ISSN 1067-4136, Russian Journal of Ecology, 2020, Vol. 51, No. 3, pp. 233–241. © Pleiades Publishing, Ltd., 2020.

Influence of the Allelopathic Properties of the Soils on the Genetic, Physiological and Morphological Parameters of *Brassica tournefortii* from Different Populations in Northern Saudi Arabia[1]

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Received July 31, 2019; revised November 14, 2019; accepted November 25, 2019

Abstract—The present study was to identify the communities of *B. tournefortii* Gouan in Al-Jouf areas in northern Saudi Arabia, to determine soil factors controlling its genetic variability and its allelopathic control. The plant communities dominated by *B. tournefortii* were investigated in fifteen localities. A collection of fifteen Saudi Arabian *B. tournefortii* populations was evaluated using five morphological traits. Analysis of variance and correlation coefficient were performed based on R software package. Soils representing each community were analyzed using eleven physico-chemical parameters. The allelopathic effects of *Portulaca oleracea* and *Pulicaria undulata* and their mixtures on germination, seedling root and shoot growth of *B. tournefortii* were investigated. The dendrogram based on trait variation using UPGMA method, shows genetic difference between the studied populations. Genetic variability analysis showed a important variability of number of seeds per plant (cv = 19.522) and number of pods per plant (cv = 11.663). The water extracts of *Portulaca oleracea* and *Pulicaria undulata* could be applied at a concentration of 10 g/L for the management of this species.

Keywords: Brassica tournefortii, soil, population, morphological traits, allelopathy

DOI: 10.1134/S106741362003011X

Sahara mustard (Bceae: *Brassica tournefortii* Gouan) is an annual native to the Mediterranean basin and much of the Middle East through to western India [1]. *B. tournefortii* is rapidly expanding and negatively affecting natural ecosystems [2]. It is considered an aggressively invasive weed in many countries like Australia [3] and the United States [4]. In Australia, it has been reported that *B. tournefortii* could reduce yield [5]. It is considered a weedy species in agricultural filds in parts of its native range [6] but also has traditional dietary uses and economic value in regions where it is cultivated [7, 8]. It has been shown that allelopathy offers great potential to increase agricultural production, decrease the harmful effects of modern agricultural practices, and maintain soil productivity and a pollution-free environment for future generations [9]. Winkler et al. [10] showed that linking life-history strategies, functional traits, and responses to environmental variation can assist in producing a mechanistically based predictive framework for ecologists to understand the behavior of invasive species in space and time [11]. When a substantial seed bank exists, seeds may cycle through different stages of dormancy, depending on environmental conditions. *B. tournefortii* Gouan is a winter annual, herbaceous and erect plant. It produces numerous seeds which buried in the soil and stay viable for several years [9]. Knowledge of ecology of this weed would help in implementing effective weed control programs and help in designing suitable weed management programs [12]. In this study, the genetic variability of 15 Saudi Arabia *B. tournefortii* populations is evaluated by morphological analysis to attain a meaningful classification of these populations. These results were further evaluated employing the principal component analysis (PCA) and UPGMA method. In addition, the present investigation aimed to evaluate the allelopathic effects of some associated weeds on it as biological control method. The effect of allelopathic control and its interaction with root and seedling of species was also assessed. We hypothesized that allelopathic, as an

[1] Supplementary materials are available for this article at DOI: 10.1134/S106741362003011X and are accessible for authorized users.

Fig. 1. Map of Saudi Arabia showing the study area and the sampling locations (15 localities in Al-Jouf province is located in the northern part of Saudi Arabia).

environmental signal, would modify the germination characteristic and growth of *B. tournefortii*.

MATERIAL AND METHODS

Study Area

Al-Jouf is located in the northern part of Saudi Arabia, where it is bounded from the north and east by the Northern Borders province and from the south by Hail and Tabuk provinces and delimited from the north and west by Jordan (Fig. 1). It is located between latitudes 29° and 32° N and longitudes 37° and 42° E. Al-Jouf province consists of the town of Sakaka and two governorates (Dawmat Al-Jandal and Al-Qurayat). The study area is composed of transverse sand dunes that often reach up to a height of about 120 m. According Gomaa [13], the study area is characterized by dry climate with hot summer and cool winter the mean monthly air temperature ranges between 9.8°C during January and 33.8°C during August. Gomaa [13] reported that the mean monthly relative humidity varied between 16% during June and 53% during January.

