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CORRELATIONS BETWEEN YIELD AND SEVERAL TRAITS IN A SET OF WINTER PEAS CULTIVARS

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ABSTRACT

Pea (*Pisum sativum* L.) has long been an important component of the human diet, providing an excellent source of protein. Twenty four winter peas cultivars of different origins were tested, along with one spring cultivar, under conditions of South-eastern part of Romania, during 2017-2019 period. The objective of the study was to analyze correlations between yield and several plant traits, and to assess possibilities of combining high yield with suitable winter hardiness, earliness, protein content and thousand grains weight (TGW) in lines selected in the National Agricultural Research and Development Institute (NARDI) Fundulea breeding program from crosses between winter and spring cultivars. Statistical analysis showed that environment (years) was the most important driving factor for the studied agronomic traits. Nevertheless, differences among cultivars were significant when tested against the GxE interaction, for all traits, except winter hardiness, the latest maturing cultivars (originated from USA) yielded less under studied conditions, but the correlation between vegetation period and yield was positive for European cultivars and Fundulea lines. Our results suggested that the most winter hardy cultivars had smaller grains.

Yield and TGW had a highly significant negative correlation with protein content when the two American cultivars were included, but the correlation was not significant in the European cultivars and Fundulea lines. Some winter peas lines, derived from winter x spring crosses, combined high yield with good levels of winter hardiness, earliness TGW and protein content.

Keywords: winter peas, grain yield, protein content, earliness, winter hardiness.

INTRODUCTION

Pea *(Pisum sativum* L.) is characterized by high yielding ability, but at the same time significant variability of yield level. It also has a high protein content in seeds and the ability to bind atmospheric nitrogen, which is of both ecological and economic importance. Peas play also an important role in crop rotation and in the plant production systems being a good previous crop for cereals and chemicals are not used or only used to a limited extent (Bocianowski et al., 2019).

Similar to other agricultural commodities, yield and nutritional characteristics of dry pea affect the benefits of both producers and end-users. For farmers, a high-yielding cultivar with desirable quality for buyers will maximize farm income, while for end-users various nutritional or chemical characteristics are required for different food and feed purposes. Traditionally, protein has been considered the most important component of pea grains, governing end-use quality (Tzitzikas et al., 2006).

The increasing demand for protein rich raw materials for animal feed or intermediary products for human nutrition have led to a greater interest in this crop as a protein source (Santalla et al., 2001). Selection for high yield, high seed protein concentration and early maturity has been extensively practiced by pea breeders to develop cultivars with superior performance. However, complex inheritance patterns and strong environmental effects may limit the value of phenotypic estimates of these traits. Furthermore, negative correlations among these traits may hinder the progress of crop improvement. Grain yield, seed protein concentration and maturity in pea are controlled by multiple genes (Guéguen and Barbot, 1988) and are strongly influenced by the environment (Santalla et al., 2001).

Bertholdsson (1990) described morphological traits in pea that are associated with high

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grain yield and high seed protein concentration. These traits included intermediate growth habit, large stipules, many vegetative and generative nodes, good standing ability and good root system.

Grain yield, seed protein concentration and early maturity are among the major selection criteria for field pea improvement (Tar'an et al., 2004).

A negative correlation was found between grain yield and seed protein concentration. Kielpinski and Blixt (1982) and Karjalainen and Kortet (1987) also reported negative correlation between grain yield and seed protein concentration in pea. Phenotypic and genotypic correlations indicate that the genes for the traits are either linked, have pleiotropic effects or are influenced similarly by the environment (Aastveit and Aastveit, 1993). In cereals, a negative correlation between grain yield and grain protein concentration has been well documented (Monaghan et al., 2001; Simmonds, 1995). Previous studies in soybean also demonstrated negative correlation between seed protein concentration and oil content (Diers et al., 1992; Lee et al., 1996; Mansur et al., 1993).

