VARIABILITY IN MACRONUTRIENT COMPOSITION OF WEED SEEDS

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Abstract. The analysis of the element composition of weed seeds and shoots could provide new data for their biological and ecological assessment. In the present study, seed samples of 30 weed species from different plant families were analysed for macronutrients (K, Ca, Mg, N, P, S) and high variability was found. There was a considerable difference in the N content of weed seeds, with the highest value for *Asclepias syriaca* and the lowest for *Xanthium spinosum*. The macroelement ratio also exhibited a wide range of values, e.g. the N to S ratio varied from 0.2 to 14.2. When crop seed data were compared to those of weed seeds from the same family, the K, Ca, Mg, P and S concentrations in weed seeds were found to be significantly higher in many cases. There were significant differences both in the macroelement concentrations and, in some cases, in the nutrient ratios of weed seeds from different plant families. Significant differences were found for K, Mg, P and S, and for the N/S and Ca/P ratios. This was confirmed by PCA, which illustrated not only differences between weed species, but also the fact that weed plants from the same family formed groups.
Keywords: *weed seeds; macroelement composition; plant families; diversity*

Introduction

In agricultural systems there is generally a prolonged time gap between two cropping cycles, which poses a potential risk of nutrient losses. Weeds, however, may preserve residual moisture and early rains, and could also fulfil the task of conserving nutrients during the fallow period (Promsakha Na Sakonnakhon et al., 2006; Lehoczky et al., 2012). Weeds may not only fix nutrients, but may also contribute to the nutrient supply of crops in the following growing season. The composition of plant residues has a great influence on how they decay and what nutrients are released from them. Palm et al. (2001) showed marked differences in the quality of residues from different plant families, e.g. leguminous plants release accumulated N more rapidly. Hence, the composition of the weed plants may have a great impact on nutrient cycling in arable soils. Although numerous studies have been carried out to determine the N content, amino acids and protein content in weed seeds (Friedman and Levin, 1989; Oderinde and Tairu, 1989; Friedman, 1996), limited information is available on the concentrations and ratios of macroelements (K, Ca, Mg, P and S).

Weeds reduce crop yields by competing for water, nutrients, space and light (Lehoczky et al., 1995; Lehoczky et al., 2005; Wang et al., 2007). Losses in crop yield caused by weeds are well documented in many studies (Akobundu, 1987; Swanton et al., 1993; Oerke and Dehne, 2004; Lehoczky et al., 2009; 2013b), leading to the conclusion that there is a need for effective weed management programmes. To

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establish such programmes, accurate information is needed on the weed flora, including the distribution, abundance and phenology of weed species and the biodiversity of weed communities (Frick and Thomas, 1992; Lehoczky et al., 2014a, b). Additionally, these data may also be valuable for understanding the dynamics of weed communities and for creating higher biodiversity on arable land (Andreasen and Skovgaard, 2009).

The uptake and accumulation of nutrients in plants depend on their genetic properties and thus on the species and the family (Singh et al., 2003; Győri et al., 2014). Consequently, it would be worth clarifying how weed families affect macroelement accumulation and revealing differences in the rates of accumulation between families. A systematic assessment of the nutrient concentrations in weed seeds, based on weed families, has not yet been carried out.

Among cereal crops, winter wheat and maize are most affected by summer weeds in Hungary (Ujvárosi, 1973). The cover percentage of the top ten weed species in Hungary was *Ambrosia artemisiifolia* L. (5.3 %), *Echinochloa crus-galli* (L.) P. B. (4.2 %), *Chenopodium album* L. (3.7 %), *Cirsium arvense* (L.) Scop. (1.8 %), *Setaria pumila* (Poir.) Roem. & Schult. (1.6 %), *Convolvulus arvensis* L. (1.5 %), *Amaranthus retroflexus* L. (1.4 %), *Tripleurospermum inodorum* (L.) Sch. Bip. (1.1 %), *Datura stramonium* L. (1.0 %) and *Panicum miliaceum* L. (1.0 %) during the 2007-2008 period (Novák et al., 2009).

The present study investigated the macronutrient composition of 30 seed samples of 30 weed species collected from sites with similar environmental conditions in Hungary. The objectives were (i) to determine the nutrient (N, P, K, Ca, Mg, S) contents in 30 weed seeds from 12 weed families, (ii) to evaluate the potential of weed seeds to conserve nutrients compared to crops, (iii) to show the influence of the weed family on the element contents, and (iv) to evaluate the diversity of weed species based on nutrient content of seeds using principal component analysis.

