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Allelopathic potential of sunflower. I. Effects of genotypes, organs and biomass partitioning

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ABSTRACT

Field-grown plants were harvested at inflorescence bud stage and the fresh weight of leaves, stems and inflorescences were recorded. Allelopathic activity of aqueous extracts of leaves, stems, inflorescences, roots, petioles and seeds was determined on mustard germination. The test genotypes differed significantly both in the biological yield (approx 9 folds) and in biomass partitioning (stems > leaves > inflorescences). Allelochemicals in leaf extracts, significantly delayed and decreased the mustard germination. Significant differences were also recorded between the plant organs, leaves showed highest and roots had no activity. Both allelopathic activity of particular organs and the biomass accumulated, together with its partitioning pattern were major components of allelopathic potential.

Key words: Biomass accumulation, distribution, genotypes, germination, *Helianthus annuus* L., organs, phytotoxicity, Pipper Index, *Sinapis alba* L.

INTRODUCTION

Weed control in organic farming is crucial for economic success. The “chemical warfare between plants” via the phenomenon termed ‘allelopathy’, offers the potential for an alternative strategy for weed management (2). Sunflower is highly allelopathic, hence, adversely affects the weeds population and is considered as tool of weed management (8). Therefore, its allelopathic potential should be explored as crop or as a pre-crop for biologically active mulch or green manure. Allelopathic potential depends on (i) genotypic differences, (ii) differences in allelopathic activity of various parts, (iii) biomass accumulation and (iv) its distribution into particular organs. Interspecies differences in allelopathic activity are well documented in literature (3,6,10,13,21), while little data is available on intra-species differences. Genotypic differences in allelopathic activity of sunflower have been reported (11,12,14) but these data were either for old genotypes or from extracts of one organ only. Differences in allelopathic activity of sunflower plant parts have been reported but results are contradictory (9,11,12,16). Accumulated biomass quantity affects the allelopathic potential, because greater biomass would release more allelochemicals into the environment. The plant’s allelopathic potential also depends on biomass partitioning patterns, because organs differs in allelopathic activity. Greater the portion of biomass partitioned to organs of higher allelopathic activity, the greater would

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be the allelopathic activity of biomass left in the field. The literature on comparative studies on biomass accumulation and its distribution in sunflower is scarce (22). In depth knowledge of sunflower genotypes and organs, specific differences in allelopathic activity, together with biomass accumulation and its partitioning is important for sunflower cultivation, because sunflower area is increasing in many countries (8) and may become an important component of local ecosystems. Therefore, there is a need to screen large number of currently available genotypes for cultivation. This study aimed to (i) characterize 37 sunflower genotypes for biomass accumulation and its distribution in various organs and (ii) compare allelopathic activity test genotypes including differences between the organs.

MATERIALS AND METHODS

Thirty seven cultivars and breeding lines of sunflower (termed as genotypes) representing all types (edible, oil, pasture and ornamental) were collected and numbered as under: **1** – ‘Giganta’, **2** – ‘Goldener Neger’, **3** – ‘Ogrodowy’, **4** - ‘Full Sun’, **5** - ‘Polizie 98-43’, **6** - ‘Herbschonheit’, **7** - ‘Evening Sun’, **8** - ‘Pardisol’, **9** - ‘Pelny’, **10** - ‘Frankasol’, **11** - ‘Optisol’, **12** - ‘Schnittgold’, **13** - 4449, **14** - ‘Printasol’, **15** - ‘Sion’, **16** - ‘Mikaflo’, **17** - ‘Hallo’, **18** - ‘Olbrzym Borowski’, **19** - ‘Sunriche Orange’, **20** - ‘Ukr - Nar 96-291’, **21** - ‘Albena’, **22** - ‘Pastewny’, **23** - ‘Wielkopolski’, **24** - ‘Borowski Ulepszony’, **25** - 57953, **26** - ‘Alphasol’, **27** - ‘Valentin’, **28** - 57959, **29** - ‘Lech’, **30** – 57960, **31** - 57957, **32** - ‘Einfache Gemischt’, **33** - ‘57958’, **34** – ‘Soraya’, **35** - ‘Borowski Prazkowy’, **36** - ‘Floristan’, **37** – 57956.

Field study

Plants of all 37 genotypes were grown in our Research Farm at Ursynow, Warsaw. The field soil was sandy loam, slightly alkaline (pH 7.2) and 50 kg N, 30 kg P₂O₅ and 140 K₂O kg/ha were applied. Seeds were sown at 60 x 40 cm spacing in second fortnight of May. Cultivation practices were performed as recommended in Poland. At inflorescences bud stage, above ground plant parts were harvested (and not roots), divided into leaves, stems and inflorescences and their fresh weight was recorded. For each genotype, 10 plants (replications) were used and they were harvested from the middle part of plots to avoid side effects and harvested shoots were called ‘biological yield’ (23). Plant material was air-dried and stored till used in further studies.

Laboratory bioassay

The effects of various concentrations of aqueous extracts of 37 sunflower genotypes organs were studied on the seeds germination of mustard (*Sinapis alba* L.) in lab bioassays for 14 days. This study consisted of 3 factors (i). Sunflower genotypes : 37, (ii). Plant parts : 4 (leaves, stems, inflorescences, roots) and (iii) Aqueous extract concentration : 5 [0, 2.5, 5.4, 7.5, 10%DM (w/v)]. For the genotypic and organ-specific comparison of allelopathic activity, all 37 genotypes of sunflower were used and the activity was evaluated by the effect of water-extracted allelochemicals in a germination biotest. Mustard (*Sinapis alba* L.) cv. ‘Nakielska’ was used as the test plant, as model for dicotyledonous weeds. For the extract preparation, air-dried leaves (together with

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petioles), stem(s) and inflorescence(s) collected from field grown plants (Experiment 1) were used. Additionally, roots of 11 genotypes of sunflower were collected from pot-grown sunflower plants at flowering. Soil from the pots, right after harvesting of the above ground parts, was placed on a sieve. Any visible roots were carefully collected and, after washing, were air dried. Allelopathic activity of whole seeds, seeds without hulls and hulls for cv. Oгородowy (#3) only, was determined. For cvv. 'Lech' (#29) and 'Oгородowy' (#3) allelopathic activity of petioles was also determined.