Knowledge of correlation between yield and other traits is essential for increasing breeding efficiency, especially for early selection (Gilbert, 1961). Correlations are important in determining the degree to which various yield contributing characters are associated (Akram et al., 2008).

The objective of this study was to analyze correlations between yield and several plant traits, in a set of winter peas of different origins, and to assess possibilities of combining high yield with suitable winter hardiness, earliness, protein content and TKW in lines selected in the NARDI Fundulea breeding program from crosses between winter and spring cultivars.

MATERIAL AND METHODS

During three growing seasons (2016/2017, 2017/2018, 2018/2019), twenty-five winter peas genotypes (12 varieties, and 13 advanced breeding lines created at National Agricultural Research and Development Institute Fundulea) were tested (Table 1). Each year, the experiment with genotypes was carried out in a randomized block design, with three replications, planted in autumn. Plant density was 130 plants/m². The size of the experimental plot was six m² and the area of harvested plot was four m². Crop were harvested mechanically with Wintersteiger machine.

Measurements and determinations for this study included: grain yield, seed protein content, thousand grains weight (TGW), earliness, height and winter hardiness. Grain yield obtained from the plots was calculated per 1 ha, considering 14% humidity, TGW were determined by weighing with high precision balances. Seed protein concentration was determined by near-infrared (NIR) method using a Grain Analyzer (Infratech 1241, Foss Tecator). The earliness was expressed as number of days from January 1st till the end of flowering time. The level of winter hardiness was estimated in the field, early in the spring, using a scale 1 to 9, where score 1 is very resistant and 9 very susceptible. Plant height was measured in cm, total length of plant from the ground till the top to the end of flowering time. The obtained results were statistically evaluated by ANOVA and regression analysis.

Table 1. The winter peas genotypes tested in this study

No.	Genotypes	Origin	Growth habit	Cross type
1.	Spectral F	USA	winter	-
2.	Windham	USA	winter	-
3.	Checo	Austria	winter	-
4.	Dove	France	winter	-
5.	Isard	France	winter	-
6.	Dexter	France	winter	-
7.	James	France	winter	-
8.	Balkan	France	winter	-
9.	Enduro	France	winter	-
10.	Aviron	France	winter	-
11.	Curlling	France	winter	-
12.	Ball trap	France	winter	-
13.	Nicoleta	NARDI Fundulea	spring	-
14.	13008MT37	NARDI Fundulea	winter	spring/winter
15.	12032MT1-4	NARDI Fundulea	winter	spring/winter
16.	13008MT28-1	NARDI Fundulea	winter	spring/winter
17.	12004MT2	NARDI Fundulea	winter	spring/winter
18.	12013MT1	NARDI Fundulea	winter	spring/winter
19.	12013MT7	NARDI Fundulea	winter	spring/winter
20.	12018MT1	NARDI Fundulea	winter	spring/winter
21.	12023MT1-1	NARDI Fundulea	winter	spring/winter
22.	12032MT1	NARDI Fundulea	winter	spring/winter
23.	13002MT	NARDI Fundulea	winter	spring/winter
24.	13020MT	NARDI Fundulea	winter	spring/winter
25.	12038MT2	NARDI Fundulea	winter	spring/winter

Regarding meteorological conditions, NARDI Fundulea area is characterized by a continental temperate climate, with uneven distribution of rainfall by months. The data regarding temperature and rainfall registered during the years of testing, delivered by the Weather station of NARDI Fundulea, are presented in Table 2. Weather conditions of the three years during winter peas vegetation period and especially during the grain filling period, were very different.