Soil Analysis

Three soil samples were taken per localities, from a depth of 0–50 cm. The samples were pooled together, forming one composite sample for each stand. The samples were air dried and sieved through a 2 mm sieve before analysis. Soil texture, water holding capacity, soil porosity, organic carbon, and sulfate were determined according to [14]. Calcium carbonate was determined by titration against 1 N NaOH and expressed as percentage [15]. Oxidizable organic carbon was determined by modified Walkley-Black method [16]. Soil–water extracts were prepared and used for determination of electrical conductivity (EC). A soil solution was prepared for each soil sample. The electrical conductivity (EC) is determined according to [15]. The sodium adsorption ratio (SAR) and potassium adsorption ratio (PAR) were calculated to express the combined effects of diffrent ions in the soil.

Genetic Variability Analysis

Mature seeds of *B. tournefortii* were collected during April 2016 from the same localities. Seeds of each location were randomly collected from the population to diminish the effect of genetic variation within the population. Immediately after collection, seeds were cleaned from the surrounding structures and debris and stored in brown paper bags. For each species, the average seed mass was determined by weighing three replicates, each of 100 seeds. To verify that plants from the different seed collections had

grown equally, the heights of three plants per localities were measured. The plant height, along with the number of plants, pods number per plant, seed mass and seed number are measured.

Allelopathic Studies

The seeds of *B. tournefortii* were collected from diffrent localities in the studied area. Seeds were sterilized with 0.3% calcium hypochlorite, rinsed in distilled water, and dried on fiter paper in the laboratory at room temperature for 7 days. *Portulaca oleracea* and *Pulicaria undulata* were harvested at a vegetative stage. For bioassay tests, extracts were prepared from the plants *Portulaca oleracea* and *Pulicaria undulata* as various concentrations (2, 4, 6, 8 and 10% w/v). Mixtures of *Portulaca oleracea* and *Pulicaria undulata* were prepared (1 : 1 v/v). The solutions were fitered through double layers of muslin cloth followed by fiter paper. The pH of the mixtures was adjusted to 7 with 1 M HCl, and then mixtures were stored in a refrigerator at 4°C until further use [17]. For germination bioassays, two layers of fiter papers were placed in 90-mm-diameter glass petri dishes. Twenty seeds were placed in each petri dish, followed by 10 mL of plant extract. A control sample was assigned with distilled water and lef at room temperature (25°C). Starting from the first day after the experiment began, germinated seeds were counted and removed daily. The experimental design was carried out as a randomized complete block (RCB) with 6 replications. The percentage of germination was calculated. For growth bioassays, the seeds of *B. tournefortii* were germinated on fiter paper in the dark at room temperature (25°C) for 2 days. Fiften germinated seeds were transferred to petri dishes, which were filed with 25 g of sterilized quartz sand, and 10 mL of tested extract (2, 4, 6, 8 and 10% w/v) was added. In addition, control sample was added to the experiment without any treatment. Shoot and root lengths of seedlings were measured 15 days after treatment (DAT).

Statistical Analysis

Analysis of variance and correlations coefficients were calculated to determine associations between the measured traits using Past software. Tukey's HSD test was performed for multiple comparisons to determine significant differences among the treatments at $P = 0.05$. The principal Component Analysis was made using measured data with the Past program. To group the populations based on morphological dissimilarity, cluster analysis was conducted on the Euclidean distance matrix with the unweighted Pair Group Method based on Arithmetic Averages (UPGMA) using the past program too. Data were subjected to ANOVA. The data were performed using the R software package (V.3.4.0).

RESULTS

Soil Parameters

Edaphic characteristics are summarized in Table 1 of the measured soil parameters of 15 localities. Altitude of localities ranged to 78 to 120 m, electrical conductivity ranged to 186.5 to 257.4 (µmhos/cm), organic carbon varies between 0.670 and 1.890%. The means of sand, silt and clay is respectively 92.332%, 6.369% and 1.298%. The means of sodium adsorption ratio, potassium adsorption ratio and water holding capacity is respectively 51.088, 11.276 and 34.595% (Table 1). The locality R8 has the highest altitude (120 m), the locality R2 contains a sand percentage of 95.67%, the high silt rate is recorded at the locality R10 (10.28%), while the highest percentage of clay is recorded at R8 (1.91%). The most porous locality is R2 (33.25%). The largest Sodium adsorption ratio (SAR) is at location R7 (57.15) and the highest Potassium adsorption ratio (PAR) is recorded at location R13 (14.25) (Supplement 1).