Materials and methods

Study area

The survey area was on cultivated land in Keszthely (Zala County, Hungary) with an average annual precipitation of 678±134 mm (Debreczeni and Németh, 2009). The soil type was Eutric Cambisol, according to the FAO classification (FAO 1998). The $pH_{(KCl)}$ of the top 30 cm soil layer was 6.8, with 1.9% organic matter content and 0.4% $CaCO_3$ content. The texture of the soil was loam. The most common crops were wheat, maize, barley, rape and sunflower.

Plant sampling procedure

Weed samples were taken from July to the end of October by sampling mature weed plants. In the laboratory, weed seeds were manually separated and ground. Prior to the digestion and ICP analysis, the seed samples was washed with distilled water. The 30 weed species investigated are listed in *Table 1*.

Laboratory analysis

The soil pH was measured in 1:2.5 soil:1 M KCl suspensions 12 hours after mixing (MSZ-08-0206/2:1978). The organic matter content was determined by the modified Walkley-Black method (Walkley and Black, 1934), which involved digesting the soil

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organic matter with 5% $K_2Cr_2O_7$ and cc. H_2SO_4 and analysing the colour of the suspension, which was related to the organic matter content of the samples, colorimetrically (MSZ-08-0452:1980). Particle-size distribution was determined by the pipette method. The soil:water suspension was mixed in a sedimentation cylinder, then sampled with a pipette to collect particles of a given size (MSZ-08-0215:1978). The $CaCO_3$ content was measured with a calcimeter; the soil was mixed with diluted HCl solution and the volume of CO_2 released was determined (MSZ-08-0206/2:1978).

Table 1. *The weed species investigated*

No.	Name	EPPO code	Family	Raunkiær's life form[a]	Ujvárosi's life form[b]
1	*Amaranthus albus* L.	AMAAL	Amaranthaceae	Th	T_4
2	*Amaranthus retroflexus* L.	AMARE	Amaranthaceae	Th	T_4
3	*Asclepias syriaca* L.	ASCSY	Asclepiadaceae	G	G_3
4	*Ambrosia artemisiifolia* L.	AMBEL	Asteraceae	Th	T_4
5	*Cirsium arvense* (L.) Scop.	CIRAR	Asteraceae	G	G_3
6	*Erigeron canadensis* L.	ERICA	Asteraceae	Th	T_4
7	*Galinsoga parviflora* Cav.	GASPA	Asteraceae	Th	T_4
8	*Tripleurospermum inodorum* (L.) Sch.Bip.	MATIN	Asteraceae	TH/H	T_4
9	*Senecio vulgaris* L.	SENVU	Asteraceae	Th	T_1
10	*Xanthium spinosum* L.	XANSP	Asteraceae	Th	T_4
11	*Xanthium strumarium* L.	XANST	Asteraceae	Th	T_4
12	*Sinapis arvensis* L.	SINAR	Brassicaceae	Th	T_3
13	*Stellaria media* (L.) Vill.	STEME	Caryophyllaceae	Th	T_1
14	*Chenopodium album* L.	CHEAL	Chenopodiaceae	Th	T_4
15	*Chenopodium hybridum* L.	CHEHY	Chenopodiaceae	Th	T_4
16	*Calystegia sepium* (L.) R. Br.	CALSE	Convolvulaceae	(G)H	G_1
17	*Convolvulus arvensis* L.	CONAR	Convolvulaceae	G	G_3
18	*Abutilon theophrasti* Medic.	ABUTH	Malvaceae	Th	T_4
19	*Veronica hederifolia* L.	VERHE	Scrophulariaceae	Th	T_1
20	*Cynodon dactylon* (L.) Pers.	CYNDA	Poaceae	G(H)	G_1
21	*Echinochloa crus-galli* (L.) P. Beauv.	ECHCG	Poaceae	Th	T_4
22	*Panicum miliaceum* L.	PANMI	Poaceae	Th	T_4
23	*Sorghum halepense* (L.) Pers.	SORHA	Poaceae	G(H)	G_1
24	*Fallopia convolvulus* (L.) Á. Löve	POLCO	Polygonaceae	Th	T_4
25	*Persicaria lapathifolia* (L.) Delarbre	POLLA	Polygonaceae	H	T_4
26	*Polygonum aviculare* L.	POLAV	Polygonaceae	Th	T_4
27	*Persicaria maculosa* Gray	POLPE	Polygonaceae	Th	T_4
28	*Consolida regalis* Gray	CNSRE	Ranunculaceae	Th	T_2
29	*Datura stramonium* L.	DATST	Solanaceae	Th	T_4
30	*Solanum nigrum* L.	SOLNI	Solanaceae	Th	T_4