Table 2. Rainfall distribution and average temperatures during winter peas vegetation

Month	2017		2018		2019	
	average t°C	rainfall (mm)	average t°C	rainfall (mm)	average t°C	rainfall (mm)
October	10.3	74.4	11.7	111.6	-13.41	10.8
November	5.7	48.8	6.9	49.2	â15.01	23
December	-0.3	0	3.6	27.8	0	48.4
January	-5.5	35.4	0.8	36	-1.16	53.8
February	0	50.5	2.2	58.6	3.81	21.4
March	8.6	47.6	3.3	40.6	9.30	7.47
April	10.6	73.6	15.8	2.4	11.20	3.67
May	16.8	65.8	19.4	34	17.20	7.30
June	22.2	96.4	22.6	120.6	23.60	7.46
Total rainfall (mm)		492.5		480.8		183.3

As shown in the Table 2, year 2017 had higher rainfall, more uniformly distributed during the vegetation, 2018 had less rainfall and not uniformly distributed, while 2019 had less rainfall but uniformly distributed in time. Mean monthly temperature in the all years was positive, not allowing a good selection of genotypes according to their frost tolerance, the lowest negative temperature registered being -5.5°C in 2017.

RESULTS AND DISCUSSION

Analyses of variance were performed considering years as a random factor and genotypes a fixed factor. The Table 3 shows the analysis of variance for average values for the traits evaluated for twenty-five winter peas genotypes. ANOVA indicated that the effect of genotypes and years were significant for earliness, protein content, grain weight and yields.

For better interpretation we grouped the genotypes studied by origin and maturity (Table 4). The American winter peas produced the lowest average yield of 2658 kg/ha, with the variation among the three years average of two cultivars between 2044 kg/ha and 3273 kg/ha. They had late maturity with 135 days from January 1st till flowering and low TGW between 130-133 g, but these genotypes have a good level of winter hardiness (1.4) and very high protein content (25.7%). The European winter peas obtained the average yield 3946 kg/ha, with the variation of the three years averages of the cultivars in this group between 3014 and 5088 kg/ha. They are early and with good winter hardiness, and TGW larger than American varieties (184.3 g), but lower protein content (21.0%). The highest average yield of 4169 kg/ha was obtained by the prospective winter peas lines with the variation among cultivars of this group between 3570 and 4996 kg/ha. These genotypes belong to the early group of maturity, with good winter hardiness and lower protein content. The spring pea cultivar produced the average yield 3329 kg/ha, TGW was close to the European winter peas (180 g) and the protein content was close to the perspective winter peas lines. Winter hardiness was low. Of course, the differences between the winter form and the spring form can be higher in the years with a severe winter. In the tested years, as can be seen from the data, the differences in winter hardiness between the winter and spring forms was not too high, because winters were milder than normal (Table 4).

Table 3. ANOVA for average grain yield, average earliness, average protein, average TGW, height and average winter hardiness for winter peas cultivars, NARDI Fundulea, 2017-2019 period

		Grain yield		Earliness		Protein concentration		TGW		Plant height		Winter hardiness	
Source of variation	df	F	P-value	F	P-value	F	P-value	F	P-value	F	P-value	F	P-value
Genotypes	24	2.93**	0.001	17.87**	0.000	18.32**	0.000	9.32**	0.000	7.39**	0.000	1.29	0.2202
Years	2	83.68**	0.000	61.65**	0.000	139.28**	0.000	27.68**	0.000	153.27**	0.000	2.34	0.1073
Interaction	48	-	-	-	-	-	-	-	-	-	-	-	-
Total	74	-	-	-	-	-	-	-	-	-	-	-	-

Table 4. Average, minimum and maximum values of the three years means for yield and several agronomic traits of the twenty-four winter peas genotypes tested in 2017-2019, grouped by origin

Code	Group of pea varieties	Yield (kg/ha)		Earliness (days from 01/01 till flowering)		Protein content (g)		TGW (g)		Winter hardiness (1-9)		Height (cm)	
		Mean	Min-max	Mean	Min-max	Mean	Min-max	Mean	Min-max	Mean	Min-max	Mean	Min-max
USA	American winter peas	2658	2044-3273	135	135	25.7	24.7-26.7	131.7	130-133	1.4	1.3-1.5	102.7	65.7-139.7
EU	European winter peas	3946	3014-5088	118.3	116-120	21.3	20.4-23.0	184	173-193	1.5	1.3-1.7	69.2	60.7-81.3
RO	Perspective winter peas lines	4169	3570-4996	118	117-121	20.9	19.8-21.9	207.2	180-227	2.2	1.5-2.5	69.6	61.0-70.0

