMI	698	1345	1400	292	805	641	692	505	1773	1523
Langgewens	**2009**	T	1043	1132	1350	481	1246	1203	1345	768	1260	1505
		AMMI	1012	1332	1255	808	987	1098	1051	961	1444	1391

T – Observed mean yield AMMI – AMMI predicted yield *Cultivar not planted at locality

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Table 4 AMMI stability values for each cultivar

Cultivar	Yield	IPCA 1	IPCA 2	ASV
Bilton	970	2.7	16.5	19.9
Laser	1100	6.2	2.4	25.7
Linus	1083	10.2	9.9	73.3
Marmalade	1038	10.5	-9.7	44.0
Capricorn	1087	-13.8	-10.8	57.7
Biltstar	1124	-15.6	16.5	66.1
Virgo	1184	-16.9	0.9	69.9
Sunrise	1094	19.5	-9.8	80.7
Gemini	944	20.4	-2.7	84.0
Taurus	1194	-23.2	-13.3	96.3

Conclusion

Cultivar Bilton gave the highest yield of 2368 kg ha^{-1} at Elsenburg during the 2006 season. Bilton also gave the second highest yield at Caledon (2008) and Koringberg 2009, and the third best yield at Koringberg 2006. Cultivars Bilton and Laser were the AMMI best choices for most of the environments. Although Bilton had a slightly lower yield (970 kgha^{-1}) it had higher stability (ASV=19.9). Laser gave higher yields (1100kg) but lower stability (ASV=25.7). Other high yield performers was the cultivar Sunrise that gave the highest yields in 5 out of the 20 environments namely Bredasdorp (2006), Napier (2008), Koringberg (2006+2007), and Langewens 2008. Cultivar Bilstar gave the highest yield in 4 out of the 20 environments, namely: Caledon (2008), Napier (2007+2009) and Koringberg (2009). Although Taurus was found to be the most unstable cultivar according to the ASV values, and showed limited adaptation to testing environments, it gave a grain yield that is above average (Table 4), whereas the most stable cultivar (Bilton) gave below average yields. For this reason, stability in itself cannot be used as the only parameter for selection, as the most stable cultivar wouldn't necessarily give the best yield performance. This contradiction was also found by cotton researchers in California[17] that found a positive correlation between yield and stability and an association that suggests that cotton cultivars producing higher yields are, in general, lower in stability.

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Conflict of interest

The author declares no conflict of interest.

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