Genetic Variability

The means plant height is 42.822 cm, the means pods lenght is 6.2 cm, the means number of pods per plant is 24.466 pods, the means number of seeds per plant is 43.266 seeds and the means weight of 100 seeds is 1.185 g (Table 2). The locality R11 is characterized by the highest average plant height (54 cm). The locality R15 has the most important means lenght of 10 pods (8.467 cm). The plants of the locality R3 are the most productive in pods because the average number of pods per plant is 39 pods. The most important means number of seeds per plant is recorded at R11 (65 means number of seeds per plant). The locality R8 has the means weight of 100 seeds (2 mg) (Supplement 2).

There is a important variability of number of seeds per plant (cv = 19.522) and number of pods per plant (cv = 11.663). This is explained by the characteristics of the soil, that are different (Supplement 1). There are a positive correlation between plant lenght and pods lenght (Fig. 2), number of pods per plant and number of seeds per plant (0.365). Altitude have negative effect of plant heigh (–0.455), pods lenght (–0.484) and number of pods per plant (–0.516). Plant lenght and pods lenght correlated negatively to salt and clay. There are a positive correlation between sand and plant height (0.393) and pods lenght (0.355). Weigh seed correlated positively with clay (0.621). Plant height, number of pods per plant and number of seeds per plant correlated positively with electrical conductivity (Fig. 2). Figure 3 showed the principal analysis component of of *B. tournefortii* populations according to the morphological characters and dendrogram based on trait variation using UPGMA method. The dendrogram shows differences between the studied populations. The dimension for the first two PCA axes are 58.78% and 38.51%, respectively (Fig. 3). We

Table 1. The means soil variables at depths of 0–50 cm in the 15 localities

Soils parameters	Mean	Standard deviation (SD)	Coefficient of variation (CV)	Min	Max	**Pr(>F)**
Altitude, m	93.800	13.502	0.143	78	120	0.001***
$CaCO_3$, %	8.155	0.873	0.107	7.150	9.450	0.024 *
Clay, %	1.298	0.308	0.237	0.850	1.910	0.001***
Electrical conductivityEC, μmhos/cm	216.464	24.043	0.111	186.5	257.4	0.001***
Organic carbon OC, %	1.328	0.344	0.258	0.670	1.890	0.045 *
Potassium adsorption ratio, PAR	11.276	1.725	0.153	8.240	14.25	0.001***
Porosity, %	31.564	1.386	0.043	28.49	33.24	0.001***
Sand, %	92.332	2.517	0.027	88.49	96.54	0.045 *
Sodium adsorption ratio, SAR	51.088	4.816	0.094	39.54	57.15	0.032 *
Silt, %	6.369	2.450	0.384	2.010	10.280	0.001***
Water holding capacity WHC, %	34.595	0.956	0.0276	33.24	36.24	0.001***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Table 2. The different parameters of plant, pods and seeds of 15 *Brassica tournefortii* populations

Parameters	Means	SD	CV	F value	Pr(>F)
Plant height, cm	42.822	7.139	0.166	18.51	5.1e-11 ***
Pods lenght, cm	6.200	1.207	0.149	28.12	2.03e-13 ***
Number of pods per plant	24.466	11.663	0.476	6.139	0.001 ***
Number of seeds per plant	43.266	19.522	0.451	2.075	0.0458 *
Weight of 100 seeds, g	1.185	0.187	0.158	8.902	0.001***

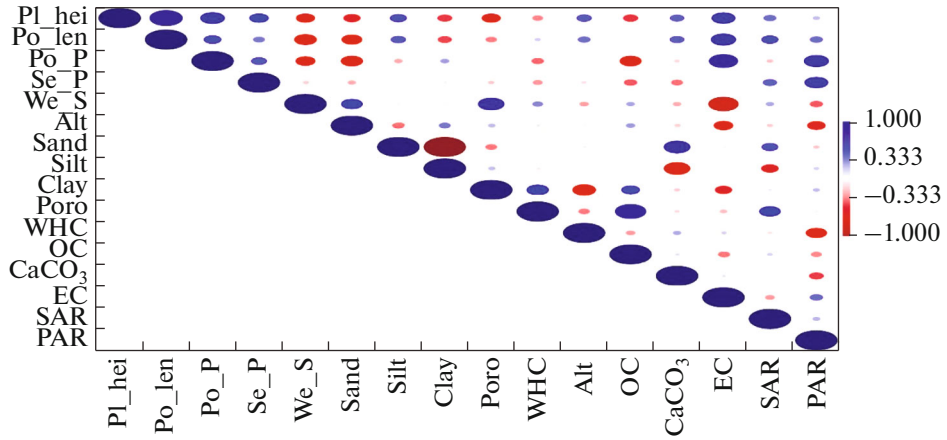
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