The American cultivars, which were quite different from the rest of cultivars, being on average the latest, tallest, lowest yielding and having the highest protein content and lowest TGW had a large influence on the correlation coefficients. This is why we analyzed the correlations both for all cultivars (including the 2 US cultivars) and for only 23 of the cultivars (excluding the 2 US cultivars) (A. above and B. below the diagonal in Table 5).

Table 5. Correlations between tested parameters, 2017-2019

	A.	Including the 2 late US cultivars (above the diagonal)					
B.		Yield	TGW	Number of days from January 1st till the end of flowering time	Protein	Winter hardiness	Height
Excluding the 2 late US cultivars (below the diagonal) B.	Yield	X	**0.57*****	**-0.44***	**-0.54*****	0.27	-0.08
	TGW	0.31	X	**-0.71*****	**-0.72*****	**0.67*****	**-0.42***
	Number of days from January 1st till the end of flowering time	**0.42***	0.01	X	**0.83*****	-0.27	**0.62*****
	Protein	-0.04	-0.27	0.01	X	**-0.45***	0.34
	Winter hardiness	0.11	**0.69*****	0.12	-0.38	X	-0.13
	Height	0.23	0.17	0.01	-0.23	0.04	X

Ns - not significant; ***** and ******* significant at $p< 0.05$ and $p< 0.01$.

The average yield of the twenty-five genotypes was **negatively** significantly correlated with the number of days from January 1st till the end of flowering time (r=-0.44) (Figure 1A). In contrast, for the twenty-three genotypes (excluding the two late US genotypes) in the tested period yield was **positively** significantly correlated with the number of days from January 1st till the end of flowering time (r=0.42) (Figure 1B). This suggests that the negative effect of lateness on yield is only present in very late cultivars, while in the narrower interval, characterizing the European cultivars and Fundulea breeding, the earliest cultivars were lower yielding.

Yield had a highly significant negative correlation with protein content (r=-0.54), but only when the two American cultivars, which were both lowest yielding and having highest protein content, were included in calculation of correlation coefficient. It seems that the contradiction between yield and protein concentration is not so strong in the earliness interval characteristic for the European cultivars and Fundulea lines.

