Indian J. Genet., 77(2): 293-297 (2017)
DOI: 10.5958/0975-6906.2017.00039.6

Genotype by environment interaction for oil content in winter oilseed rape (*Brassica napus* L.) using additive main effects and multiplicative interaction model

Kamila Nowosad[1], Alina Liersch[2], Wieslawa Poplawska[2] and Jan Bocianowski*

Poznañ University of Life Sciences, Department of Mathematical and Statistical Methods, Wojska Polskiego 28, 60-637 Poznañ, Poland; [1]Wroclaw University of Environmental and Life Sciences, Department of Genetics, Plant Breeding and Seed Production, Grunwaldzki 24A, 53-363 Wroclaw, Poland; [2]Plant Breeding and Acclimatization Institute – National Research Institute, Department of Oilseed Crops, Strzeszyñska 36, 60-479 Poznañ, Poland

(Received: October 2016; Revised: February 2017; Accepted: March 2017)

Abstract

The objective of this study was to assess genotype by environment interaction for oil content in winter rapeseed cultivars grown in West Poland by the additive main effects and multiplicative interaction model. The study comprised of 25 winter rapeseed genotypes (15 F_1 CMS *ogura* hybrids, parental lines and two European cultivars: open pollinated Californium and F_1 hybrid Hercules), evaluated at five locations in a randomized complete block design, with four replicates. Oil content of the tested genotypes ranged from 35.2 to 48.8%, with an average of 44.55%. AMMI analyses revealed significant genotype by environmental interaction with respect to oil content. The hybrid PN66×PN18 is recommended for further inclusion in the breeding program due to its high oil content, CMS *ogura* line PN66 and hybrid PN68×PN18 are recommended because of its stability and high oil content.

Key words: *Brassica napus*; oil content; AMMI

Introduction

The mature seeds of oilseed rape are characterized by high oil content: 45-50% in winter forms and 40-47% in summer forms. The oil from double low/canola (low erucic acid content < 2% in oil of seeds and low glucosinolate content < 25 μmol g^{-1} of seeds) quality oilseed rape varieties contains high amounts of C_{18} fatty acids, including monounsaturated oleic acid ($C_{18:1}$) approximately 61%, along with moderate amounts of the polyunsaturated linoleic acid ($C_{18:2}$) ~20%, linolenic acid ($C_{18:3}$) ~11% and eicosenoic acid ($C_{20:1}$) ~1.5%. The total saturated fatty acids (palmitic $C_{16:0}$, stearic $C_{18:0}$, arachidic $C_{18:1}$ and behenic) content is low and amounts 4-6%. Such fatty acid composition is make rapeseed oil an universal oil, perfect for edible purposes and better than that in others plant oils and also as an important renewable resource for non-food purposes as well as production of bio-components for biodiesel, tensides for detergent, biodegradable plastics and hydraulic oils (Wittkop et al. 2009). The world production of rapeseed oil with 24 mt takes third place after oil palm with production of 54 mt and soybean 42 mt (FAOSTAT 2016). The European Union rapeseed oil is a major edible oil, and in Poland is about 80% of all consumed vegetable oils.

One of the primary objectives in rapeseed breeding has always been increasing seed oil content as a way of maximizing oil production. This is also so essential for biodiesel market development for which the production costs must be as low as possible (Wittkop et al. 2009). A better knowledge of genetic determinism of oil content could help the breeders to control the genetic advance for the crop. Oil content is a very complex quantitative trait, which expression is the result of genotype, environment as well as the genotype x environment (GE) interaction (e.g. temperature, water and nutrient supply). Complexity of oil content is a results of different reactions of genotypes on changeable environmental conditions during plant development. Many breeders have understood the importance of GE interactions in plant

*Corresponding author's e-mail: jboc@up.poznan.pl
Published by the Indian Society of Genetics & Plant Breeding, F2, First Floor, NASC Complex, PB#11312, IARI, New Delhi 110 012
Online management by indianjournals.com; http://epubs.icar.org.in/journal/index.php/IJGPB

breeding programme for a long time (Shafii et al. 1992; Moghaddam and Pourdad 2011).