[a]Th: therophyta; H: hemikryptophyta; G: kryptophyta; TH: hemitherophyta (Raunkiær, 1934).
[b]G_1: Geophyta, rhizomatous plants; G_3: Geophyta, perennials with reproductive roots; T_1: Therophyta, winter annuals, ripen seeds in spring; T_2: Therophyta, winter annuals, ripen seeds in summer; T_3: Therophyta, summer annuals, emergence in spring, ripen in summer; T_4: Therophyta, summer annuals, emergence in summer, ripen in autumn (Ujvárosi, 1973).

The K, Ca, Mg, P and S concentrations in the weed seeds was determined with the ICP-MS method after microwave Teflon bomb digestion with cc. HNO_3 + H_2O_2 (Kovács et al., 1996). The N c ontent of the weed seeds was analysed with an Elementar VarioMax instrument (Hanau, Germany) based on the Dumas combustion method (Jones, 1992).

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Quality control

The high purity water (18.2 MΩ cm^{-1}) used for the preparation of all blanks, standards and sample solutions was obtained from a Millipore water purification system (Millipore, France). The instrument was calibrated using multi-element standard solutions prepared in 1% nitric acid by mixing and diluting AAS stock solutions of individual elements.

For ICP-MS analysis, each sample was analysed in triplicate, using an external standard (BCR CRM 189 wheat) to assure the accuracy of the whole analytical procedure (*Table 2*).

Table 2. *Results of analysis on certified samples*

Element	Certified value	Measured value
K (mg kg^{-1})	33800±800[a]	32786±2563
Ca (mg kg^{-1})	6400±100	6384±175
Mg (mg kg^{-1})	1450±40	1601±114.2
P (mg kg^{-1})	2360±70	2440±116.8
S (mg kg^{-1})	3160±40	3308±112

[a] mean±standard deviation

Statistical methods

Analysis of variance (ANOVA) was carried out on the element concentrations in the different weed species and families using SPSS 16.0 software. To evaluate the ranking order of macroelement contents in the plant families, the Duncan pot hoc test was performed at $p<0.05$, using only families represented by more than one species.

Principal component analysis (PCA) was used to evaluate the diversity of weeds with respect to nutrient content. PCA is a multivariate technique in which new variables (called principal components or PCs) are calculated as linear combinations of the original variables (nutrient concentrations of weed seeds). The PCA was performed using varimax rotation and the PCA scores were displayed as a biplot diagram, which attempts to represent both the observations and variables of multivariate data in the same plot.

Results and Discussion

Nutrient concentrations and ratios in weed seeds

Both the whole weed plant and its various parts, including the seeds, can be considered as a nutrient pool for the soil and consequently as a nutrient source for crops grown for human or animal consumption. There is a considerable difference in the N content of weed seeds, with the highest value for *Asclepias syriaca* and the lowest for *Xanthium spinosum*. The S content ranged from 1.3 g kg^{-1} in *Persicaria lapathifolia* to 17.8 g kg^{-1} in *Sinapis arvensis*. High variability was found in the K concentration, with the highest value of 20.5 g kg^{-1} in *Erigeron canadensis* and the lowest value of 2.2 g kg^{-1} in *Panicum miliaceum* (*Table 3*). The Ca content ranged from 17.4 g kg^{-1} in *Polygonum aviculare* to only 0.2 g kg^{-1} in *Panicum miliaceum*. In the case of Mg, there was a moderate variability in the concentrations, from 1.3 to 4.0 g kg^{-1}. Five-fold

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differences were revealed for P, with values of 10.2 g kg^{-1} in *Abutilon theophrasti* and 1.9 g kg^{-1} in *Cynodon dactylon*.

With respect to element ratios, the Ca/P ratio ranged from 0.06 to 7.6 in the weed seeds investigated (*Table 3*), with the highest value for *Polygonum aviculare*. The N/S ratio varied from 0.2 to 14.2, with the highest value for *Abutilon theophrasti*.