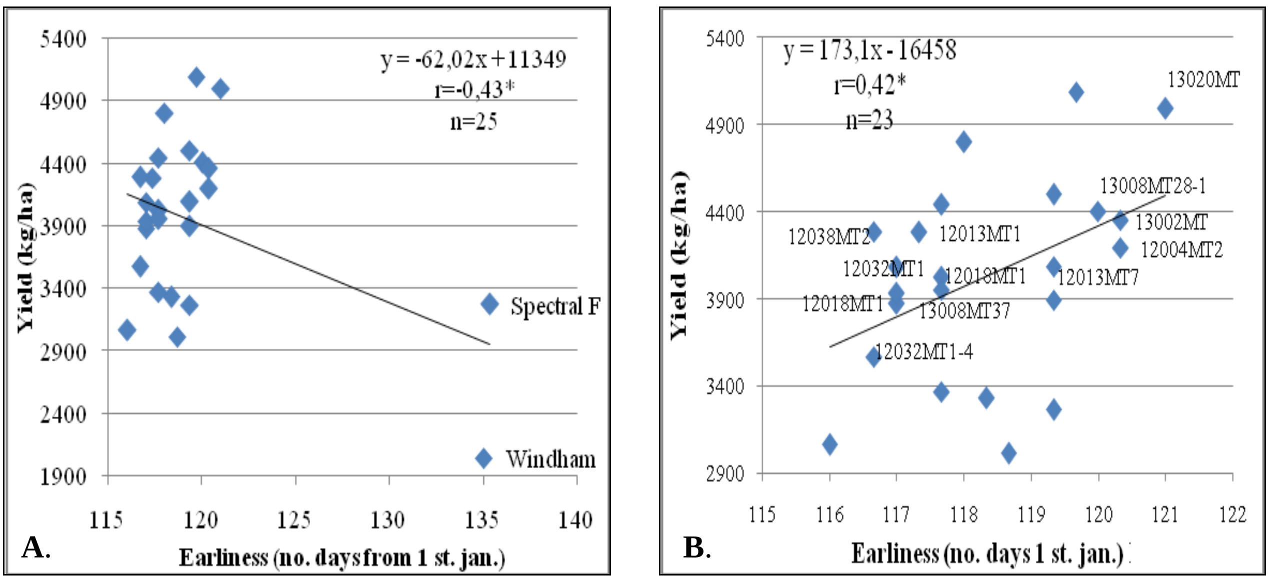

Figure 1. Relationships between earliness and yield of 25 genotypes (A) and 23 genotypes winter peas (B)

The data presented in Figure 1B show that some of the prospective winter peas lines created at NARDI Fundulea combine earliness with high levels of yield.

The relationship between winter hardiness and yield was not significant both if all 25 genotypes (A) or only 23 genotypes of winter peas (B) were taken into account (Figure 2). This suggests that breeding high yielding winter hardy peas cultivars might be feasible.

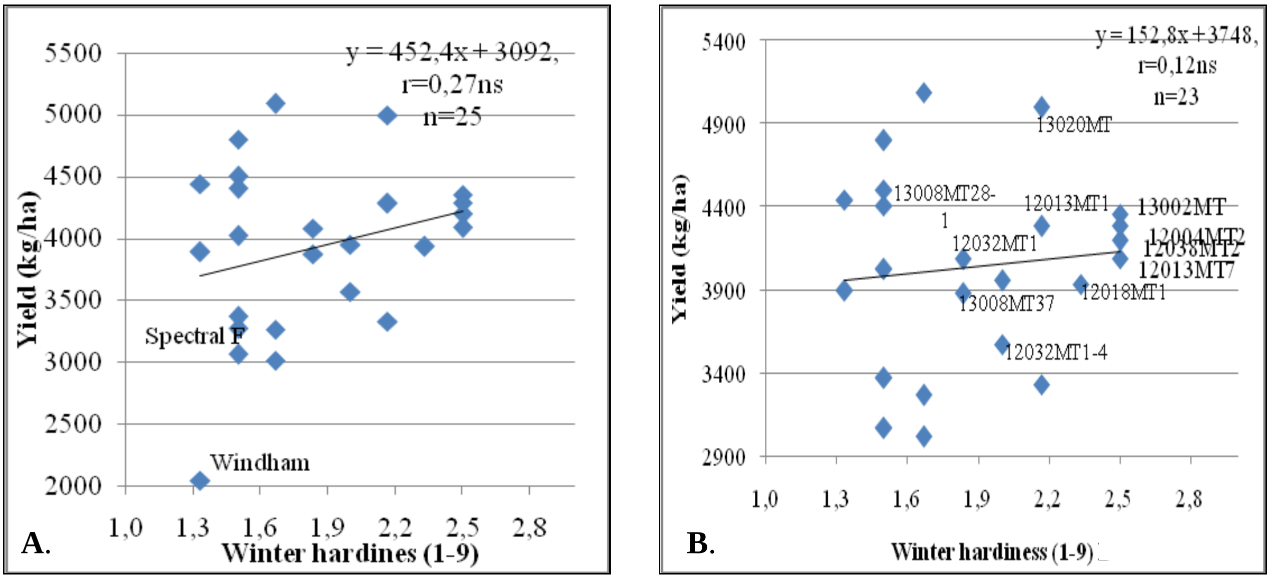

Figure 2. Relationships between winter hardiness and yield for 25 genotypes (A) and 23 genotypes of winter peas (B)

The average yield of the twenty-five genotypes in the testing period was positively highly significantly correlated with TGW (r=0.57), but the correlation was not significant when the two American cultivars were not taken into account.