The GE interaction is often analyzed by the additive main effects and multiplicative interaction (AMMI) model (Zobel et al. 1988). The AMMI model is a combines the analysis of variance for the genotype and environment main effects and the principal component analysis (PCA) with multiplicative parameters in a single analysis. The objective of this study was to assess genotype by environment interaction for oil content in winter oilseed rape grown in West Poland by the AMMI model.

Materials and methods

Plant material for field trials consisted of 25 winter rapeseed genotypes: 15 F_1 CMS *ogura* hybrids (PN64×PN17, PN64×PN18, PN64×PN21, PN64×PN05, PN64×PN07, PN66×PN17, PN66×PN18, PN66×PN21, PN66×PN05, PN66×PN07, PN68×PN17, PN68×PN18, PN68× PN21, PN68×PN05, PN68×PN07), five restorer lines for Ogura system (PN05, PN07, PN17, PN18, PN21), three CMS *ogura* lines (PN64, PN66, PN68), two European cultivars (Californium and Hercules F_1).

The study was carried out at five locations: Baków (E1: 18°18'45'' E, 50°57'58'' N), Borowo (E2: 16°47'19'' E, 52°07'12'' N), Lagiewniki (E3: 17°14'13'' E, 51°45'40'' N), Malyszyn (E4: 18°37'31'' E, 51°14'42'' N) and Zielêcin (E5: 16°22'56'' E, 52°10'19'' N) in 2009. The field trials at all the locations were arranged in a randomized complete block design, with four replicates (Nowosad et al. 2016). After the harvest, oil content in dry seeds (about 5% moisture) was determined via pulsed nuclear magnetic resonance (NMR, 7005 MOA Oxford Instruments). A two-way fixed effect model was fitted to determine the magnitude of the main effects of variation and their interaction on oil content. Least-squares means were simultaneously produced for the AMMI model. The model first fits additive effects for the main effects of genotypes (G) and environments (E) followed by multiplicative effects for GE interaction by principal component analysis. The AMMI model (Gauch and Zobel 1990; Nowosad et al. 2016) is given by:

$$y_{ge} = \mu + \alpha_g + \beta_e + \sum_{n=1}^{N} \lambda_n \gamma_{gn} \delta_{en} + Q_{ge},$$

where y_{ge} is the oil content mean of genotype *g* in environment *e*, μ is the grand mean, α_g is the genotypic mean deviations, β_e is the environmental mean deviations, *N* is the number of PCA axis retained in the adjusted model, λ_n is the eigenvalue of the PCA axis *n*, γ_{gn} is the genotype score for PCA axis *n*, δ_{en} is the score eigenvector for PCA axis *n*, Q_{ge} is the residual, including AMMI noise and pooled experimental error. Expected distribution of Q_{ge} is normal. The AMMI stability value (ASV) was used to compare the stability of genotypes as described by Purchase (1997):

$$ASV = \sqrt{\left[\frac{SS_{IPCA1}}{SS_{IPCA2}}\left(IPCA_1\right)^2\right] + \left(IPCA_2\right)^2},$$

where SS is the sum of squares, IPCA1 and IPCA2 are the first and the second interaction principal component axes, respectively; and the $IPCA_1$ and $IPCA_2$ scores were the genotypic scores in the AMMI model. Genotypes with lower ASVs were considered relatively stable. The PCA analysis level of significance was tested with the *F* test. For the AMMI analysis, statistical package GenStat v. 17 was used.

Results and discussion

The results of field trials demonstrated the impact of weather conditions, environment and genotypes on the oil content of winter oilseed rape cultivars and lines. Oil content of the tested genotypes varied from 35.2 (for Hercules F_1 in E2) to 48.8% (for PN66×PN18 in E3) throughout the five seasons, with an average of 44.55% (Table 1). The PN66×PN18 hybrid had the highest average oil content, and the line PN18 had the lowest. The average oil content per location also varied from 38.97% in Borowo, to 46.77% in £agiewniki.