The air-dried matter is called as dry matter (DM). To prepare aqueous extract, the air dried leaves (including petioles), stems and inflorescences from field study were ground with a mill (WT - Z 1) into a fine powder. 2.5, 5.0, 7.5 and 10.0 g of the powder were soaked in 100 ml of water for 24 h at room temperature and filtered through several layers of cheese cloth.. Mustard seeds were placed on Petri dishes layered with filter paper moistened with 5 ml of extracts at four concentrations (2.5, 5.0, 7.5 and 10.0% DM w/v) and with water (H₂O) only (control). Seeds were cultured in a cabinet, in darkness at 20±0.5°C for 14 days. Germinating seeds were counted daily and removed.

Dynamics of germination: To evaluate the dynamics of germination, the Pipper Index (PI) was used (18). PI refers to number of days needed for one seed to germinate and was calculated by following formula:

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$$PI = x_1 s_1 + x_2 s_2 + \dots x_n s_n / s_1 + s_2 + \dots + s_n$$

Where, x_1, x_2, \dots, x_n - day of germination, S : number of seeds that germinated at given day, n : last day of experiment.

For each cultivar, 6 replicates (Petri dish) were used with 50 seeds per replication. Due to large number of Petri dishes needed to evaluate of 37 genotypes; the organs used and the 4 concentrations (> 2800 dishes) the test was done in several lots. To ensure the comparison of results between lots, fresh extracts were prepared for each lot and germination in control (water) was conducted in parallel with every lot.

Statistical Analysis: The results were statistically analyzed by ANOVA of Statgraphics Plus 4.1 (Statistical Graphics Corp., USA) and differences between combinations were estimated by Honestly Significant Difference (HSD) of the Tukey test. Values of HSD or letter indices (following data in tables) are provided when differences between combinations were significant at $P \leq 0.05$. Presented data are mean ±SE (where indicated), n = 10 (field experiment) or 6 (germinating biotests).

RESULTS AND DISCUSSION

Biomass accumulation and partitioning

The test sunflower genotypes differed significantly in biological yield and in its partitioning into particular organs. The total biomass accumulated in shoot (above ground organs) differed in various genotypes about 9-folds and ranged from 260.0 g/plant (# 37) to 2281.0 g/plant cv. # 1) (Table 1).

Table 1. Fresh matter of leaves, stem(s) and inflorescence(s) of test 37 sunflower genotypes

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Sunflower genotypes (number)	Fresh weight (g/plant)			
	Whole plant	Leaves	Stem(s)	Inflorescence(s)
Giganta (1)	2281.0+78.3	553.0+43.4	1392.0+63.0	336.0+14.4
Goldener Neger (2)	1847.1+71.5	481.1+20.7	1158.8+44.2	207.2+24.1
Ogrodowy (3)	1779.3+64.3	418.1+22.5	735.6+23.8	625.6+25.0
Full Sun (4)	1686.1+38.2	346.8+16.8	715.6+25.9	623.7+12.8
Polizie 98-43 (5)	1257.5+60.8	250.0+16.2	471.0+22.8	536.5+24.4
Herbschonheit (6)	1201.0+32.0	266.5+8.5	671.0+25.3	263.5+15.4
Evening Sun (7)	1171.6+57.6	310.0+18.5	645.0+38.4	216.6+12.2
Pardisol (8)	1076.0+72.0	231.1+20.0	413.3+23.0	431.6+34.8
Pelny (9)	1014.9+19.7	315.6+17.2	462.5+20.0	236.8+17.5
Frankasol (10)	916.0+22.1	301.0+11.5	503.5+7.3	111.5+4.4
Optisol (11)	899.5+40.1	274.0+16.0	511.5+20.3	114.0+7.3
Schnittgold (12)	853.8+53.5	212.7+16.4	521.1+29.2	120.0+10.3
4449 (13)	813.5+47.7	221.0+13.5	371.5+23.4	221.0+13.5
Printasol (14)	763.7+30.8	227.7+9.7	426.6+14.9	109.4+7.7
Sion (15)	738.0+43.1	236.0+14.3	361.5+20.2	140.5+12.1
Mikaflor (16)	734.9+31.1	255.0+10.0	356.8+19.9	123.1+8.3
Hallo (17)	729.0+49.6	275.5+36.5	389.5+26.2	64.0+5.6
Olbrzym Borowski (18)	728.3+43.1	153.3+7.9	305.0+21.1	270.0+13.2
Sunriche Orange (19)	723.2+22.2	268.3+10.1	348.3+11.5	106.6+3.9
Ukr-Nar 96-291 (20)	721.0+36.6	232.0+13.7	387.0+21.7	102.0+5.2
Albena (21)	669.3+24.0	222.7+12.0	340.5+12.9	106.1+5.5
Pastewny (22)	661.0+24.2	241.0+14.0	310.0+11.8	110.0+6.5
Wielkopolski (23)	653.0+36.7	214.5+12.5	292.5+12.5	146.0+13.7
Borowski Ulepszony (24)	642.0+64.8	171.1+16.8	275.5+25.3	189.4+25.8
57953 (25)	632.1+36.9	193.3+11.2	271.6+11.7	167.2+14.8
Alphasol (26)	603.7+31.1	210.5+11.8	293.8+4.3	99.4+8.8
Valentin (27)	574.9+48.2	162.2+13.6	342.7+28.8	70.0+7.0
57959 (28)	551.8+15.3	137.2+4.6	273.3+8.6	141.3+3.9
Lech (29)	543.0+33.3	177.0+12.8	209.5+13.9	156.5+15.4
57960 (30)	540.5+22.7	159.5+7.0	264.5+11.7	116.5+7.1
57957 (31)	535.5+13.1	151.0+5.8	268.0+6.0	116.5+2.8
Einfache Gemischt (32)	491.0+25.1	162.0+7.4	301.0+20.1	28.0+2.8
57958 (33)	463.1+16.8	120.6+4.4	231.5+9.2	111.0+4.2
Soraya (34)	393.2+20.2	105.5+7.1	253.3+11.6	34.4+2.5
Borowski Prazkowany (35)	336.7+11.0	100.6+3.7	152.8+6.6	83.3+5.1
Floristan (36)	296.0+13.6	67.7+4.0	141.1+5.5	87.2+5.3
57956 (37)	260.0+18.9	58.5+4.5	116.0+9.1	85.5+5.7
HSD _{0.05} for genotype	454.4	178.4	257.9	154.5
Mean	831.8	229.3	418.5	184.0

Significant differences between sunflower genotypes were estimated by HSD of the Tukey test at P ≤ 0.05. Data are mean ±SE, n=10. Bold refers to highest and to lowest values.