The TGW was negatively significantly correlated with height (r=-0.42), with the number of days from January 1st till the end of flowering time (r=-0.71) and with protein content (-0.72) when all 25 cultivars were analyzed, but these traits were not significantly correlated when the two American cultivars were excluded. This suggests that these correlations were determined by the special behavior of the American cultivars.

The correlation between yield and winter hardiness (Figure 2B) demonstrated that some of the prospective winter peas lines had both good level of winter hardiness and high yield.

Although testing years did not favor a good characterization of winter hardiness, a correlation was found between TGW and winter susceptibility (r=0.67) when all cultivars were included (Figure 3A) and r=0.69 when the two American cultivars were excluded (Figure 3B). This suggests the existence of a tendency for the most winter hardy cultivars to have smaller grains.

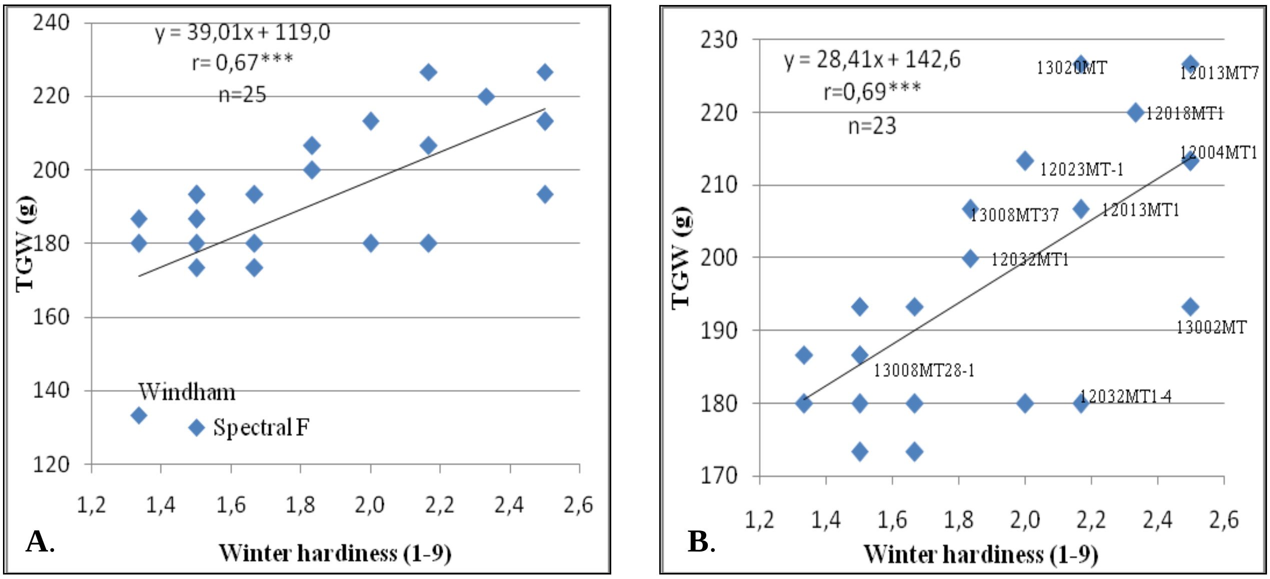

Figure 3. Relationships between winter hardiness and TGW of 25 genotypes (A) and 23 genotypes of winter peas (B)

The number of days from January 1st till the end of flowering was highly significantly positively correlated with protein content (r=0.83) when all 25 cultivars were taken into account (Figure 4A), but the relationship between vegetation period and protein content was not significant when the two American cultivars were ignored (Figure 4B).

Figure 3B shows that some of the prospective winter peas lines recombine a good enough level of winter hardiness with large TGW traits transferred from spring peas forms.