The three sources of variation were highly significant. In the analysis of variance, the sum of squares for environment main effect represented 68.21% of the total, and this factor had the highest effect on oil content. The differences between genotypes explained 9.46% of the total oil content variation, while the effects of GE interaction explained 6.33%. Values for the two principal components were also highly significant. The two principal components of GE interaction accounted jointly for 83.11% of the whole effect it had on the variation of oil content. The first principal component (IPCA 1) accounted for 45.64% of the variation caused by interaction, while IPCA 2 accounted for 37.47%. Oil content in winter oilseed rape (*Brassica napus* L.) is a trait determined by multiple genes that cause change in the performance of genotypes depending on the cultivation environment. Beeck et al. (2010) and Cullis et al. (2010) reported that there was little GE interaction for oil content despite of a large GE interaction on seed yield.

The AMMI1 biplot (Fig. 1) shows the stability of genotypes and environments, as well as specific GE interactions. Among the tested genotypes, the line PN21 had the highest IPCA 1 value of 0.84 while the highest value of IPCA 1 was 2.23 in Zielêcin (Fig. 1).

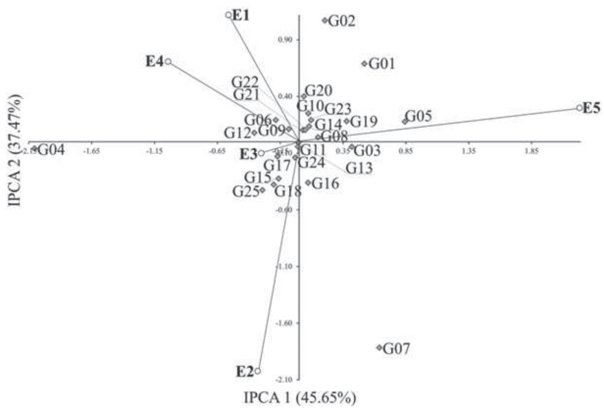

Fig. 1. Biplot for genotype by environment interaction of winter rapeseed (*Brassica napus* L.) lines and hybrids in five environments, showing the effects of primary and secondary components (IPCA 1 and IPCA 2, respectively)

Genotype stability is considered as consistent reaction to changing environmental conditions, weather conditions, agronomic factors, biotic and abiotic stresses. In this study, climatic conditions were the source of this variation component. The stability of tested genotypes can be evaluated according to biplot for oil content (Fig. 2). The hybrids PN64×PN18, PN64×PN07, and PN68×PN18 interacted positively with the E1 and E4 locations, but negatively with the E2 and E5 (Figs. 1 and 2). The lines PN68×PN07 and PN07 interacted positively with the E2 location, but negatively with the E1, E3, E4 and E5 locations. The analysis showed that some genotypes have high adaptation; however, most of them have specific adaptability. AMMI stability values (ASV) revealed variations in oil content stability among the 25 genotypes (Table 1). According to Purchase (1997), a stable variety is defined as one with ASV value close to zero. Consequently, the line PN66 with ASV of 0.01 and hybrids PN68×PN18 with ASV of 0.04 were the most stable while the lines such as PN18, PN64 and

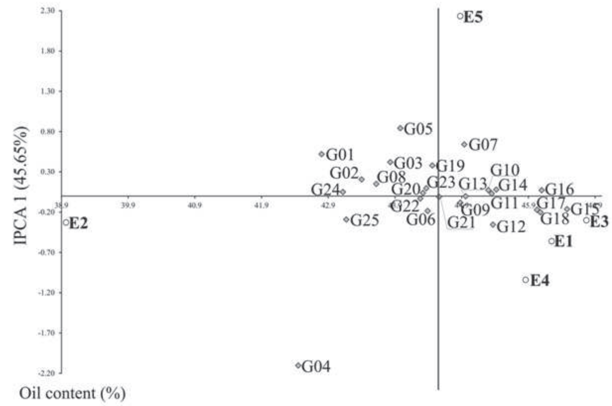

Fig. 2. Biplot for the primary component of interaction (IPCA 1) and average rapeseed (*Brassica napus* L.) oil content (%). Vertical line at the centre of biplot is the general grand mean

Hercules F_1 were the least stable (Table 1). Genotypes on the highest point in certain sections of the graph have the best results in environments located in the same section (Fig. 2). Hybrid PN68×PN18, with average oil content close to the general mean of 44.56%, is distinguished on the biplot. This line had the highest stability. A group of hybrids: PN66×PN18, PN66×PN21, PN66×PN05, and PN66×PN07 had the highest averages of oil content, but with different adaptations (Figs. 1 and 2): PN66×PN18 showed specific adaptation to the conditions of Lagiewniki, and PN66×PN07 to Baków.

