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Adaptability to organic farming of lentil (*Lens culinaris* Medik.) varieties developed from conventional breeding programmes

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SUMMARY

The development of organic agriculture has raised the demand for crop varieties well-adapted to organic farming systems. Most of the varieties presently cultivated in organic agriculture were developed from conventional breeding programmes. The objective of the present work was to study the adaptability to organic farming systems of lentil (*Lens culinaris* Medik.) varieties developed from conventional breeding programmes. Twenty varieties were evaluated over five environments under organic and conventional farming systems from 2005 to 2007. Genotype × system interactions (GSI) for grain yield were significantly different in four out of the five environments and GSI explained 0·03–0·17 of the variance. Spearman's rank correlation index of the 20 varieties between the conventional and organic system ranged from 0·27 to 0·93 in the five environments. Direct selection of the top five varieties in organic systems resulted in significantly higher grain yields than indirect selection in one out of the five environments. However, among the top five varieties, the highest yielding varieties under conventional farming systems were not always the highest yielding varieties under organic farming systems. These results indicate that the demands of organic agriculture for yield performance could be only partially satisfied by varieties developed under conventional breeding programmes.

INTRODUCTION

Legumes are of great importance for organic agriculture, mainly because they capture nitrogen (N) from the atmosphere and benefit soil fertility. Lentil (*Lens culinaris* Medik.) is one of the oldest grain legumes. In Greece, lentil cultivation dates back to 6000–5000 BC (Hopf 1962). Lentil is currently cultivated as a non-irrigated crop and the average yield obtained is *c*. 1·1 t/ha (Hellenic National Statistical Service 2005). Lentil cultivation has increased in recent years, largely due to consumers' interest in the crop for its nutritional quality and also lentil, being a legume crop, is considered to be an important factor in rotation systems with cereals (Muehlbauer *et al*. 2002) and N reduction programmes.

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The development of organic agriculture has raised the demand for varieties well adapted to organic farming systems (Lammerts van Bueren *et al*. 2003; Wolfe *et al*. 2008). Most of the varieties presently cultivated in organic agriculture were developed from high-input breeding programmes and adapted to conventional farming systems. Comparative trials between conventional and organic systems, however, indicated that these varieties exhibit lower yield and decreased adaptability under organic systems (Stanhill 1990; Porter *et al*. 2003; Ryan *et al*. 2004; Jones *et al*. 2010). The environment of selection is critical when breeding for organic farming systems. One of the key issues for breeders involved in such programmes is whether selection can either be performed directly under the organic environment (direct selection) or whether selection within conventional programmes could satisfy the demands of organic agriculture (indirect selection). References related to direct *v.* indirect selection are contradictory. Indirect selection was predicted to be either as efficient (Atlin & Frey 1989; Burger *et al.* 2008; Lorenzana & Bernardo 2008), more efficient (Calhoun *et al.* 1994) or less efficient (Ceccarelli *et al.* 1992; Sinebo *et al.* 2002; Brancourt-Hulmel *et al.* 2005; Murphy *et al.* 2007; Ghaouti & Link 2009) than direct selection in the target environment. Therefore, the adaptability of varieties among different environments is of great value for indirect selection.

Studying the response of lentil varieties to organic and conventional farming systems, Vlachostergios & Roupakias (2008) concluded that the grain yield obtained depends on the variety's response in each environment and recognized two adaptability types: those with specific and those with broad adaptability. In addition, Malhotra *et al.* (1971) observed that some lentil varieties produced higher yields under high-input environments, while others better-than-average yields under poor environments but failed to exploit better environmental conditions.

The object of the present study was to investigate the adaptability of 20 lentil varieties developed under conventional breeding programmes to organic farming systems under five environments.

MATERIALS AND METHODS

Plant material

Twenty lentil varieties (Table 1) selected from a germplasm collection maintained at the Fodder Crops and Pastures Institute (FCPI), Larissa, Greece were grown under conventional and organic farming systems. All varieties evaluated were developed under conventional breeding and originated from genetic material from Greece, ICARDA, Canada and USA. Varieties were screened using random amplification of polymorphic DNA (RAPD) and proved to be genetically distinct from each other (Vlachostergios *et al.* 2006). Two types of lentil varieties were used: small-seeded (Type I) and large-seeded (Type II). Small-seeded varieties are those with a mean seed weight <50 mg, while large-seeded varieties are those with mean seeds weight >60 mg. There is also an intermediate lentil type (Type III), with mean seed weight between 50 and 60 mg, but these were not used in the present work. The sowing rate was adjusted to provide 160–170 plants/m^2 for small-seeded lentils and 150–155 plants/m^2 for large-seeded lentils.