found that there is a wide variability among populations. There are four groups of populations which are distinguished according to the morphological parameters of the plant. BraR4 is distinguished by its low valeus; sodium adsorption ratio: 39.54, potassium adsorption ratio: 8.24, number of seeds per plant: 11 seeds and weight of 100 seeds: 0.96 g. Figure 4 showed the factor analyses of correspondances of 15 populations of plants of *B. tournefortii* and their 15 localities and of soils parameters. The first axis presents 58.78% of the information and he represents the sand, clay and Potassium adsorption ratio. The second axe presents 38.51% of information and he represents the silt. The morphological parameters are much correlated with soil parameters than the production of the plant in pods and seeds.

Allelopathic Studies

Effect of diffrent extracts on *B. tournefortii* germination. The allelopathic activities of water-soluble extracts from studied weeds on seed germination of *B. tournefortii* are shown in Tables 3 and 4. After 7 days of treatment, all extracts signifiantly reduced the germination of *B. tournefortii* in dose dependent manner except for treatment of *Portulaca oleracea* at a low concentration (2 g/L), when the differences in comparison to the control samples were not detected. According the Table 3, the data between the control and *Portulaca oleracea* + *Pulicaria undulata* are significantly different therefore this combination of extracts show signifiant inhibition in germination capacity. Hence, the combination of extracts from *Portulaca oleracea* and *Pulicaria undulata* signifiantly increased the allelopathic activity on germination of *B. tournefortii* seeds (Table 3, Fig. 5). Table 4 showed that concentartion have a signifiantly effect of germination capacity ($P \leq 0.05$). There are a interaction between concentration and species.

Effect of diffrent extracts on root growth of *B. tournefortii* seedlings. Th allelopathic activities of water-soluble extracts from investigated weeds on root growth of *B. tournefortii* seedlings are shown in Table 3, and Fig. 5. Mixed extracts of *Portulaca oleracea* and *Pulicaria undulata* and extract of *Portulaca oleracea* and extract of *Pulicaria undulata* showed inhibitory effect on root growth at low concentrations (2 and 4 g/L). The higher concentrations (6, 8, and 10 g/L) expressed signifiant inhibitory and very important effects (Table 3, Fig. 5). Table 4 showed that concentartion have a signifiantly effect of seedling root lenght ($P \leq 0.05$).



	Pl_hei	Po_len	Po_P	Se_P	We_S	Alt	Sand	Silt	Clay	Poro	WHC	OC	$CaCO_3$	EC	SAR	PAR
Pl_hei	1	0.779	0.573	0.448	−0.445	−0.400	0.393	−0.348	−0.445	−0.255	0.352	−0.354	0.334	0.555	0.297	0.165
Po_len		1	0.410	0.275	−0.528	−0.484	0.355	−0.331	−0.267	0.138	0.295	0.004*	0.342	0.588	0.398	0.303
Po_P			1	0.365	−0.464	−0.516	−0.201	0.210	−0.022	−0.293	0.002	−0.511	−0.124	0.680	−0.15	0.587
Se_P				1	−0.126	−0.195	−0.029	0.048	−0.148	−0.232	−0.108	−0.311	−0.281	0.028	0.331	0.556
We_S					1	−0.502	−0.042	−0.034	0.621	0.250	−0.218	0.201	−0.198	−0.711	0.194	−0.309
Alt						1	−0.288	0.275	0.164	0.057	−0.039	0.217	−0.128	−0.455	−0.143	−0.429
Sand							1	−0.992	−0.275	−0.001	0.047	−0.030	0.620	0.040	0.388	−0.146
Silt								1	0.156	−0.063	0.020	−0.022	−0.619	0.008	−0.408	0.130
Clay									1	0.517	−0.550	0.431	−0.140	−0.402	0.074	0.163
Poro										1	−0.270	0.731	−0.118	−0.174	0.500	−0.068
WHC											1	−0.223	0.192	0.115	−0.101	−0.496
OC												1	0.078	−0.28	0.127	−0.253
$CaCO_3$													1	0.068	0.012	−0.342
EC														1	−0.226	0.307
SAR															1	0.177
PAR																1