The AMMI biplot allows the visualization of the main effects of the genotypes in different environments, in addition to the most important GE interactions. The AMMI model was often used in study of many species (Abakemal et al. 2016; Edwards 2016; Nowosad et al. 2016). The AMMI model provides a useful tool in diagnosing GE interaction patterns and improving the accuracy of response estimates. It enables clustering of genotypes based on similarity of response characteristics and identifying potential trends across environments. The suggested strategy could extract more information from the GE interaction, thereby aiding researchers in identifying specific cultivars with competitive yields across diverse environments.

The genotype and environment main effects as well as GE interaction had the strongest effect on oil content expression in West Poland. AMMI analyses permits estimation of interaction effect of a genotype in each environment and it helps to identify genotypes

Table 1. Average oil content (%), for genotypes and environments, principal component analysis values of tested rapeseed (*Brassica napus* L.) lines and hybrids and AMMI stability value (ASV)

Genotype	Code	E1	E2	E3	E4	E5	Mean	IPCA 1	IPCA 2	IPCA 3	ASV
Californium	G01	45.08	35.53	45.35	43.68	44.4	42.81	0.52	0.69	0.39	0.94
Hercules F_1	G02	45.78	35.20	46.60	45.02	44.4	43.40	0.21	1.07	0.66	1.10
PN17	G03	45.70	38.35	45.68	44.38	45.05	43.83	0.42	–0.04	–0.04	0.51
PN18	G04	45.58	37.55	46.03	45.23	37.9	42.46	–2.10	–0.06	0.56	2.56
PN21	G05	46.10	37.78	46.35	43.62	46.05	43.98	0.84	0.18	0.47	1.04
PN05	G06	47.15	38.92	45.5	45.95	44.42	44.39	–0.19	0.19	–0.56	0.30
PN64	G07	44.07	42.52	48.12	43.93	46.03	44.93	0.64	–1.82	0.61	1.98
PN64×PN17	G08	45.25	38.17	44.77	45.40	44.48	43.61	0.15	0.04	–0.68	0.19
PN64×PN18	G09	46.42	39.00	47.27	46.60	45.10	44.88	–0.08	0.11	0.02	0.15
PN64×PN21	G10	47.75	39.27	47.48	46.20	45.77	45.29	0.07	0.25	0.15	0.27
PN64×PN05	G11	47.05	39.60	47.33	46.95	45.85	45.36	0.03	0.10	–0.18	0.11
PN64×PN07	G12	46.83	39.67	47.60	47.70	45.05	45.37	–0.36	0.08	–0.21	0.44
PN66	G13	46.28	39.28	47.38	46.55	45.33	44.96	0.00	–0.01	0.02	0.01
PN66×PN17	G14	47.15	39.70	46.95	47.20	46.10	45.42	0.08	0.14	–0.46	0.17
PN66×PN18	G15	47.62	41.55	48.80	48.00	46.40	46.47	–0.16	–0.32	–0.06	0.38
PN66×PN21	G16	47.45	41.45	47.58	47.43	46.60	46.10	0.07	–0.36	–0.48	0.37
PN66×PN05	G17	47.20	40.62	48.53	47.80	46.00	46.03	–0.17	–0.13	0.01	0.25
PN66×PN07	G18	47.43	41.43	48.03	47.60	45.93	46.08	–0.20	–0.38	–0.26	0.45
PN68	G19	46.05	38.35	46.60	45.57	45.70	44.45	0.38	0.18	0.01	0.50
PN68×PN17	G20	46.45	37.90	46.53	45.85	44.85	44.32	0.04	0.40	0.03	0.40
PN68×PN18	G21	46.33	38.97	47.20	45.52	44.78	44.56	–0.01	–0.04	0.31	0.04
PN68×PN21	G22	45.80	38.92	46.75	45.45	44.48	44.28	–0.03	–0.14	0.14	0.15
PN68×PN05	G23	46.20	38.35	46.60	45.73	44.98	44.37	0.10	0.19	0.03	0.22
PN68×PN07	G24	44.43	37.32	44.95	45.15	43.75	43.12	0.05	0.10	–0.38	0.12
PN07	G25	45.15	38.75	45.17	44.1	42.68	43.17	–0.29	–0.43	–0.07	0.56
Mean		46.25	38.97	46.77	45.86	44.88	44.55				
IPCA 1		–0.56	–0.33	–0.30	–1.04	2.23					
IPCA 2		1.12	–2.02	–0.10	0.71	0.30					
IPCA 3		0.04	–0.39	1.48	–0.87	–0.25					