Locations and experimental design

Field experiments were established at the central farm of the Fodder Crops and Pastures Institute (FCPI) in Larissa, Greece (39°36′N, 22°25′E) during three consecutive growing seasons (2005–2007), and at the farm of Aristotle University (AUTH) near Thessaloniki, Greece (40°32′N, 22°59′E) during two consecutive growing seasons (2006–2007). This results in five 'environments', each a site–year combination, viz: Environment 1 (Envt 1) was at FCPI in 2005, Envt 2 at FCPI in 2006, Envt 3 at AUTH in 2006, Envt 4 at FCPI in 2007 and Envt 5 at AUTH in 2007. Environments had different climatic conditions and soil properties (Table 2).

Lentil varieties were grown in a randomized complete block within three organic and three conventional fields under each site–year (environment). Individual plots (4 m^2) consisted of five rows spaced 0·25 m apart and 4 m long. All plots in each replication were separated by 1 m buffer zones and replications were separated by 2 m buffer zones. The organic and conventional experiments were located *c.* 300 m apart at FCPI and 250 m apart at AUTH. Soil properties and microclimatic environment were more or less similar for organic and conventional fields within each environment (Table 2).

Table 1. *Variety origins and types*

Code No.	Variety	Origin	Seed type	Maturity group
1	F-75*	Greece	I	E
2	ILL-96	ICARDA	I	I
3	F-77	Greece	I	I
4	F-39*	Greece	I	I
5	FLIP/03-24L	ICARDA	I	I
6	ILL-590	ICARDA	I	E
7	LL-35	ICARDA	I	E
8	F-43*	Greece	II	I
9	CAN-I	Canada	II	L
10	73	ICARDA	I	E
11	US-2	USA	II	L
12	FLIP/02-1L	ICARDA	I	E
13	FLIP/94-5L	ICARDA	I	E
14	F-85	Greece	I	L
15	M-12490*	Greece	II	I
16	US-1	USA	I	L
17	FLIP/03-12L	ICARDA	I	E
18	M-17003	Greece	I	I
19	LC-960254	ICARDA	II	E
20	CAN-III	Canada	I	L

* A released cultivar.
ICARDA: International Centre for Agricultural Research in the Dry Areas, Syria.
Seed type: I small seeded, II large seeded.
Maturity group: E: early, I: intermediate, L: late.

Cultivation practices

Cultivation practices are presented in Table 3. The organic fields at FCPI have been certified since 2006. Varieties were harvested by hand and threshed using a Wintersteiger plot combine. The harvested area was

Table 2. *Precipitation recorded and soil characteristics of the trial fields*

		Conventional fields							Organic fields						
	Precipitation (mm)	Sand (%)	Silt (%)	Clay (%)	OM (mg/kg)	NO_3^- (mg/kg)	P* (mg/kg)	K (mg/kg)	Sand (%)	Silt (%)	Clay (%)	OM (mg/kg)	NO_3^- (mg/kg)	P* (mg/kg)	K (mg/kg)
Env-1	213	26	29	45	13	–	12	1·5	32	25	43	13	–	11	1·5
Env-2	386	33	24	43	14	46	15	1·31	37	24	39	16	31	13	1·1
Env-3	292	43	25	32	13	68	14	0·38	57	28	15	15	29	11	0·7
Env-4	184	34	20	46	12	32	14	1·4	36	22	42	15	31	10	1·1
Env-5	246	34	42	24	12	123	13	0·3	48	30	22	14	126	12	0·4

OM: organic matter.
* Olsen P.

Table 3. *Summary of crop management for organic and conventional systems*

Culture management	Organic system	Conventional system
Rotation system	Wheat/legume	Wheat/legume
Planting date	15–30 Nov	15–30 Nov
Fertilizer application		
Nitrogen	None	106 kg/ha (to previous cereal crop)
Phosphorus	None	58 kg/ha (to previous cereal crop) 60 kg/ha (lentil)
Pest control	None	Endosulfan (*Thrips* sp., *Bruchus* sp.), azinphos methyl (*Etiella zinkenella*)
Weed control	Deep summer field ploughing, row cultivation, hand weeding	Prometryne (broad leaf weeds), fluazifop-butyl (grass weeds)
Harvest date		
Early maturing var.	20–30 May	20–30 May
Intermediate maturing var.	1–10 Jun	1–10 Jun
Late maturing var.	after 10 Jun	after 10 Jun

3 m^2 per plot, as only the three central rows were harvested. Grain yield was adjusted to a moisture content of 130 mg/g fresh weight (FW).