Fig. 2. Correlation matrice between morphological trait of plant, pods and seeds and soils characteristics. (Plant height; Pl_hei, Pods lenght; Po_len, Number of pods per plant; Po_P, Number of seeds per plant; Se_P, Weight of 100 seeds; We_S, Alt; Altitude, $CaCO_3$, Electrical conductivity (EC), Organic carbon (OC), Potassium adsorption ratio (PAR), Porosity (Poros), Sand, Sodium adsorption ratio (SAR), Silt, and Water holding capacity (WHC)). Correlation coefficients are coded according to circle size and to the color scale at the bottom, with significant correlations ($P < 0.05$).

There are a interaction between concentration and species.

Effect of diffrent extracts on shoot growth of *B. tournefortii* seedlings. The allelopathic activities of water-soluble extracts from investigated weeds on the shoot growth of *B. tournefortii* seedlings are shown in Table 3 and Fig. 5. The mixed extracts of *Portulaca oleracea* and *Pulicaria undulata* showed signifiant effects at 2, 4 and 6 g/L to seedling shoot lenght. At higher concentrations (8 and 10 g/L), all extracts induced signifiant inhibitory effects (Table 3). The mixed extracts of *Portulaca oleracea* and *Pulicaria undulata* was the most effective extract as it inhibited shoot growth of seedlings (varies from 34.33 to 4.16 cm). *Pulicaria oleracea* extract was second as it inhibited seedling root growth. Generally, the combination of extracts enhance the allelopathic activity on the seedling shoot growth. The extracts of all mixtures signifiantly increses their allelopathic effects on the seedling shoot growth of *B. tournefortii* ($P \leq 0.05$). Table 4 showed that concentartion have a signifiantly effect of seedling shoot lenght ($P \leq 0.05$). There are a interaction between concentration and species.

DISCUSSION

We found that the means plant height is 42.822 cm, the means pods lenght is 6.2 cm, the means number of pods per plant is 24.466 pods, the means number of seeds per plant is 43.266 seeds and the means weight of 100 seeds is 1.185 g. This is a much smaller difference than would be found in the average seed mass was determined by weighing, each of 100 seeds and means seed mass of *B. tournefortii* Gouan is 1.426 mg [18]. Singh et al. [7] noted that means plant height 88.8 cm, means pod length 3.6 cm, number of seeds/pod 15, seed weight/plot (g) 258.08. Choudhary and Joshi [19] noted that *B. tournefortii* means plant height (cm) is 131 cm, means pods lengh is 5.3 cm, means seed per pods 14.8, means pods per plant 256 and 1000 seeds weight is 2.92 g. Our results in this sense are broadly in agreement with the findings of [20], they observed that plant height is between 40 and 46 cm, mass of 1000 seeds is between 1.21 and 1.46 g and seed number per plant is between 200 and 600 seeds per plant of *B. tournefortii*. Precipitation explained a percentage of variance for the highest number of functional traits, including days to germination, timing of the first leaf,