Table 3. *Nutrient contents and macroelement ratios in the weed seeds investigated*

Code[a]	Family	N	P	K	Ca	Mg	S	N/S	Ca/P
		g kg^{-1}						*ratio*	
AMAAL	Amaranthaceae	23.0	3.4	3.8	3.6	3.2	2.2	10.4	1.0
AMARE	Amaranthaceae	25.7	5.7	5.3	3.4	3.7	2.4	10.9	0.6
ASCSY	Asclepiadaceae	58.5	7.7	7.9	3.5	4.0	4.7	12.6	0.5
AMBEL	Asteraceae	44.6	7.7	9.5	4.1	3.2	4.1	10.9	0.5
CIRAR	Asteraceae	22.5	6.3	6.7	6.2	2.5	2.5	9.0	1.0
ERICA	Asteraceae	31.8	6.3	20.5	12.3	2.7	4.0	7.9	1.9
GASPA	Asteraceae	16.1	4.0	11.1	6.8	2.1	2.4	6.6	1.7
MATIN	Asteraceae	27.0	6.1	11.3	3.2	2.6	2.9	9.2	0.5
SENVU	Asteraceae	39.0	5.9	8.9	7.2	3.2	3.7	10.4	1.2
XANSP	Asteraceae	9.9	2.7	11.8	2.6	1.7	1.7	5.9	1.0
XANST	Asteraceae	31.0	5.6	12.6	1.9	2.4	2.7	11.5	0.3
SINAR	Brassicaceae	45.2	9.9	6.3	5.2	3.5	17.8	2.5	0.5
STEME	Caryophyllaceae	27.7	4.3	3.9	2.6	2.7	2.5	11.0	0.6
CHEAL	Chenopodiaceae	24.9	4.4	8.8	2.1	2.4	2.2	11.2	0.5
CHEHY	Chenopodiaceae	20.6	3.0	11.3	1.6	2.0	2.0	10.1	0.5
CALSE	Convolvulaceae	33.9	6.5	15.7	1.2	2.9	3.0	11.2	0.2
CONAR	Convolvulaceae	34.9	6.3	16.7	1.4	2.7	2.7	13.0	0.2
ABUTH	Malvaceae	35.1	10.2	13.4	1.9	3.6	2.5	14.2	0.2
CYNDA	Poaceae	18.6	1.9	3.5	4.7	2.6	2.2	8.6	2.4
ECHCG	Poaceae	19.3	5.4	5.8	2.2	3.0	2.0	9.9	0.4
PANMI	Poaceae	20.9	3.5	2.2	0.2	1.2	1.9	10.9	0.1
SORHA	Poaceae	17.1	4.4	2.6	0.7	1.9	2.0	8.5	0.2
POLAV	Polygonaceae	24.0	2.3	5.3	17.4	2.1	1.8	13.0	7.7
POLCO	Polygonaceae	19.2	2.8	11.4	4.7	2.7	2.0	9.6	1.7
POLLA	Polygonaceae	16.3	3.2	2.8	1.0	2.0	1.3	12.5	0.3
POLPE	Polygonaceae	17.4	5.1	7.7	1.2	2.2	1.5	11.9	0.2
CNSRE	Ranunculaceae	32.2	6.6	7.2	11.4	2.9	3.4	9.6	1.7
VERHE	Scrophulariaceae	20.1	4.8	5.5	2.2	1.3	2.1	9.6	0.5
DATST	Solanaceae	29.1	5.9	5.4	1.1	3.1	3.2	9.1	0.2
SOLNI	Solanaceae	26.0	8.8	4.1	0.9	3.9	2.6	9.9	0.1

[a] The full name of the weeds are in *Table 1.*

Comparison of weed data to crop seed concentrations

To evaluate the nutrient conservation potential of the weeds, the nutrient content of crop species was compared to that of w eed species from the same family. High nutrient contents were determined in the thirty weed seed samples in comparison with crop seed concentrations, as shown in *Table 4*. Differences in the element concentrations have been reported both for crop seeds (White and Broadley, 2009; Lehoczky et al., 2013a) and for weed seeds, due to a combination of environmental and genetic factors.

In the *Poaceae* family the potassium concentration in weed seeds was found to be higher than in the seeds of small grain crops. In experiments in Keszthely (Győri, 2009) maize and wheat grains were found to have lower values of K than those recorded for weed seeds in the present work, despite the differences in species, genotypes and

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environmental conditions. This was particularly true of the very high K value found in the weed seed *Erigeron canadensis* (20.0 g kg^{-1}). Similar conclusions could be drawn for the *Polygonaceae* family, while the rest of the families had comparable K concentrations in weed and crop seeds.