Statistical analysis

The experiment was analysed as a split-plot. Systems (organic or conventional) were main plots and varieties were sub-plots within systems. Partitioning of sum squares treatment (SS_{TRMT}) was applied to study the effect of each variance component. Ranks were assigned to genotypes for grain yield and Spearman's rank correlation coefficient (*Rs*) was calculated. The computer program MSTAT version 1.2 (Michigan State University, East Lansing, MI, USA) was used to conduct the analysis of variance and the comparison of means. Direct selection was defined as the selection applied in the target environment. Indirect selection was defined as the selection applied in a system other than the target environment.

RESULTS

Variance component effect

Under the conventional farming system, the mean grain yield over the 20 varieties was 3, 34, 18, 21 and

37% more than under the organic farming system for Envts 1–5, respectively (Table 4). Significant differences in grain yield between systems were observed in Envts 2, 3 and 5, but not in Envts 1 and 4 (Table 5). Significant differences between lentil varieties ($P<0{\cdot}001$) were detected in each of the five environments, while genotype system interactions (GSI) were also highly significant in Envts 1, 2, 3 and 5 ($P<0{\cdot}001$; Table 5). Partitioning of the treatment sum squares (SS_{TRMT}) indicated that genotype was the main source of variation (0·69–0·93 of the total variation), followed by the farming system (0·002–0·14) or GSI (0·04–0·17; Table 5). Coefficients of variation (CV) ranged from 0·06 to 0·30 among the five environments (Table 5). The relatively high CV value observed Envt 4 was attributed to a serious infection of *Fusarium oxysporum* f. sp. *lentis*.

Ranking

In all environments, a positive rank correlation between yields in the conventional and organic system, ranging from 0·27 to 0·93 (Table 5), was observed. The rank correlation was significant for Envts 1–4 ($P<0{\cdot}05$), but not in Envt 5. Alterations in the ranking of the top five varieties were observed under both farming systems (Fig. 1). Minor ranking differences were observed in Envt 2, whereas major differences were seen in Envt 5. Listing the top five varieties in the conventional and organic system in each environment showed that only two were common in Envt 1, four in Envt 2, two in Envt 3, three in Envt 4 and one in Envt 5 (Table 4 and Fig. 1). Variety 9 (CAN-I) was the lowest producer in 6 out of 10 environment–system combinations, while variety 11 (US-2) was the next lowest producer in 8 out of 10 environment–system combinations and lowest in one.

Direct and indirect selection

The differences in the mean grain yield among the top five varieties under both farming systems subjected to direct and indirect selection are given in Fig. 2. Direct selection under conventional systems produced yields 11, 3, 14, 5 and 17% higher than the yields resulting from indirect selection for Envts 1–5, respectively. Similarly, direct selection in organic systems produced yields 6, 1, 12, 8 and 29% higher than the yields resulting from indirect selection for Envts 1–5, respectively. In Envt 1, when the target system was conventional farming, direct selection produced significantly ($P<0{\cdot}1$) higher yields than indirect selection. Similarly, in Envt 3, when the target was organic farming, direct selection produced significantly ($P<0{\cdot}1$) higher yield than indirect selection (Fig. 2). Finally, no significant differences were observed between direct selection and indirect selection under Envts 2, 4 or 5 for both farming systems. The data presented in Fig. 2 are not biased, since highly significant GSI were observed (Table 5).

DISCUSSION

The higher yields observed under conventional systems in all environments (Tables 4 and 5) are probably due to higher levels of phosphorus (P) inputs and pest control than in the organic systems. The experimental fields had low levels of P (Table 2) and thus the application of P fertilizer in the conventional fields was expected to increase the final yield performance. In addition, it was estimated that the application of pesticides resulted in 15–40% less pest damage under the conventional management (data not shown). Thus, the conventional farming system produced 3–37% more grain yield than the organic farming system in the five environments (Table 4).