In all organs, the maximum biomass accumulated (34.8-64.4%) in stems, followed by leaves (leaf blades with petioles) (19.9-37.9%) and smallest in inflorescences (5.7-42.6%) (Figure 1). The mean fresh weight of stems, leaves and inflorescences was

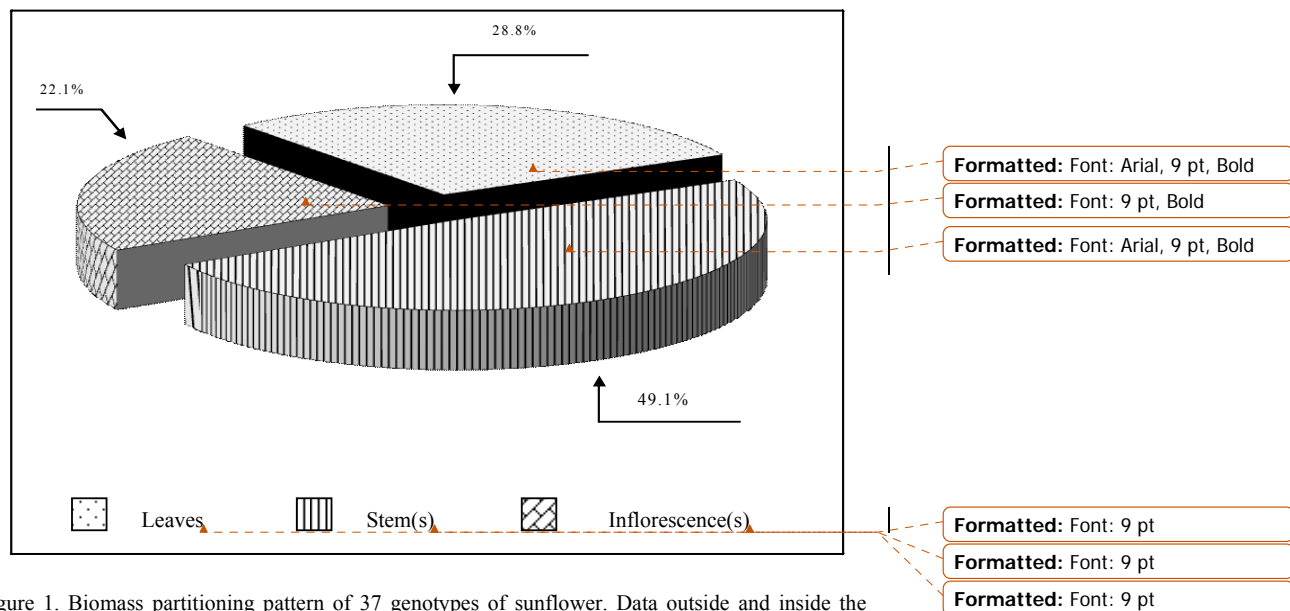


Figure 1. Biomass partitioning pattern of 37 genotypes of sunflower. Data outside and inside the graph show mean value and range for given organ.

418.5, 229.3 and 184.0 g/plant, respectively. The accumulated biomass in leaves, stems and inflorescences ranged from 58.5 g to 553.0 g/plant, 116.0 g/plant to 1392.0 g/plant, and 28.0 g to 625.6, g/plant respectively. The maximum fresh weights of leaves and stems were recorded in Giganta (1) and of inflorescences in cv. Ogradowy(#3). Contrarily, the lowest biomass in leaves and stems was in Accession 57956 (#37) and in inflorescences in cv. - Einfache Gemischt (#32) (Table 1).

In most genotypes, the highest proportion of biomass was partitioned to stems, then to leaves and the lowest to inflorescences (Figure 1). Significant genotypic, intra-species, differences in biological yield and in partitioning patterns are known (7) but such data for sunflower are available for only 4 genotypes (22).

Allelopathy activity

Seed germination

Mustard seeds used in germination tests were healthy having a high germinating capacity as in control conditions, depending on lot, between 95.6 and 99.7% of sown seeds germinated (Table 2).

The allelochemicals contained in water extracts of shoots (of above ground organs) of sunflower genotypes delayed and reduced the germination of mustard seeds (Table 2). However, the responses differed significantly, depending on genotype, plant organ, and extract concentration. In most cases, both delay and reduction in mustard

Table 2. Effects of aqueous extracts of leaves of 37 sunflower genotypes on germination of mustard (*Sinapis alba* L.) cv. 'Nakielska' in lab bioassay at 14 days after sowing