Table 4. *Comparison of the nutrient contents of weed seeds and crop seeds from the same family*

K	Ca	Mg	P	S	Crop	Family
g kg^{-1}						
5.1	0.46	1.5	3.9	1.3	wheat[1]	Poaceae
3.0	0.4	1.5	3.2	1.5	wheat[2]	Poaceae
2.4-3.2	0.01-0.13	0.8-1.6	2.4-4.6	0.97-1.8	maize[3]	Poaceae
3.5±1.6	*1.9±2.0*	*2.2±0.8*	*3.8±1.5*	*2.0±0.1*	*weeds*	Poaceae
15.6±3.6	6.4±2.4	5.3±2.2	4.6±0.7	3.1±0.5	sunflower[4]	Asteraceae
11.6±4.1	*5.5±3.4*	*2.5±0.5*	*5.5±1.5*	*3.0±0.8*	*weeds*	Asteraceae
2.4	0.30	0.92	1.3	0.47	buckwheat[5]	Polygonaceae
0.80-1.3	0.52-0.74	0.50-0.78	1.6-2.4	-	buckwheat[6]	Polygonaceae
6.8±3.7	*6.1±7.7*	*2.2±0.3*	*3.3±1.2*	*1.6±0.3*	*weeds*	Polygonaceae
2.4-6.9	0.01-0.28	0.11-0.38	0.33-1.3	-	potato[7]	Solanaceae
4.1	0.09	0.21	0.62	-	potato[8]	Solanaceae
47±0.9	*1.0±0.1*	*3.5±0.6*	*7.3±2.0*	*2.9±0.4*	*weeds*	Solanaceae
8.2	3.5	2.7	5.7	-	rapeseed[9]	Brassicaceae
6.3	*5.2*	*3.5*	*9.9*	*17.8*	*weed*	Brassicaceae
7.1-7.7	7.4-9.3	4.6-6.8	5.9-6.5	-	amaranth[10]	Amaranthaceae
4.5±1.1	*3.5±0.1*	*3.5±0.4*	*4.6±1.6*	*2.3±0.1*	*weeds*	Amaranthaceae

[a] Mean±standard deviation;
[1] Győri, 2009; [2] Kádár and Daood, 2001; [3] Menkir, 2008; [4] Kötschau et al., 2014; [5] Vogel-Mikuš et al., 2009; [6] Peng et al., 2014; [7] Burlingame et al., 2009; [8] USDA National Nutrient Database, No: 11365; [9] Kádár, 2002; [10] Haghighi et al., 2012.

The Ca concentrations in weed seeds were found to be an order of magnitude higher than those in crop species from the *Poaceae*, *Polygonaceae* and *Solanaceae* families (*Table 4*). In the *Amaranthaceae, Asteraceae* and *Brassicaceae* families, the Ca content was similar in crop and weed seeds. Some weed species were found to have very high Ca concentrations, e.g. *Erigeron canadensis*, *Consolida regalis* and *Polygonum aviculare* gave values of 12.3, 11.4 and 17.4 g kg^{-1} Ca, respectively.

Very little variation was detected in the Mg concentration of the weed seeds, indicating that no weed species have extremely high or low Mg contents. However, in crop seeds, significant differences were recorded in many cases. For instance, the Mg content of weed seeds from the *Poaceae*, *Polygonaceae* and *Solanaceae* families was higher than in crop seeds from the same family.

The average P concentrations in crop seeds ranged from 0.33 to 6.5 g kg^{-1} (*Table 4*). Among the *Solanaceae* the crop species (potato) was found to have a significantly lower P content than the average P concentration of weed seeds from the same family. Especially high P concentrations were determined for *Abutilon theophrasti* (11.1 g kg^{-1}) and *Sinapis arvensis* (9.9 g kg^{-1}).

Consistently with the well-known fact that plants of the *Brassicaceae* family have high S concentration due to the mustard oil content of the seeds (Björkman et al., 2011;

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Li et al., 2012), 17.8 g kg^{-1} S was detected in *Sinapis arvensis.* The concentrations in all the weed seeds ranged from 1.4 to 4.6 g kg^{-1}, which was higher than the values recorded for the crop species.

In general, all the macroelements investigated had in higher or at least comparable concentrations in the weed seeds. The Ca concentration in particular was found to be much higher in weed seeds than in crop seeds.