Small-seeded lentil varieties ranked higher than the large-seeded ones under both farming systems and therefore were selected in the top five (Table 4). The exception was the large-seeded variety 9 (LC-960254), which ranked among the five highest yielders in Envt 3 under both farming systems and generally exhibited a stable yield performance, near or above the middle of the rank order. The rest of the large-seeded varieties (8, 9, 11 and 15) ranked among the low-yielding varieties and therefore were not selected. Variety no. 6 indicated a stable performance under the conventional farming system, as it was among the five high yielders over environments (Table 4). A corresponding variety for the organic farming systems was not identified.

Partitioning of the treatment sum squares (SS_{TRMT}) indicated that the genotype was the main source of variation in all environments (Table 5). The contribution of the genotype to the total experimental variation ranged from 0·69 to 0·93; such values indicate strong genetic differences between the varieties studied. The highest contribution of the genotypic effect was observed in Envt 4. This could be attributed to the fact that the genotypes in this environment were seriously infected by the fungus *F. oxysporum* f. sp. *lentis*. Fusarium wilt, as a soil-borne disease, cannot be controlled even in conventional systems, because field applications are not practical due to the cost and technical difficulty of incorporating chemicals into the soil during the growing season (Bayaa *et al.* 1997; Stoilova & Chavdarov 2006; Taylor *et al.* 2007). Consequently, in Envt 4, the main trait affecting the yield performance was the level of resistance to the disease and therefore no differences in GSI were observed. Thus, GSI for yield were significantly different in four out of the five environments. The variance that could be explained by GSI ranged from 0·04 to 0·17 of the total (Table 5). These results suggest that genotypes performed differently under organic and conventional systems. Similarly, Jones *et al.* (2010)

Table 4. *Rank order and grain yield (t/ha) of 20 lentil varieties in organic or conventional systems in five environments*

Ranking order	Envt 1				Envt 2				Envt 3				Envt 4				Envt 5			
	Org		Conv		Org		Conv		Org		Conv		Org		Conv		Org		Conv	
	Entry	Yield	Entry	Yield	Entry	Yield	Entry	Yield	Entry	Yield	Entry	Yield	Entry	Yield	Entry	Yield	Entry	Yield	Entry	Yield
1	13	1·64	1	1·91	17	1·76	1	2·26	18	1·97	5	2·61	6	1·98	6	2·07	6	1·56	6	1·91
2	5	1·60	17	1·67	1	1·69	6	2·23	14	1·87	19	2·61	7	1·53	7	1·62	7	1·15	19	1·54
3	17	1·53	18	1·64	6	1·67	3	2·14	13	1·84	6	2·57	17	0·89	20	0·89	20	1·03	5	1·36
4	10	1·50	5	1·62	18	1·54	17	1·93	19	1·73	14	2·10	5	0·72	14	0·83	12	0·94	10	1·33
5	3	1·47	6	1·60	5	1·52	18	1·90	17	1·72	3	2·07	12	0·69	5	0·80	3	0·92	17	1·23
6	1	1·36	4	1·55	7	1·49	5	1·84	5	1·61	18	1·98	14	0·62	5	0·74	1	0·88	3	1·16
7	18	1·36	13	1·54	13	1·47	13	1·81	4	1·51	10	1·92	18	0·61	17	0·74	14	0·88	18	1·15
8	14	1·36	12	1·50	3	1·42	7	1·78	7	1·45	13	1·82	19	0·58	12	0·74	2	0·77	7	1·13
9	19	1·34	3	1·37	19	1·34	10	1·71	12	1·43	4	1·80	20	0·53	16	0·66	15	0·72	1	1·13
10	4	1·33	10	1·33	10	1·17	4	1·69	3	1·40	2	1·70	13	0·51	1	0·64	13	0·71	2	1·02
11	15	1·25	19	1·30	4	1·16	19	1·69	2	1·36	17	1·69	3	0·49	11	0·59	10	0·70	13	1·02
12	6	1·25	16	1·22	12	1·13	14	1·48	6	1·36	7	1·55	1	0·44	4	0·58	16	0·69	4	0·96
13	12	1·18	2	1·20	16	0·89	12	1·44	1	1·33	1	1·41	4	0·42	19	0·52	19	0·66	12	0·95
14	16	0·98	14	1·12	20	0·86	16	1·42	10	1·33	15	1·38	10	0·34	9	0·42	18	0·63	20	0·95
15	7	0·94	7	0·91	2	0·84	2	1·10	15	1·20	12	1·31	16	0·33	13	0·42	17	0·61	14	0·90
16	8	0·88	15	0·91	14	0·64	15	0·77	20	1·09	20	1·18	2	0·23	10	0·36	4	0·57	15	0·62
17	2	0·88	8	0·77	15	0·60	9	0·76	8	0·91	8	1·04	15	0·17	15	0·32	5	0·48	16	0·55
18	20	0·81	20	0·71	8	0·48	20	0·76	16	0·83	9	0·65	8	0·07	2	0·31	8	0·36	8	0·43
19	11	0·77	11	0·63	11	0·41	11	0·71	9	0·82	11	0·59	11	0·05	3	0·26	11	0·29	11	0·38
20	9	0·73	9	0·39	9	0·26	8	0·60	11	0·73	16	0·51	9	0·04	8	0·18	9	0·18	9	0·27
mean ± s.e. (d.f.:76)		1·21 ± 0·142		1·25 ± 0·142		1·12 ± 0·071		1·50 ± 0·071		1·38 ± 0·112		1·63 ± 0·112		0·56 ± 0·079		0·68 ± 0·079		0·73 ± 0·141		1·0 ± 0·141