Genotypes (number)	Water (control)	Air dried leaves aqueous extracts conc. (% DM w/v)			
		2.5	5.0	7.5	10.0
Albena (21)	98.0d	81.7c	22.7b	11.0ab	2.3a
Mikafior (16)	96.0d	77.3c	42.7b	5.0a	2.0a
Printasol (14)	96.0d	70.3c	42.3b	19.0ab	1.3a
Alphasol (26)	97.7d	84.0c	45.7b	7.0a	4.3a
Sunriche Orange (19)	95.7d	80.7c	51.0b	11.3a	2.3a
Floristan (36)	96.0c	85.7c	48.7b	11.7a	4.0a
57958 (33)	99.0e	82.7d	51.3c	17.0b	4.0a
4449 (13)	98.0d	83.7c	66.0b	14.3a	3.0a
Sion (15)	98.0c	84.7c	67.7b	12.3a	4.3a
Wielkopolski (23)	98.3d	82.0c	77.0b	12.7a	1.3a
Lech (29)	98.7c	94.0c	53.3b	2.3ab	4.7a
57959 (28)	99.0d	84.7c	62.0b	22.0a	13.0a
Pastewny (22)	98.3d	84.7c	81.0c	19.3b	3.3a
Giganta (1)	98.3c	93.0bc	83.3b	8.3a	6.3a
Pardisol (8)	95.7d	89.3d	69.0c	29.7b	5.7a
57956 (37)	99.0d	83.0cd	72.0c	33.0b	5.0a
Soraya (34)	98.0d	85.7cd	71.3c	32.3b	11.0a
57957 (31)	99.7b	92.0b	77.7b	35.7a	9.3a
Borowski Ulepszony (24)	98.0d	91.0d	78.3c	30.7b	7.7a
Hallo (17)	97.7d	90.3d	76.3c	41.7b	11.3a
57960 (30)	96.0d	85.0cd	78.7c	48.7b	19.7a
57953 (25)	99.0d	86.0c	74.7c	40.0b	15.0a
Full Sun (4)	98.7d	91.7cd	82.7c	48.3b	9.0a
Herbstschonheit (6)	98.7d	91.0cd	82.7c	50.7b	10.0a
Valentin (27)	97.7d	88.7c	83.3c	60.3b	4.0a
Einfache Gemitsch (32)	97.7d	88.7cd	79.7c	56.0b	20.3a
Evening Sun (7)	98.7c	93.3c	86.7c	45.7b	22.0a
Borowski Prazkowany (35)	98.0d	90.3d	79.3c	62.7b	19.3a
Optisol (11)	95.6c	87.0c	79.3bc	63.6b	27.0a
Schnittgold (12)	98.0d	91.7cd	79.7c	57.3b	33.7a
Frankasol (10)	99.0d	94.7cd	85.3bc	79.7b	24.7a
Ogrodowy (3)	98.7c	91.3bc	88.3bc	71.3ab	58.7a
Polizie 98-43 (5)	99.7c	95.0bc	82.0bc	76.3b	51.3a
Pelny (9)	99.0b	92.3b	86.3b	80.7ab	62.7a
Olbrzym Borowski (18)	99.0b	92.7b	87.0ab	82.0ab	67.3a
Ukr Nar 96-291 (20)	99.7c	94.0bc	91.7bc	82.7ab	74.7a
Goldener Neger (2)	98.7d	94.0bc	93.3bc	90.3b	80.0a

HSD_{0.05} for genotype

Mean	98.0e	87.8d	71.9c	40.7b	19.7a
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Data are mean of 6 replicates with 50 seeds in each. Values in rows marked by different letters differ significantly according to HSD of the Tukey test at $P \leq 0.05$. Bold refers to highest and lowest values.

germination showed concentration-dependent response. Allelochemicals extracted from the leaves were more potent in reducing mustard germination than from stems and inflorescences. The leaf extracts of 2.5, 5.0, 7.5 and 10.0% [w/v] concentration reduced the mustard germination by 87.8, 71.9, 40.7 and 19.7%, stem extracts by 91.1, 87.1, 79.2, 66.8% and inflorescence extracts by 92.8, 87.8, 80.2, 64.6% respectively (Fig. 2, Table 2).

The presence of allelocompounds in leaves extracts of 11 tested sunflower genotypes reduced the mustard germination to 45.0% of sown seeds. Besides the leaf extract of 10.0% (w/v) concentration of 14 genotypes drastically reduced the germination by 95.0%; 12 genotypes by 80.0% and only 6 genotypes reduced germination below 50.0% (Table 2).

The cv. (#21), Albena extracts was most potent and reduced the mustard germination to 29.4% (Figure 2). The cv. Goldener Neger (#2) proved least inhibitory (10.6% inhibition) to mustard seed germination (Figure 2). Although stems and inflorescences extracts exhibited allelopathic activity, but their adverse effects were less than leaves

In contrast to leaf extracts, the stems extracts only of three genotypes (cv. #14 #24 and breeding line #25) and inflorescences of two genotypes (cv. #34 and #32) at the highest concentration, drastically reduced the germination above 90% and 80.0% respectively. However, lower concentrations of extracts of these two organs had no inhibitory effect on mustard seed germination. Thus, concentrations of stem and inflorescence extracts were less inhibitory to mustard germination (Figure 2). These results are in agreement with several studies (9,11,12,16), which showed that sunflower leaves have higher allelopathic activity than stems.

The higher allelopathic activity of leaves over stem and inflorescence has also been found in black mustard (19) and rice (5). However, in other work (15) stems of sunflower were reported more allelopathic, followed by leaves and roots. Similarly, stem extract from buckwheat (*Fagopyrum esculentum* Moech.) was more inhibitory than leaf extract against rice seedlings (23). Our results of inflorescence allelopathic activity do not agree with other studies (20), which showed that, among all evaluated organs, flowers were most inhibitory to test plant species.

We also studied the allelopathic potential of petioles of two cultivars (#3 and #29). As expected, allelocompounds extracted from petioles were less inhibitory to mustard germination than leaves, but had effects similar to stems and inflorescences extracts (Table 3). At the highest extract concentration, petiole extracts of cv. #3 were more inhibitory (44.3%) than cv. #29 (26.7%).

The allelopathic activity of leaf petioles similar to stem(s) is understandable, since these two organs are similar in structure and function and characterized by lower cellular metabolism (including synthesis of secondary metabolites) than leaf blades. We also examined the effects of allelocompounds extracted from whole seeds, seeds without hulls and hulls alone of sunflower cv. #3 and none of these extracts inhibited the mustard seed germination (data not shown). Contrary to this, rice hull extracts exerted strong toxic effects on barnyard grass (*Echinochloa crus-galli* P. Beauv. var. *oryzicola* Ohwi) (1).

Allelochemicals extracted from sunflower roots almost did not inhibit mustard germination and the differences between used concentration were very small (Figure 3).