Differences in the element contents and ratios between weed seeds of different families

Among the macroelements significant differences between weed families were found in the concentrations of P, K, Mg and S (*Fig. 1*).

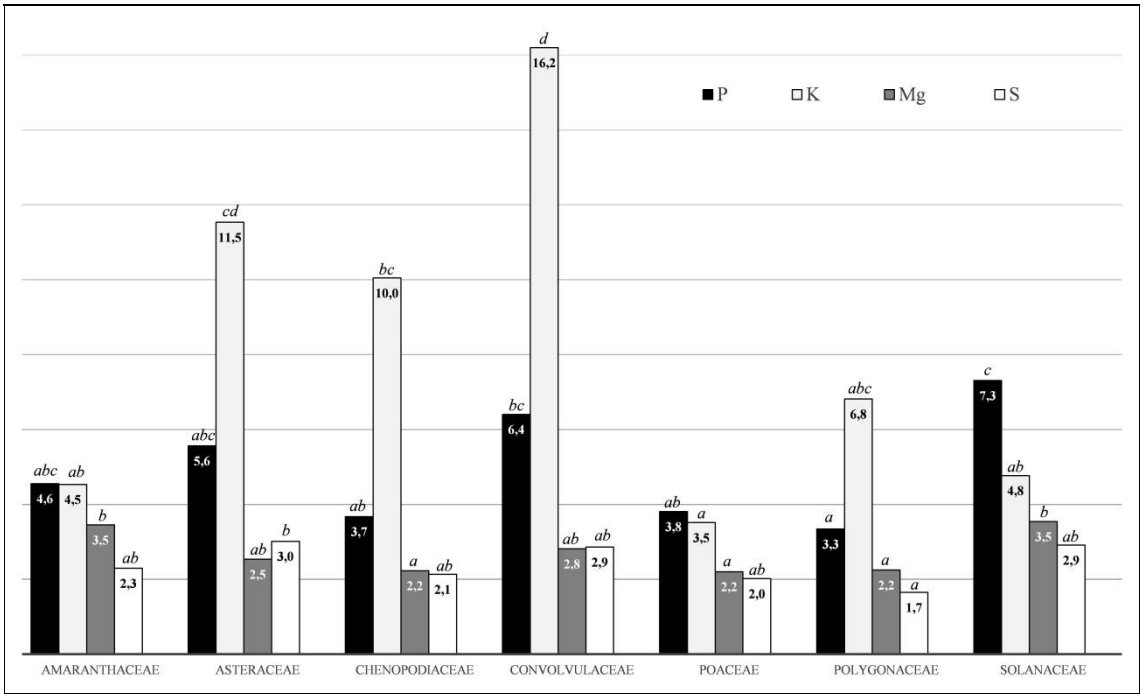

Figure 1. *Macronutrient contents in weed seeds from different families (a–d indicate significant differences within families for the given element at the 5% level of probability according to Duncan's test)*

For K, the following ranking order was found for the weed families from the highest to the lowest K contents: Convolvulaceae > Asteraceae > Chenopodiaceae > Amaranthaceae = Polygonaceae > Poaceae = Solanaceae. Similar orders were found for P and S, with the highest contents in Asteraceae, Convolvulaceae and Solanaceae, and relatively low concentrations in Polygonaceae, Poaceae and Amaranthaceae. For Mg the ranking order was as follows: Solanaceae > Asteraceae = Amaranthaceae = Convolvulaceae > Chenopodiaceae = Poaceae = Polygonaceae.

Other authors investigating the effect of the family on the element concentrations in weed seeds also reported significant differences in most cases (Tanji and Elgharous, 1998). The fact that individual genotypes may differ in their nutrient demands, uptake ability and nutrient transport within the plant is well documented (Ramage and Williams, 2002; Lovkova et al., 2008; White and Brown, 2010).

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The main factor affecting the concentrations of different elements in a plant appears to be the nutrient requirements of the plant rather than the nutrient supplies in the soil (Markert, 1989). This was confirmed by surveys showing different concentrations of trace and macro-elements in different plants even if they were grown in the same place (Løbersli and Steinnes, 1988; Willey et al., 2005; Lehoczky et al., 2013b).

Evaluation of diversity based on nutrient content of seeds using PCA

As shown in the previous section, significant variability has been found between weed families with respect to macroelement status. Principal component analysis is another way to reveal the diversity or similarity between weed communities. The factor loadings and score plots obtained using this method are presented for the 30 weed seeds in *Table 5* and *Figures 2A* and *B*.