Table 5. *Split plot analysis of variance and proportion of the sum of squares (SS_{TRMT}), coefficient of variation (CV) and Spearman's rank correlation (Rs) for each environment*

Source	D.F.	Envt 1 SS	Envt 1 *P*	Envt 1 SS_{TRTM}	Envt 2 SS	Envt 2 *P*	Envt 2 SS_{TRTM}	Envt 3 SS	Envt 3 *P*	Envt 3 SS_{TRTM}	Envt 4 SS	Envt 4 *P*	Envt 4 SS_{TRTM}	Envt 5 SS	Envt 5 *P*	Envt 5 SS_{TRTM}
System	1	0·99	ns	0·002	142·33	<0·001	0·14	56·68	<0·001	0·06	20·70	ns	0·03	72·22	<0·05	0·14
Error (i)	2	26·39			0·04			0·74			9·70			3·59		
Genotype	19	396·94	<0·001	0·88	828·06	<0·001	0·82	775·01	<0·001	0·80	702·01	<0·001	0·93	367·78	<0·001	0·69
G×S	19	49·33	<0·001	0·11	42·62	<0·001	0·04	139·78	<0·001	0·14	25·17	ns	0·04	90·35	<0·001	0·17
Error (ii)	76	70·74			15·64			37·14			85·83			76·11		
CV		0·16			0·06			0·09			0·30			0·20		
Rs		0·77	<0·05		0·93	<0·05		0·76	<0·05		0·76	<0·05		0·27	ns	

concluded that the selection of wheat cultivars under conditions of high agrochemical inputs selected for cultivars that yielded well under high-input conditions and which also performed relatively better in non-organic compared to organic systems. However, in these lentil trials, the proportion of the treatment sum squares accounted for by GSI was not high enough to suggest that separate breeding programmes are required. Furthermore, although significant GSI were detected, some of the high-yielding varieties under the conventional system were also high yielders under the organic system (Table 4). Under these circumstances, separate breeding programmes for organic agriculture seem to be of no value. This is further supported by the high genotypic rank correlations (*Rs*) observed for yield in four (Envts 1–4) out of the five environments. Nevertheless, in one environment, Envt 5, the rank correlation between the two systems was very low (0·27) and so indirect selection is not a reliable predictor of high-yielding varieties for organic farming systems. Interestingly, in Envt 4, which was seriously affected by fusarium wilt, the two highly resistant varieties were those that ranked 1st and 2nd across the two farming systems without ranking alterations.

The main question to be answered is whether the top varieties bred under the conventional system have the appropriate adaptability when cultured under the organic culture system. Although Spearman's index was high for Envts 1 and 3 (Table 5), considerable ranking alterations were observed among the top five varieties (Fig. 1). However, according to Murphy *et al.* (2007), plotting ranks could accentuate the changes if there are no yield differences among the top five varieties when subject to direct and indirect selection in both systems. Murphy *et al.* (2007) observed both significant ranking alterations and yield differences among the top five varieties when subject to direct and indirect selection, and reported considerable evidence for direct selection to the organic environment. In the present research, the evidence for direct selection of organic environments was not so clear. Direct selection in organic systems produced yields 6, 1, 12, 8 and 29% higher than the yields resulting from indirect selection for Envts 1–5, respectively. However, direct selection resulted in significantly higher grain yields than indirect selection in only one out of the five comparisons (Envt 3; Fig. 2). Therefore, the majority of the results indicated that varieties relatively suitable for organic agriculture could be identified after the evaluation of varieties developed from conventional breeding programmes in an organic environment.