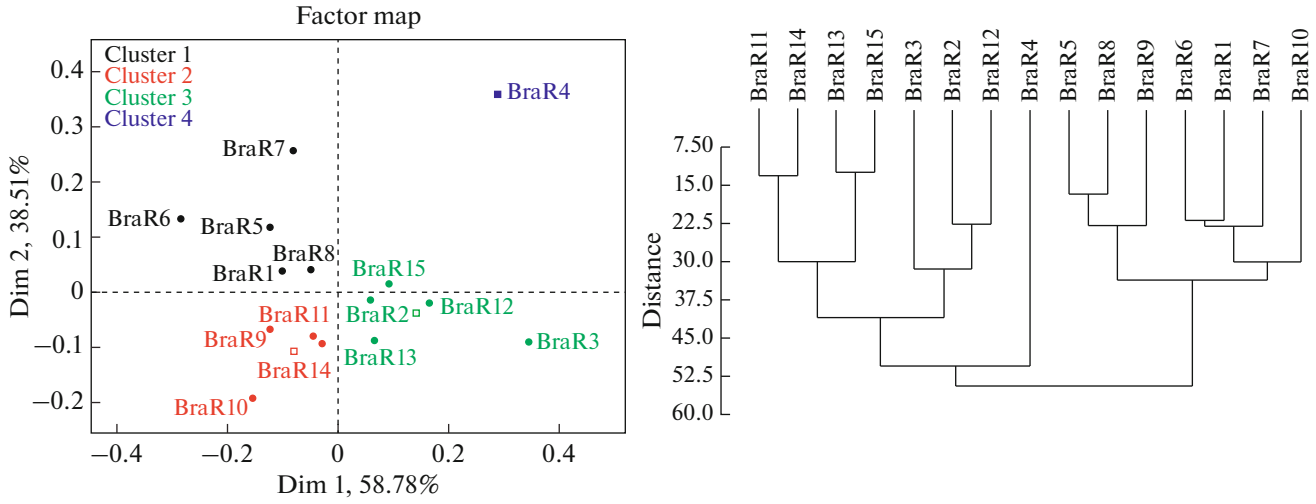


Fig. 3. Principal component analysis and dendrogram based on trait variation using UPGMA method of 15 *Brassica tournefortii* populations according to the morphological characters in 15 localities of soil (Bra; *Brassica tournefortii*, R: relevés).

seed weight, and percentage of biomass allocated to reproductive structures [10]. Abd El-Gawad [9] showed that *B. tournefortii* have nearly 1 m tall or more and it produces between 750 and 9000 seeds per plant. Plant height as a covariate significantly predicted pods production [21]. Water increased the pods production and height of *B. tournefortii* [21]. *B. tournefortii* pods production was significantly associated with soil. Plants produced more pods for their height relative to plants in control plots, indicating that *B. tournefortii* utilized available resources for pods production. Therefore, an increased number of pods can be equated to an increase in the number of seeds produced per plant. Greater seed production would translate into a high probability for persistence and possibly expansion of populations [21]. Others authors have found a strong relationship between plant size and seed count, and have reported that individual plants can produce more than 16,000 seeds [22]. Clearly, *B. tournefortii* is capable of copious seed production, and our results have demonstrated that individuals on average can be more fecund in disturbed habitats.

In the present study we found that the combination of extracts from *Portulaca oleracea* and *Pulicaria undulata* signifiantly increased the allelopathic activity on germination of *B. tournefortii* seeds. *Portulaca oleracea* L. (purslane) is a common troublesome weed worldwide. Mature foliage extract of *P. oleracea* showed an inhibitory effect on germination and radicle growth of glycine max [23]. The extract of *Pulicaria undulata* was

Table 3. The effect of different extracts on the germination percentage (at 7 DAT), on the seedling root length (mm) and on the seedling shoot length (mm) of *Brassica tournefortii* at 15 DAT (Means ± SD)

		Concentration of the extract				
		2 g/L	4 g/L	6 g/L	8 g/L	10 g/L
Germination capacity, %	Control	86.16 ± 1.16c	83.50 ± 1.87c	85 ± 1.25c	84.5 ± 1.22c	85 ± 1.78c
	Portulaca oleracea	79 ± 2.28bc	43 ± 3.033b	33.66 ± 2.065b	21.33 ± 5.58ab	4.33 ± 1.75ab
	Pulicaria undulata	74.33 ± 2.58b	35.66 ± 2.58ab	19.33 ± 4.22ab	6.16 ± 2.48a	1.66 ± 1.21a
	Portulaca + *Pulicaria*	41 ± 2.19a	13.5 ± 1.643a	7.16 ± 2.31a	2.66 ± 1.36a	1.33 ± 0.51a
Seedling root length, cm	Control	43.33 ± 1.63c	44 ± 2.52c	44 ± 1.89c	42.66 ± 1.21c	42 ± 2.28c
	Portulaca oleracea	34 ± 33b	28 ± 1.41ab	16 ± 2.75a	4.16 ± 1.72a	2.33 ± 1.50a
	Pulicaria undulata	31.16 ± 0.98b	22.16 ± 1.471ab	19.16 ± 1.471ab	11.5 ± 1.51b	2.33 ± 0.81a
	Portulaca + *Pulicaria*	18 ± 0.63a	12.83 ± 1.47a	10.66 ± 0.816a	6 ± 0.894ab	3.33 ± 1.50ab
Seedling shoot lenght, cm	Control	44 ± 2c	43.66 ± 1.96c	44.33 ± 2.33c	46.33 ± 1.21c	46 ± 0.98c
	Portulaca oleracea	35.5 ± 1.048bc	24.33 ± 1.36b	16.33 ± 1.63ab	8 ± 1.1a	2 ± 0.63a
	Pulicaria undulata	43.33 ± 1.75bc	36 ± 1.41ab	25.16 ± 0.75ab	11.33 ± 0.81ab	7.66 ± 1.50ab
	Portulaca + *Pulicaria*	34.33 ± 1.63a	16.66 ± 1.63a	12.5 ± 1.516a	7.66 ± 1.505a	4.16 ± 1.47b