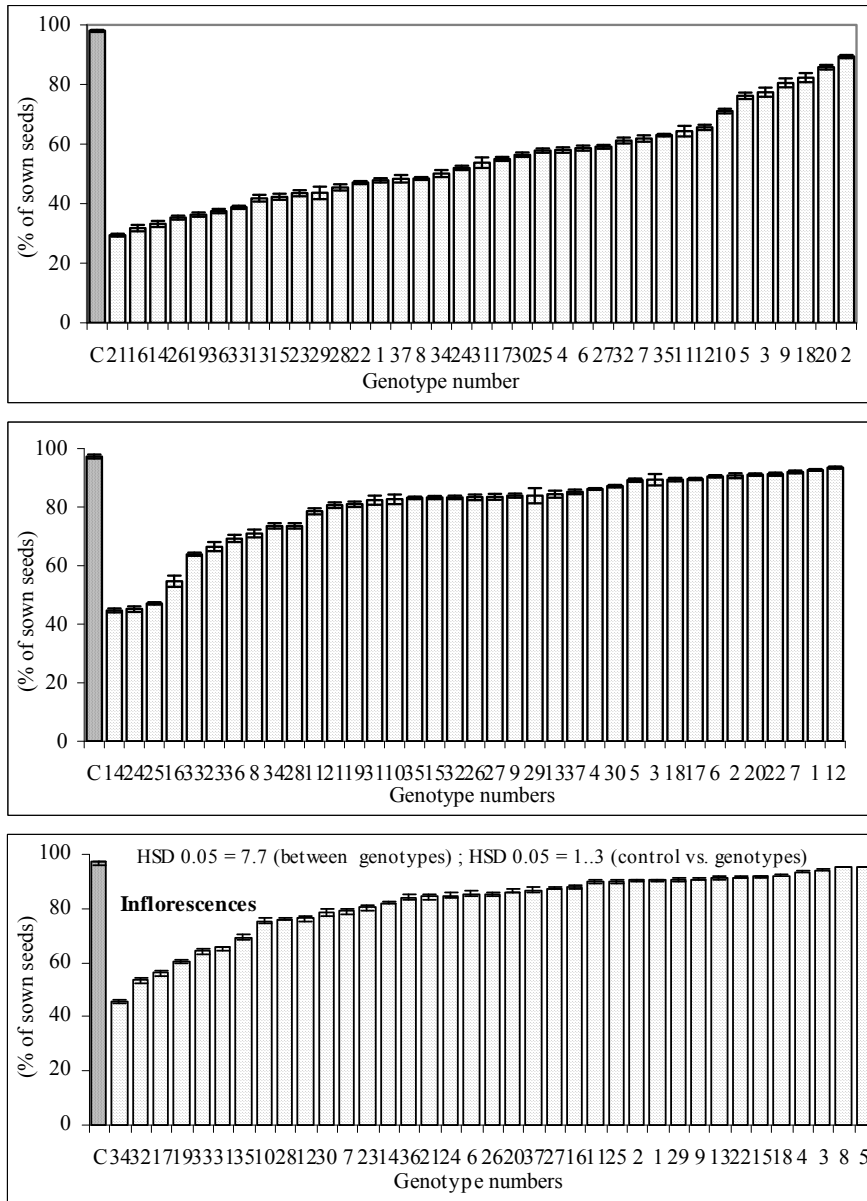


Figure 2. Effects of aqueous leaf, stems and inflorescences extracts of 37 sunflower genotypes on germination of mustard (*Sinapis alba* L.) cv. 'Nakielska'. Significant differences between genotypes and between control vs. genotypes were estimated by HSD of the Tukey test at $P \leq 0.05$. Dark bar represents seed germination in H_2O (control - C). Data are average for all four concentrations, \pm SE, $n = 6$ with 50 seeds in each.

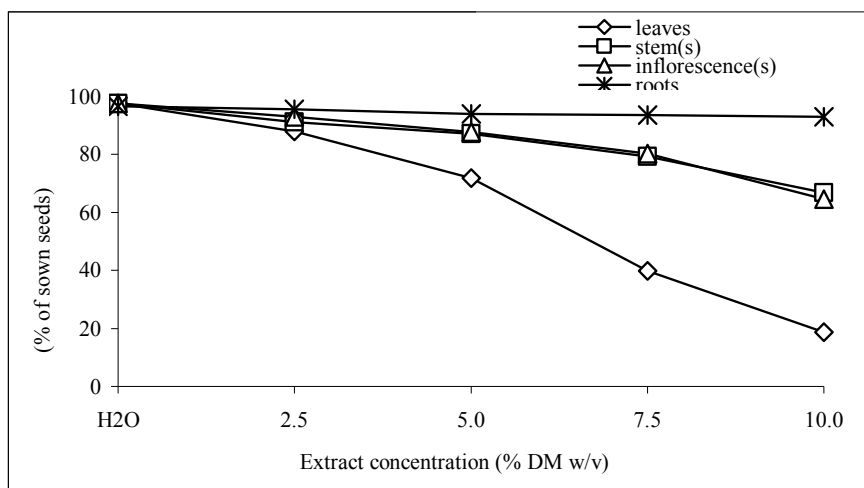


Figure 3. Effects of water extracts of sunflower leaves, stem(s), inflorescence(s) of 37 genotypes and of roots of 11 genotypes on germination of mustard. Significant differences between genotypes and organs were estimated by HSD of the Tukey test at $P \leq 0.05$.

Table 3. Effects of aqueous extracts of petioles of 2 sunflower cultivars on germination and Pipper Index of mustard (*Sinapis alba* L.) cv. 'Nakielska' in lab bioassay at 14 days after sowing

Cultivar	Control (H ₂ O)	Extract concentration (% DM w/v)				Average
		2.5	5.0	7.5	10.0	
Germination (% of sown seeds)						
Ogrodowy	98.0	95.0	85.0	80.7	55.7	79.1
Lech	98.0	98.0	81.3	80.3	73.3	83.6
HSD _{0.05} for cultivar = 3.5; HSD _{0.05} for concentration = 5.5						
Pipper Index (days)						
Ogrodowy	1.6	4.2	4.8	4.9	5.1	4.8
Lech	1.6	4.3	5.3	5.4	5.9	5.2
HSD _{0.05} for cultivar = 0.2; HSD _{0.05} for concentration = 0.3						

Data are mean of 6 replicates with 50 seeds in each.