However, another parameter that should be taken into account in deciding whether the breeder should apply direct or indirect selection is the number of different varieties among the top five selected under each of the two systems. In Envt 5, for example,

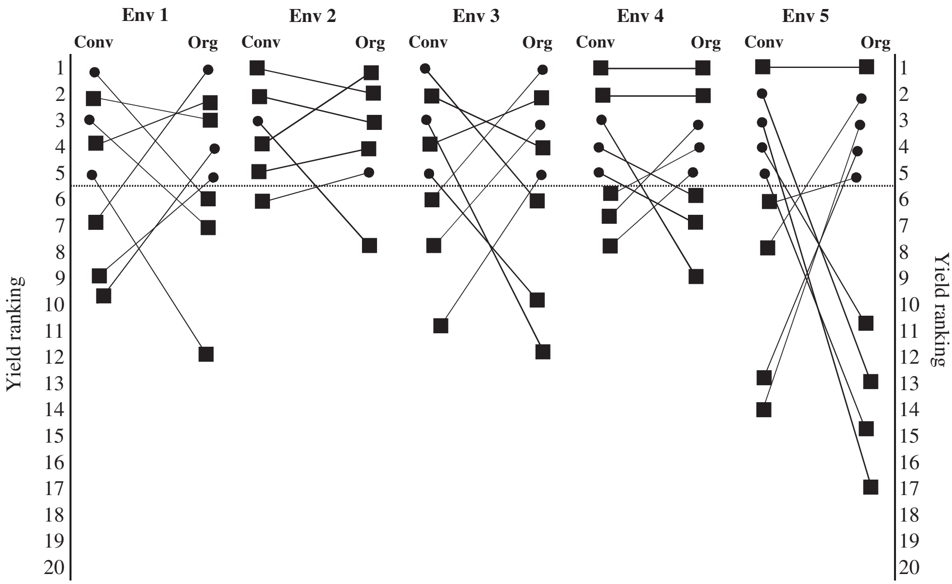

Fig. 1. Alterations in the rank order of the top five yielding varieties under organic and conventional systems for each environment. Varieties were ranked in descending order from 1 (highest yield) to 20 (lowest yield). For the top 5 varieties in each system, ■——■ shows reciprocal movement of ranking order (i.e. the cvar ranked 2nd under conventional farming in Envt 1 moved to 3rd under organic farming and vice versa), whereas ●——■ shows any cvar whose ranking moved from among the top 5 to below the top 5.

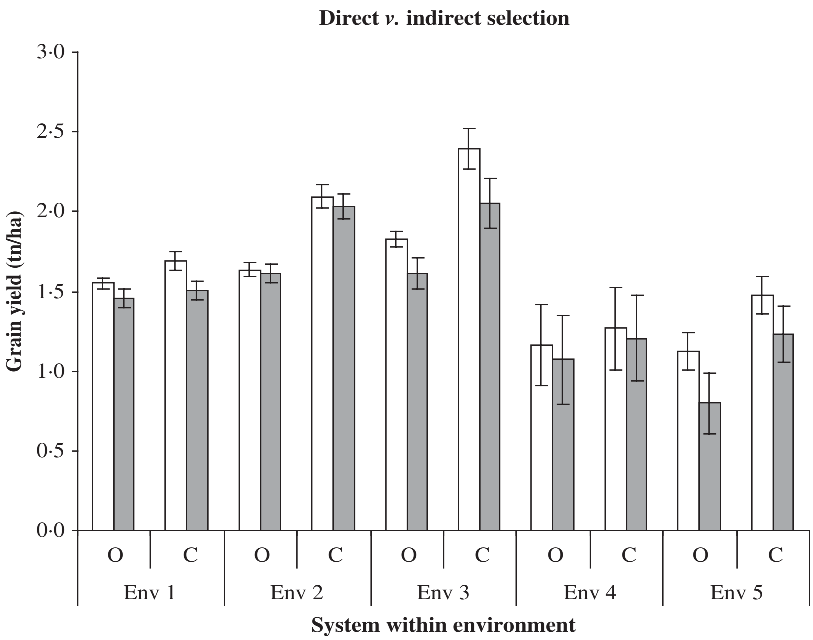

Fig. 2. Direct *v*. indirect selection for grain yield (t/ha) under organic and conventional systems within environments. White columns: direct selection (mean yield of the top five varieties in the target culture system); grey column: indirect selection (mean yield of the top five varieties under the opposite system, when grown under the target system). The bars represent the ±S.E. ($n=5$). O: organic system; C: conventional system.