The first three principal components were found to have eigenvalues > 1 and accounted for 36.6 %, 23.6 % and 17.9 % of total variation, respectively, giving a cumulative variance of 78.1 %.

Table 5. *Factor loadings for the elements analyzed in the weed seed samples*

	PC1	PC2	PC3
N	**0.914**	0.034	0.076
P	**0.858**	-0.260	0.206
K	0.382	0.140	-0.147
Ca	0.117	**0.960**	0.108
Mg	**0.830**	-0.059	0.049
S	0.479	0.020	**0.817**
N/S	0.194	-0.026	**-0.929**
Ca/P	-0.156	**0.952**	-0.070

The first PC (PC1) showed high loadings for N, P and Mg, while PC2 gave high loadings for Ca and the Ca/P ratio and PC3 for S and the N/S ratio (shown in bold in *Table 5*). The high loadings for N and P in PC1 can be attributed to the fact that these elements have similar chemical and consequently biological properties, being non-metal elements. Surprisingly, Mg also made a high contribution to PC1 rather than to PC2, which consists of metal elements, especially Ca.

To visualize the differences and similarities in the nutrient contents of weed species, PC scores were calculated, as displayed on the biplots (*Fig. 2A* and *2B*) illustrating the patterns of nutritional status in weed seeds. The great differences between the weed species are indicated by the scattered dots plotted for the weed plants. The position of the given weed in the factor space shows the nutritional status of the weeds, e.g. the PC3 value is very high for the *Brassiceae* due to the high S content (*Fig. 2B*), while the PC1 score for the *Malvaceae* family is indicative of its high content of N, P and Mg (*Fig. 2A*).

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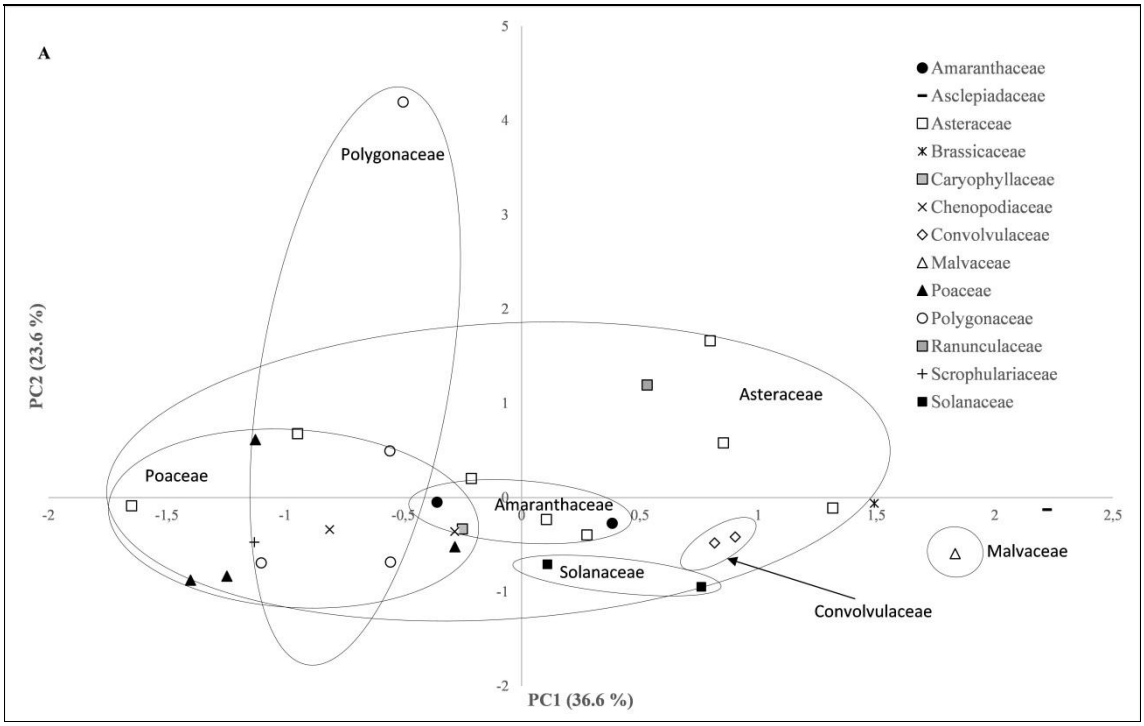