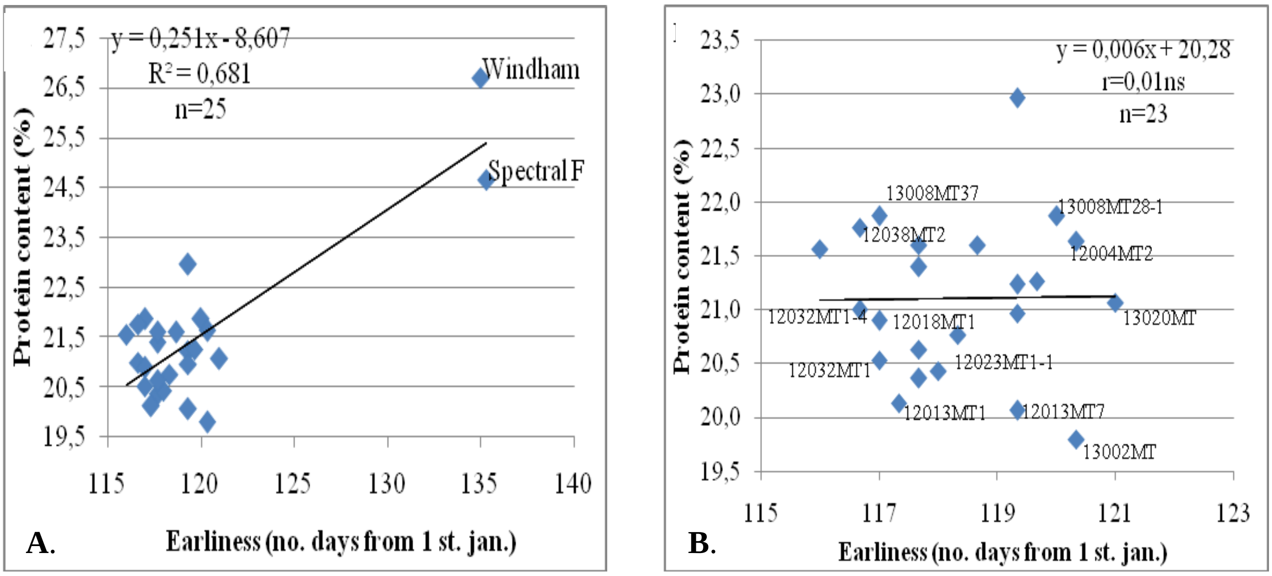

Figure 4. Relationships between the number of days from January 1st till the end of flowering and protein content of 25 genotypes (A) and 23 genotypes winter peas (B)

The two winter peas varieties (Windham and Spectral F) originated from USA had the highest protein content, confirming other studies, which mentioned that high seed protein concentration might be obtained from genotypes that mature late. Physiological bases for this mechanism have been proposed (Bertholdsson, 1990; Berthlenfalvay et al., 1978). The source/sink relationship of the vegetative organs alters at anthesis, with the pods becoming the N sink. To support pod-fill with N, the plant relies on the soil N uptake, N_2 fixation and remobilized N from its vegetative tissue (Bertholdsson, 1990). The late maturing genotypes may have more continuous N supply from soil uptake and fixation.

Relationship between earliness and protein content (Figure 4B) demonstrates that the perspective winter peas lines belong to the early group of maturity, but have a low protein content.

CONCLUSIONS

This study revealed that environment is the most important driving factor in winter peas grain yield, protein content, TGW, earliness, plant height and winter hardiness, but there were significant differences among cultivars when tested against GxE interaction. Correlations between traits were much dependent on the earliness interval taken into account, being strongly influenced by the two latest maturing US cultivars. Correlations found in the earliness interval of interest for the target environment are expected to be more meaningful for breeding programs.

The data obtained in this study indicated that some winter peas lines, derived from winter x spring crosses, combined high yield with good levels of winter hardiness, earliness and protein content.

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