IPCA, principal component of interaction

best suited for specific environmental conditions. AMMI analyses revealed significant GE interaction with respect to oil content. The AMMI stability value exposed high genotypes stability. The hybrid PN66×PN18 is recommended for further inclusion in the breeding program due to its high oil content, CMS *ogura* line PN66 and hybrid PN68×PN18 are recommended because of its stability and high oil content. The AMMI results displayed on the GE biplot enables determination of the main effect of the genotype, the environment, and the most meaningful GE interactions. AMMI models are capable of measuring the weight of the environments, the genotypes and their interactions throughout a value that measures how stable a genotype is in all environments in terms of oil content.

Author's contribution

Conceptualization of research (KN, JB); Designing of the experiments (AL, WP); Contribution of experimental materials (AL, WP); Execution of field/lab experiments

and data collection (AL, WP, JB); Analysis of data and interpretation (KN, JB); Preparation of the manuscript (KN, AL, WP, JB).

Declaration

The authors declare no conflict of interest.

References

Abakemal D., Shimelis H. and Derera J. 2016. Genotype-by-environment interaction and yield stability of quality protein maize hybrids developed from tropical-highland adapted inbred lines. Euphytica, **209**: 757-769.

Beeck C. P., Cowling W. A., Smith A. B. and Cullis B. R. 2010. Analysis of yield and oil from a series of canola breeding trials. Part I. Fitting factor analytic mixed models with pedigree information. Genome, **53**: 992-1001.

Cullis B. R., Smith A. B., Beeck C. P. and Cowling W. A. 2010. Analysis of yield and oil from a series of canola breeding trials. Part II. Exploring variety by environment interaction using factor analysis. Genome, **53**: 1002-1016.

Edwards J. W. 2016. Genotype× environment interaction for plant density response in maize (*Zea mays* L.). Crop Sci., **56**: 1493-1505.

FAOSTAT 2016. hhtp://faostat3.fao.org.

Gauch H. G. and Zobel R. W. 1990. Imputing missing yield trial data. Theor. Appl. Genet., **79**: 753-761.

Moghaddam M. J. and Pourdad S. S. 2011. Genotype x environment interactions and simultaneous selection for high oil yield and stability in rainfed warm areas rapeseed (*Brassica napus* L.) from Iran. Euphytica, **180**: 321-335.

Nowosad K., Liersch A., Poplawska W. and Bocianowski J. 2016. Genotype by environment interaction for seed yield in rapeseed (*Brassica napus* L.) using additive main effects and multiplicative interaction model. Euphytica, **208**: 187-194.

Purchase J. L. 1997. Parametric analysis to describe G x E interaction and yield stability in winter wheat. PhD Thesis, University of the Orange Free State, Bloemfontein, South Africa.

Shafii B., Mahler K. A., Price W. J. and Auld D. L. 1992. Genotype x environment interaction effects on winter rapeseed yield and oil content. Crop Sci., **32**: 922-927.

Wittkop B., Snowdon R. and Friedt W. 2009. Status and perspectives of breeding for enhanced yield and quality of oilseed crops for Europe. Euphytica, **170**: 131-140.

Zobel R. W, Wright M. J. and Gauch H. G. 1988. Statistical analysis of yield trial. Agron. J., **80**: 388-393.