The root extracts of 11 test genotype at 2.5, 5.0, 7.5 and 10.0% (w/v) concentrations reduced the seed germination to 95.9, 93.9, 93.6 and 92.9%, respectively (Figure 3). These results correspond to earlier data (5), which showed that rice roots have lower allelopathic potential than above ground organs. On the other hand, considering that roots are organs of high exudation activity, low root allelopathic activity seems to be surprising. It probably can be attributed to the fact that even very careful collecting of roots from pot experiments, does not remove all roots especially the tiny ones with root hairs. Since these are most physiologically active, including exudation of allelocompounds, it can be expected that their actual allelopathic potential would be much

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higher than shown in this and earlier study (5). Results of our second paper (4) support this point of view.

Dynamics of germination

The sunflower extracts of all genotypes and organs delayed the seed germination. Similar to reduction in germination, the most effective allelochemicals were extracted from leaves. According to Pimper Index (PI), one seed needs 1.6 days to germinate when cultured in water (control). The leaf extracts concentrations of 2.5, 5.0, 7.5 and 10.0%, took 3.2, 4.3, 5.4 and 6.2 days to germinate, respectively (Table 4).

The stem and inflorescence extracts took 3.2, 4.4, 5.1, 5.3 and 3.4, 4.7, 4.7 and 4.9 days, respectively (Tables 4 and 5). Depending on sunflower genotype and extract concentration, PI values for leaf, stem and inflorescence extracts ranged from 1.3 to 8.6, 2.2 to 8.0, and 2.4 to 7.4 days respectively (Tables 4, 5 and 6).

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Among the test sunflower genotypes, leaf extract of Polizie 98-43 at highest concentration (10 % DM w/v), caused maximum delay of 8.5 days (6.7 days more than in water), while the extracts of breeding lines: 57958 (#33) and 57957 (#28) delayed mustard germination by 3.2 days over control (Table 4).

The stem and inflorescence extracts of breeding line #31 and cv.#17 at the highest concentration, delayed the mustard germination by 6.2 and 6.0 days respectively. While the extract from stems of breeding line 57960 (#30) or cv. Goldener Neger (#2), and from inflorescences cv. Borowski Ulepszony (#24) caused least delay (2.4 and 2.6 days) (Tables 5 and 6). Besides, allelocompounds extracted from leaf petioles also delayed the mustard germination, depending on extract concentration PI values ranged from 4.2 to 5.1 days and from 4.3 to 5.9 days for cvs. Oгородowy (#3) and Lech (#29) respectively (. Although petiole extract of cv. #3 caused greater reduction in seed germination, but caused less delay in germination (Table 3). The root extracts had little effect on the speed of germination.

The allelocompounds of donor plants sunflower (17), buckwheat (23) etc often delayed the seed germination. However, these are the first results for sunflower for dynamics of seed germination. The effects allelochemicals to delay and reduce germination may be used for weed control. The crops having fast germination and early vigorous growth smothers the weeds, partly due to delayed and reduced germination through interference i.e. competition and allelopathic effects. This described reduction and delay may be due to compounds contained in water extracts of sunflower tissues. Therefore, we may conclude that the negative impact of water extracts from sunflower has a chemical, toxic, mode of action due to allelopathy.

These results demonstrated that aqueous extracts of all 37 test genotypes inhibited the seed germination of mustard. There is significant genetic variation among sunflower native species, 13 cultivars and breeding lines (11). Besides 26 cultivars of sunflower decreases the germination and seedling growth of lettuce (14). These results and our findings confirms great genotypic differences in sunflower for allelopathic traits and that there is potential to breed cultivars with high allelopathic activity. The test genotypes also differed in biological yield and allelopathic activity. Cultivars with higher biological yield would be preferred either in (i) crop rotation, (ii) or as biologically active mulch or (iii) residues left on soil surface because biomass contains allelochemicals thus serve as source

Table 4. Values of Pimper Index for mustard (*Sinapis alba* L.) cv. 'Nakielska' seeds germinated in the presence of allelochemicals contained in water extracts from leaves of 37 genotypes of sunflower (*Helianthus annuus* L.) evaluated during 14 days of culture