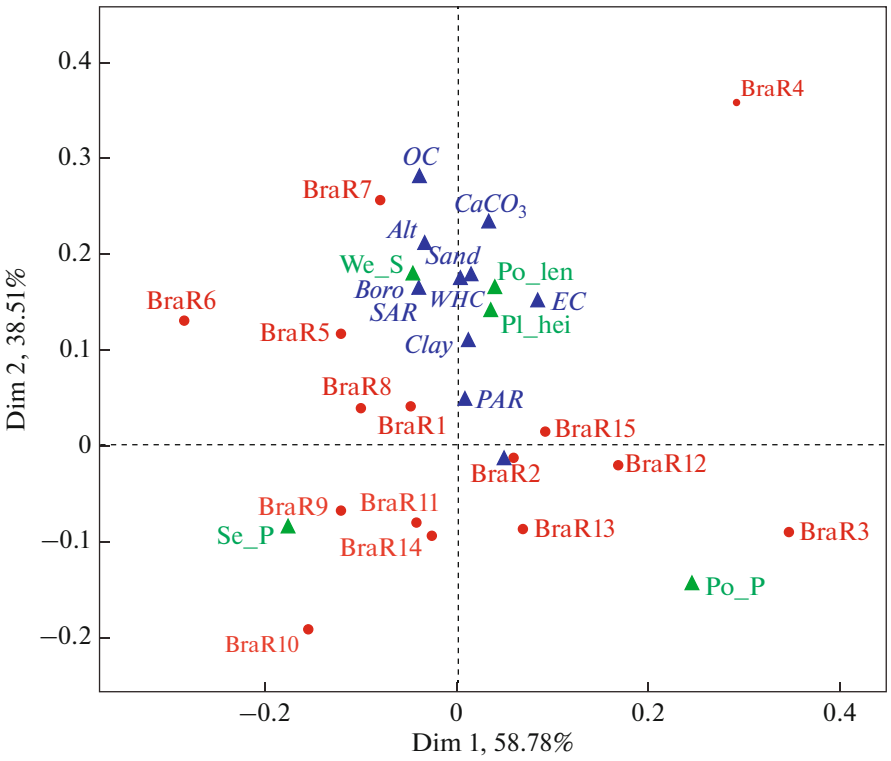


Fig. 4. factor analyses of correspondances of 15 populations of plants of *Brassica tournefortii* and their 15 localities and of soils parameters (Plant height; Pl_hei, Pods lenght; Po_len, Number of pods per plant; Po_P, Number of seeds per plant; Se_P, Weight of 100 seeds; We_S, Alt; Altitude, $CaCO_3$. Electrical conductivity (EC), Organic carbon (OC), Potassium adsorption ratio (PAR), Porosity (Poros), Sand, Sodium adsorption ratio (SAR), Silt, and Water holding capacity (WHC)).

the most effctive extract as it completely inhibited germination. Corsato et al. [24] stated that the allelopathic effect is a natural interference in which the plant produces substances and metabolites that may benefit or harm other plants/organisms when released. After 7 days of treatment, all extracts significantly reduced the germination of *B. tournefortii* in dose-dependent manner, combination of extracts from *Portulaca oleracea* and *Pulicaria undulata* did show signifiant inhibition and was the most effective. Germination bioassays are used widely to assess the allelopathic potential, speed of accumulated germination index is the most sensitive for this evaluation [25]. Shehata [26] indicated that, the *P. oleraecea* seed extracts inhibit the germination and growth of the treated plant species at high concentrations, inhibition of germination may be due to the reduced rate of cell division and cell elongation due to the presence of

Table 4. The concentrations effect of germination capacity, Seedling root and shoot length and interaction between species and concentartion factors