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although no significant differences between direct and indirect selection were detected, only one out of the top five varieties selected under each environment was common (Fig. 1). In contrast, in Envt 2, four out of the five varieties selected in each environment were common. This illustrates that even when other parameters (e.g. GSI, Spearman's index, differences on yield between direct and indirect selection) indicate no need for separate breeding programmes, the number of different varieties among the top ones selected within systems is an extra and a critical point that could help the breeder to decide whether separate breeding programmes are advisable or not for organic farming systems. It is generally accepted that organic agriculture is concerned not only with yield but also with several other important characteristics (Löschenberger *et al.* 2008). Working with maize, Lorenzana & Bernardo (2008) concluded that high-yielding cultivars for organic systems can be largely developed by screening conventional inbreds or hybrids for their performance under organic systems, but testing and selection under organic conditions is required for other traits. Lammerts van Bueren (2002) and Lammerts van Bueren *et al.* (2002) elaborated a general organic ideotype with desired traits for organic agriculture. It is possible, then, that lentil varieties selected under organic environments could incorporate certain traits (i.e. early growth, appropriate root system for competitive P uptake, competition ability against weeds, resistance to soil-borne diseases, pests, etc.) that make them more suitable for organic agriculture than the one selected under conventional environments.

In conclusion, the demands of organic agriculture for yield performance could be partially satisfied by varieties developed under conventional breeding programmes. The yield performance, however, is expected to be maximized from varieties bred under organic conditions.

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REFERENCES

ATLIN, G. N. & FREY, K. J. (1989). Predicting the relative effectiveness of direct versus indirect selection for oat yield in three types of stress environments. *Euphytica* **44**, 137–142.

BAYAA, B., ERSKINE, W. & SINGH, M. (1997). Screening lentil for resistance to *Fusarium* wilt: methodology and sources of resistance. *Euphytica* **98**, 69–74.

BRANCOURT-HULMEL, M., HEUMEZ, E., PLUCHARD, P., BEGHIN, D., DEPATUREAUX, C., GIRAUD, A. & LE GOUIS, J. (2005). Indirect versus direct selection of winter wheat for low-input or high-input levels. *Crop Science* **45**, 1427–1431.

BURGER, H., SCHLOEN, M., SCHMIDT, W. & GEIGER, H. H. (2008). Quantitative genetic studies on breeding maize for adaptation to organic farming. *Euphytica* **163**, 501–510.

CALHOUN, D. S., GEBEYEHU, G., MIRANDA, A., RAJARAM, S. & VAN GIKHEL, M. (1994). Choosing evaluation environments to increase wheat grain yield under drought conditions. *Crop Science* **34**, 673–678.

CECCARELLI, S., GRANDO, S. & HAMBLIN, J. (1992). Relationship between barley grain yield measured in low- and high-yielding environments. *Euphytica* **64**, 49–58.

GHAOUTI, L. & LINK, W. (2009). Local vs. formal breeding and inbred line vs. synthetic cultivar for organic farming: Case of *Vicia faba* L. *Field Crops Research* **110**, 167–172.

NATIONAL STATISTICAL SERVICE (2005). http://www.statistics.gr/

HOPF, M. (1962). Bericht Uber die Untersuchung von Samen und Holzkohlenresten von der Argissa-Magula aus den präkeramischen bis mittelbronzezeitlichen Schichten. In *Die Deutschen Ausgrabungen auf der Argissa-Magula in Thessalien. Vol. I* (Eds V. Milojcic, J. M. Boessneck & M. Hopf), pp. 101–119. Bonn: Rudolf Habelt Verlag.

JONES, H., CLARKE, S., HAIGH, Z., PEARCE, H. & WOLFE, M. (2010). The effect of the year of wheat variety release on productivity and stability of performance on two organic and two non-organic farms. *Journal of Agricultural Science, Cambridge* **148**, 303–317.