Genotypes	H ₂ O	Air dried leaves aqueous extracts conc (% DM w/v)			
	(control)	2.5	5.0	7.5	10.0
Mikaflo (16)	1.5a	1.3a	2.1a	4.5b	5.5b
57956 (37)	1.6a	2.4b	3.6c	3.8c	5.0d
57959 (28)	1.6a	2.8b	3.5c	3.7c	4.8d
Printasol (14)	1.5a	5.2b	4.8b	4.3b	5.6c
57958 (33)	1.6a	3.1b	3.5b	3.8b	4.8c
Alphasol (26)	1.5a	2.6ab	3.5b	3.7b	5.5c
Sunriche Orange (19)	1.4a	2.0a	3.5b	4.2b	6.0c
57960 (30)	1.5a	3.1b	4.4c	5.3d	5.5d
Sion (15)	1.5a	2.9b	4.3c	4.6c	5.0c
Albena (21)	1.5a	2.3a	4.4b	4.3b	5.7c
Pardisol (8)	1.4a	2.7b	4.2c	4.4c	5.6d
Valentin (27)	1.5a	2.8b	3.0b	5.2c	5.8c
Einfache Gemitsch (32)	1.5a	2.7ab	3.7bc	5.0cd	5.7d
Goldener Neger (2)	1.4a	3.0b	3.8bc	4.9c	6.3d
Giganta (1)	1.6a	3.5ab	3.8ab	5.2b	5.7b
Soraya (34)	1.7a	3.7ab	4.2b	4.4b	5.9c
Borowski Prazkowany (35)	1.7a	3.8b	4.0b	5.4c	5.6c
Borowski Ulepszony (24)	1.7a	3.5b	4.8c	5.3c	5.4c
Pastewny (22)	1.6a	3.9b	4.4bc	5.3c	5.3c
4449 (13)	1.5a	3.5b	4.3bc	5.2c	5.7c
Floristan (36)	1.5a	3.6b	4.9c	7.6d	7.9d
57953 (25)	1.6a	2.9b	4.9c	5.3cd	6.3d
Wielkopolski (23)	1.6a	2.5ab	4.7bc	5.9c	6.0c
Optisol (11)	1.4a	3.5b	4.1b	5.6c	6.0c
Herbstschonheit (6)	1.7a	3.5b	4.8c	5.5d	6.0d
Hallo (17)	1.5a	3.6b	3.9b	6.0c	6.9c
Ogrodowy (3)	1.4a	2.7b	4.7c	5.8d	6.8e
Schnittgold (12)	1.7a	3.3b	5.3c	5.4c	6.2d
Full Sun (4)	1.7a	3.3b	5.1c	5.6c	6.5c
Evening Sun (7)	1.7a	3.2b	5.4c	5.7c	6.5c
Lech (29)	1.4a	3.6ab	4.4ab	5.9ab	6.8b
Frankasol (10)	2.1a	3.3a	5.9b	6.4b	7.4b
Olbrzym Borowski (18)	2.1a	4.4b	5.5bc	6.4cd	8.4d
Pelny (9)	2.1a	3.9b	5.7c	6.4c	8.6d
57957 (31)	1.8a	4.0ab	6.4b	6.9b	7.0b
Ukr Nar 96-291 (20)	1.8a	4.4b	5.5c	6.7d	8.0e
Polizie 98-43 (5)	1.8a	3.6a	7.2b	7.9b	8.5b
HSD _{0.05} for genotype	1.6				
Average for genotype	1.6a	3.2b	4.3c	5.4d	6.2e

Data are mean of 6 replicates with 50 seeds in each. Values in rows marked by different letters differ significantly according to HSD of the Tukey test at $P \leq 0.05$. Bold refers to highest and lowest values.

Table 5. Values of Pimper Index for mustard (*Sinapis alba* L.) cv. 'Nakielska' seeds germinated in water extracts from stems of 37 genotypes of sunflower (*Helianthus annuus* L.) at 14 days after culture

Genotypes	H ₂ O (control)	Concentration of air dried stem(s) (% DM w/v)			
		2.5	5.0	7.5	10.0
Ogrodowy (3)	1.5a	2.8b	3.8bc	3.6bc	4.3c
Lech (29)	1.5a	3.6ab	4.1ab	5.5b	6.3b
Goldener Neger (2)	1.5a	3.0b	3.5bc	3.9c	3.9c
Olbrzym Borowski (18)	2.1a	3.0a	6.5b	6.6b	6.9b
Pelny (9)	2.1a	3.2ab	4.2b	6.2c	7.0c
Frankasol (10)	2.1a	4.1ab	5.2bc	7.7c	8.0c
Wielkopolski (23)	1.6a	3.5b	4.5c	5.9d	6.9e
Pastewny (22)	1.6a	3.0b	3.9c	4.6c	6.4d
Giganta (1)	1.6a	2.7b	3.8c	4.3c	4.9d
57957 (31)	1.7a	3.4a	6.4b	7.0b	7.9b
Ukr Nar 96-291(20)	1.7a	3.6b	4.3bc	5.6cd	6.6d
Polizie 98-43 (5)	1.7a	2.8b	4.1c	5.1d	5.7d
Full Sun (4)	1.8a	3.0b	4.0c	4.6d	5.5e
Herbstschonheit (6)	1.8a	2.6b	4.3c	4.9d	5.3e
Evening Sun (7)	1.8a	2.5b	3.2c	4.4d	4.5d
4449 (13)	1.5a	3.4b	4.7c	5.7c	5.7c
Sion (15)	1.5a	3.4b	4.5c	5.8d	5.9d
Albena (21)	1.5a	3.5b	5.2c	5.7cd	6.2d
Pardisol (8)	1.5a	2.5b	5.1c	5.6c	5.7c
Optisol (11)	1.5a	2.8b	4.1c	4.4c	4.7c
Sunriche Orange (19)	1.5a	3.1b	4.8c	5.6d	6.1d
Alphasol (26)	1.6a	3.0b	4.3c	4.8c	4.9c
Valentin (27)	1.6a	2.9b	3.3c	3.7cd	4.0d
Einfache Gemischt (32)	1.6a	2.8b	3.8c	5.7d	6.2d
Hallo (17)	1.6a	2.7b	3.5c	3.7c	5.3d
Borowski Prazkowany (35)	1.5a	3.4b	4.1c	5.1d	5.2d
Soraya (34)	1.5a	3.3b	4.6c	5.6d	5.8d
Borowski Ulepszony (24)	1.5a	4.4b	6.3c	6.3c	6.5c
Schnittgold (12)	1.5a	3.4b	3.7b	4.3c	4.4c
Mikaflor (16)	1.7a	3.1a	4.6b	5.3c	5.3c
Floristan (36)	1.7a	3.7b	4.9c	5.4cd	5.5d
Printasol (14)	1.7a	4.7b	6.0b	6.4b	6.8b
57960 (30)	1.7a	3.3b	3.5bc	3.8bc	4.1c
57959 (28)	1.5a	2.9b	3.4b	4.4c	4.5c
57958 (33)	1.5a	2.8b	3.7c	3.9d	4.1d
57956 (37)	1.5a	2.7b	3.0b	4.0c	4.0c
57953 (25)	1.5a	2.2ab	3.0bc	3.2bc	4.0c
HSD _{0.05} for genotype	1.1				
Average	1.6a	3.2b	4.4c	5.1d	5.3d

Data are mean of 6 replicates with 50 seeds in each. Values in rows marked by different letters differ significantly according to HSD of the Tukey test at $P \leq 0.05$. Bold refers to highest and lowest values.