Parameters	Factors	F value	Pr(>F)
Germination capacity	Concentartion	41765.17	<2.2e-16 ***
	Species	6324.64	<2.2e-16 ***
	Concentration* species	243.31	<2.2e-16 ***
Seedling root lenght	Concentartion	506.041	<2.2e-16 ***
	Species	2345.257	<2.2e-16 ***
	Concentration* species	84.641	<2.2e-16 ***
Seedling shoot lenght	Concentration	990.56	<2.2e-16***
	Species	2432.09	<2.2e-16***
	Concentration* species	154.99	<2.2e-16***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

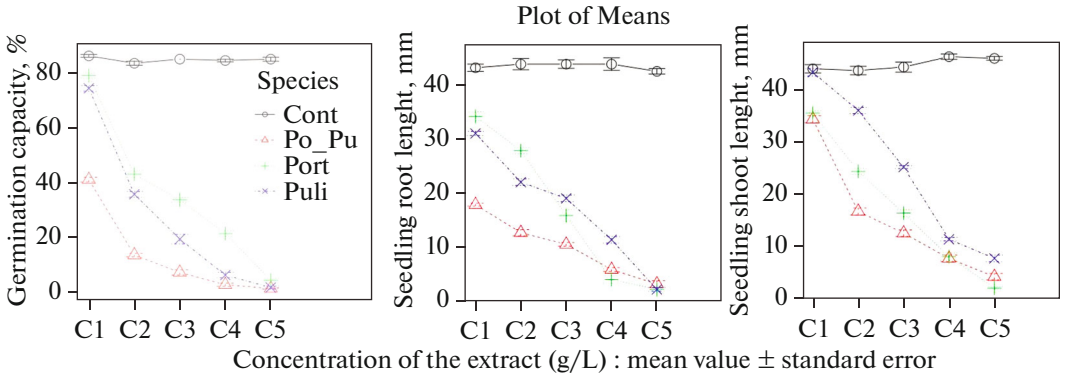


Fig. 5. Plot of effect of different extracts on the germination percentage (at 7 DAT), on the seedling root length (mm) and on the seedling shoot length (mm) of *Brassica tournefortii* at 15 DAT (Means ± SD). Cont; Control, Port; *Portulaca oleracea, Puli; Pulicaria undulata, Po_Pu; Pulicaria undulata* + *Portulaca oleracea.*

allelochemicals [23]. Inhibition of germination comparing to control could be explained by the presence of glycol alkaloids and tannins in the studied extracts [27]. The inhibition effect of all *Portulaca oleracea* seed extracts in the present study increased with an increase of extract concentrations indicating that the effect of plant extracts depends very much on their concentrations [26]. *Portulaca oleracea* (10 g/L) followed *Pulicaria undulata* in its allelopathic potential as it inhibited the seed germination of *B. tournefortii*, root growth and shoot growth. The results of the present study are in harmony with those of [28], who found that root length is more affected than shoot growth. These results could be attributed to the presence of many allelochemicals, which enhance the defense system in the plant at low concentrations [29]. The germination and seedling growth of *B. tournefortii* inhibited by the different *P. oleraecea* seed extracts at higher concentration which are comparable to the *Tribulus terrestris* on the same weed [30]. All extracts of the tested weeds signifiantly reduced the germination of *B. tournefortii* at high concentrations (2, 4, 6, 8, and 10 g/L), *Portulaca oleracea* and *Pulicaria undulata* did show signifiant inhibition ($P \leq 0.05$). The combination of diffrent extracts increased the allelopathic activity on seed germination and seedling growth of *B. tournefortii* and these results agree with those of [31]. Most allelopathic activities are due to the presence of several compounds in the mixture, where the concentration of each compound in a mixture might be signifiantly less than the concentration of individual compounds needed to cause growth inhibition. This is related to the inactivation of the enzymatic and nonenzymatic systems in the plant by diffrent allelochemicals [32].

CONCLUSIONS

In conclusion, this paper represents the important study of genetic diversity of *Brassica toournefortii* populations in Saudi Arabia. In this study we concluded that the variability in the physico-chemical properties of the soil between localities influenced the morphological traits of the *Brassica* species and some of the morphological traits depend on the soil characteristics. *Portulaca oleracea* and *Pulicaria undulata* are considered as weeds, the present results suggest that their water extracts could be used at 10 g/L for management of *B. tournefortii* as an alternative control method. The characterization of allelochemical properties of these weeds needs investigation.

COMPLIANCE WITH ETHICAL STANDARDS

The authors declare that they have no conflict of interest. This article does not contain any studies involving animals or human participants performed by any of the authors.

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