Figure 2A. *PCA ordination of weed species investigated (PC1 vs PC2)*

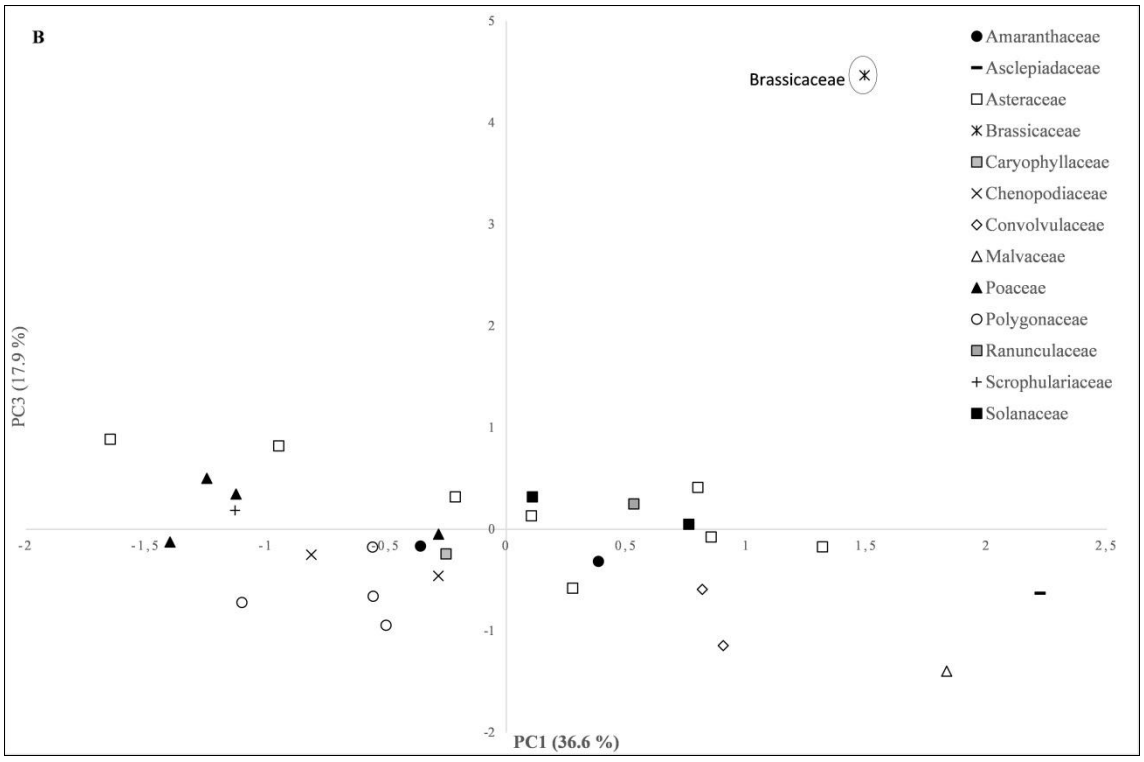

Figure 2B. *PCA ordination of weed species investigated (PC1 vs PC3)*

Although the points representing the weed samples are very scattered, it is possible to detect groups of weeds that belong to the same family. The *Polygonaceae* family, for instance, has similar scores on axis 1 (-0.5 to -1), indicating that the common feature of

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this family is the N, P and Mg content. In the case of the *Asteraceae*, the weed samples had similar PC scores on axis 2, which indicates that the common feature for weeds classified as *Asteraceae* is the Ca content. For the other families, there is no clear orientation, implying that they have a mixed type of features. However, the weed families can be separated by their PC scores: the *Polygonaceae*, *Convolvulaceae* and *Malvaceae* can be separated on the basis of PC1, while, as shown earlier, the *Brassicaceae* differ from the other weed families in terms of PC3.

Conclusions

Although great variability was observed for the nutrient quantities in weed seeds, the N, K, Ca, Mg, P and S concentrations in weed seeds were significantly higher than those in crop seeds from the same family, indicating that they could help to improve nutrient conservation during the fallow period. However, the variability in the nutrient content must be taken into account when determining the beneficial impact of weeds on the nutritional status of soil-plant systems; e.g. weeds from the *Asteraceae* family have more potential to conserve N as they have significantly higher N content than weeds from the *Polygonaceae* family.

Differences between weed families were mainly found in the case of macroelement accumulation, and these differences were mainly caused by the genetic diversity of weed species belonging to different families.

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