Table 6. Values of Pimper Index for mustard (*Sinapis alba* L.) cv. 'Nakielska' seeds germinated in the presence of allelochemicals contained in water extracts from **inflorescences** of 37 genotypes of sunflower (*Helianthus annuus* L.) evaluated during 14 days of culture

Genotypes	H ₂ O (control)	Concentration of air dried inflorescence(s) (% DM w/v)			
		2.5	5.0	7.5	10.0
Soraya (34)	1.4a	2.4b	2.7b	4.0c	4.4c
57958 (33)	1.5a	2.9b	3.4bc	3.6bc	4.7d
Einfache Gemischt (32)	1.5a	2.6b	3.2bc	3.9c	5.5d
Full Sun (4)	1.5a	2.7b	3.8c	3.9c	4.9d
Sunriche Orange (19)	1.9a	3.1b	3.5b	4.1c	5.4d
Mikaflo (16)	1.4a	2.8b	3.9c	4.6d	4.7d
Borowski Ulepszony (24)	1.9a	3.2b	4.0c	4.5c	4.5c
Olbrzym Borowski (18)	1.4a	3.1b	4.1c	4.4c	4.7c
Pelny (9)	1.4a	2.8b	3.9c	4.5d	5.1e
Ogrodowy (3)	1.7a	3.0b	3.7c	4.6d	5.1d
57957 (31)	1.9a	3.7b	4.5c	5.0d	5.6e
Evening Sun (7)	1.5a	3.2b	4.6c	4.7c	5.4d
Borowski Prazkowany (35)	1.4a	3.2b	3.8bc	4.1c	5.7d
Goldener Neger (2)	1.5a	2.9b	4.1c	4.9d	5.1d
Alphasol (26)	1.4a	3.5b	4.0bc	4.5cd	4.9d
Lech (29)	1.7a	3.1b	4.0c	4.7d	5.1d
57956 (37)	1.4a	3.0b	3.4b	4.9c	5.6d
Polizie 98-43 (5)	1.7a	3.2b	4.2c	4.9d	5.3d
57960 (30)	1.9a	3.5b	4.0b	4.9c	5.3c
Valentin (27)	1.5a	3.3b	4.7c	4.9c	4.9c
Sion (15)	1.4a	3.4b	4.2c	5.0d	5.6e
Floristan (36)	1.3a	3.5b	4.6c	4.9cd	5.3d
4449 (13)	1.7a	3.2b	4.4c	4.6c	6.3d
Herbstschonheit (6)	1.5a	3.2b	4.8c	5.1c	5.5c
Pastewny (22)	1.4a	3.2b	4.5c	5.3cd	5.7d
Hallo (17)	1.4a	3.2b	4.0c	4.1c	7.4d
57953 (25)	1.9a	3.7b	4.5c	5.0d	5.6e
57959 (28)	1.9a	3.7b	3.9b	5.6c	5.7c
Pardisol (8)	1.7a	3.8b	3.9b	5.4c	5.9c
Printasol (14)	1.7a	3.4b	4.4c	5.3d	6.1e
Frankasol (10)	1.9a	3.6b	4.4c	5.6d	6.1d
Ukr Nar 96-291 (20)	2.0a	3.6b	5.2c	5.5c	5.5c
Albena (21)	1.7a	3.4b	4.9c	5.2c	6.4d
Wielkopolski (23)	1.7a	3.9b	4.6bc	5.4cd	6.2d
Optisol (11)	1.7a	3.6b	4.9c	5.3c	7.1d
Schnittgold (12)	1.9a	3.5b	4.9c	5.9d	6.5e
Giganta (1)	1.7a	3.7b	5.1c	6.1d	6.3d
HSD _{0.05} for genotype	0.46				
Average	1.6a	3.4b	4.7c	4.7c	4.9c

Data are mean of 6 replicates with 50 seeds in each. Values in rows marked by different letters differ significantly according to HSD of the Tukey test at $P \leq 0.05$. Bold refers to highest and lowest values.

of potential natural herbicide. This knowledge is important to find plant parts cultivar(s) with (i) high allelopathic activity and fast release of allelochemicals or (ii) with lower allelopathic activity and slow release of allelochemical over a prolonged time. In first case, genotypes with high contribution of leaves in total biomass will be desired because the leaves are rich in allelochemicals and easier to decompose than stems and inflorescences. Also, volatiles released from sunflower leaves are highly allelopathic than from stem(s) (4). Such cultivars may effectively control crop weeds during the early crop vegetation and quickly after mulching or maintaining plant residues on soil surface. Thus, in fields heavily infested with winter weeds, we should either grow sunflowers in rotation or a pre-crop for biologically active mulch, choosing cultivars leafy e.g. cvv. Pelny (#9) and Frankasol (#10) contains 31 and 33% leaves of total shoot biomass (Table 1). Although, some cultivars possess higher allelopathic activity per unit of leaf biomass basis (Table 2), but they accumulated less biomass (#17, #19 or #22).

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In contrast in second case, i.e. if the release of allelochemicals over a longer period of time and/or of lower allelopathic activity is more important cultivars with a higher proportion of biomass in stems and inflorescences would be of better choice e.g. cultivars #1 and #2. The sunflower stem and inflorescence have lower allelopathic activity than leaves and their slower biomass decomposition ensures prolonged release of allelochemicals, thus controlling weeds for long time. This was observed in our earlier studies (8), where reduction in number of weeds was still recorded during spring vegetation in organic winter wheat field, which was mulched with sunflower biomass before crop sowing (autumn of previous year). For further study we chose cultivars 'Ogrodowy' (#3) (producing high biomass, low partitioning to leaves and of lower allelopathic activity) and 'Lech' (#29) (producing less biomass, higher portion distributed to leaves and high allelopathic activity).

The sunflower allelochemicals of most evaluated genotypes and organs, significantly delayed and reduced the mustard germination, which was concentration-dependent. Leaves were most allelopathic followed by stems and inflorescences. Sunflower roots from pot culture, had very little or no allelopathic activity. The 37 test genotypes significantly differed in (i) biological yield, (ii) biomass partitioning patterns, (iii) genotypic differences in allelopathic activity and (iv) allelopathic activity of particular organs.

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