LAMMERTS VAN BUEREN, E. T. (2002). *Organic plant breeding and propagation: concepts and strategies*. PhD Thesis, Wageningen University, Wageningen, The Netherlands.

LAMMERTS VAN BUEREN, E. T., STRUIK, P. C. & JACOBSEN, E. (2002). Ecological concepts in organic farming and their consequences for an organic ideotype. *Netherlands Journal of Agricultural Science* **50**, 1–26.

LAMMERTS VAN BUEREN, E. T., STRUIK, P. C., TIEMENS-HULSCHER, M. & JACOBSEN, E. (2003). Concepts of intrinsic value and integrity of plants in organic plant breeding and propagation. *Crop Science* **43**, 1922–1929.

LORENZANA, R. E. & BERNARDO, R. (2008). Genetic correlation between corn performance in organic and conventional production systems. *Crop Science* **48**, 903–910.

LÖSCHENBERGER, F., FLECK, A., GRAUSGRUBER, G., HETZENDORFER, H., HOF, G., LAFFERTY, J., MARN, M., NEUMAYER, A., PFAFFINGER, G. & BIRSCHITZKY, J. (2008). Breeding for organic agriculture – the example of winter wheat in Austria. *Euphytica* **163**, 469–480.

MALHOTRA, R. S., SINGH, K. B., BHULLAR, G. S. & SETHI, S. C. (1971). Phenotypic stability in lentil. *Indian Journal of Genetics and Plant Breeding* **31**, 21–25.

MUEHLBAUER, F. J., SUMMERFIELD, R. J., KAISER, W. J., CLEMENT, S. L., BOERBOOM, C. M., WELSH-MADDUX, M. M. & SHORT, R. W. (2002). *Principles and Practice of Lentil Production*. Washington, DC: USDA.

MURPHY, K. M., CAMPBELL, K. G., LYON, S. R. & JONES, S. S. (2007). Evidence of varietal adaptation to organic farming systems. *Field Crops Research* **102**, 172–177.

PORTER, P. M., HUGGINS, D. R., PERILLO, C. A., QUIRING, S. R. & KENT CROOKSTON, R. (2003). Organic and other management strategies with two- and four-year crop rotations in Minnesota. *Agronomy Journal* **95**, 233–244.

RYAN, M. H., DERRICK, J. W. & DANN, P. R. (2004). Grain mineral concentrations and yield of wheat grown under organic and conventional management. *Journal of the Science of Food and Agriculture* **84**, 207–216.

Sinebo, W., Gretzmacher, R. & Edelbauer, A. (2002). Environment of selection for grain yield in low fertilizer input barley. *Field Crops Research* **74**, 151–162.

Stanhill, G. (1990). The comparative productivity of organic agriculture. *Agriculture, Ecosystems and Environment* **30**, 1–26.

Stoilova, T. & Chavdarov, P. (2006). Evaluation of lentil germplasm for disease resistance to Fusarium wilt (*Fusarium oxysporum* f. sp. *lentis*). *Journal of Central European Agriculture* **7**, 121–126.

Taylor, P., Lindbeck, K., Chen, W. & Ford, R. (2007). Lentil diseases. In *Lentil: An Ancient Crop for Modern Times* (Eds S. S. Yadav, D. L. McNeil & P. C. Stevenson), pp. 291–313. Dordrecht, The Netherlands: Springer.

Vlachostergios, D. N., Mavromatis, A. G., Korkovelos, A. & Roupakias, D. G. (2006). Phylogenetic relationships of lentil (*Lens culinaris* Medik.) varieties. In *Book of Abstracts of the 10th Panhellenic Congress: Plant Breeding and Rural Development* (Eds Hellenic Scientific Society of Genetics and Plant Breeding), p. 129. Orestiada, Greece (in Greek): Hellenic Scientific Society of Genetics and Plant Breeding.

Vlachostergios, D. N. & Roupakias, D. G. (2008). Response to conventional and organic environment of thirty-six lentil (*Lens culinaris* Medik.) varieties. *Euphytica* **163**, 449–457.

Wolfe, M. S., Baresel, J. P., Desclaux, D., Goldringer, I., Hoad, S., Kovacs, G., Loschenberger, F., Miedaner, T., Östergärd, H. & Lammerts van Bueren, E. T. (2008). Developments in breeding cereals for organic agriculture. *Euphytica* **163**, 323–346.