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Original Research

The Interspecific Competition of *Xanthium italicum* Moretti Significantly Reduces the Growth of *Helianthus annuus* and the Yield and Quality of Its Seeds

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Abstract

The alien weed *Xanthium italicum* (Italian cocklebur) severely decreases the *Helianthus annuus* (oil sunflower) seed yield; however, its mechanisms remain unknown. To explore the relative intensity of competition between the two plants and to test the hypothesis that interspecific competitive pressure from Italian cocklebur causes a reduction in the yield and quality of oil sunflower seeds, a replacement experiment using the two species was performed under simulated common water-supply conditions of sunflower farmlands, and differences in growth parameters, seed yield, and seed quality of oil sunflower between monoculture and interplanting conditions were compared. The results showed that compared with those under monoculture conditions, the seed yield (biomass), oil content, and 1000-seed weight of oil sunflower interplanted with Italian cocklebur decreased by 7.75%, 23.48%, and 13.86%, respectively, under low water supply. Moreover, these parameters were reduced by 19.85%, 24.36%, and 16.19%, respectively, under high water supply. The interspecific competitive intensity of *X. italicum* was significantly higher than that of oil sunflower under both water-supply conditions. Given the competitive inhibition from the exotic plant, the vegetative and reproductive growth of the native crop was significantly impaired, and its seed yield and oil content were significantly reduced.

Keywords: *Xanthium italicum*, *Helianthus annuus*, competition, seed yield, seed oil content

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Introduction

Invasion of alien species often induces loss of biodiversity, changes, or even degradation of the structure and function of ecosystems, which threatens regional ecological security and human health, and elicits huge social economic losses [1, 2]. When exotic plants are introduced to new habitats, they often have obvious advantages in competing with native plants for resources [3], and strong interspecific competitiveness may be attributed to their successful invasion [4, 5]. After spreading into farmlands, they compete with crops for water, mineral nutrition, light, and space [6, 7], which destroys the credibility of the soil [8] and causes severe crop yield reduction [9], thus posing serious threats to local agricultural production [10, 11].

Italian cocklebur, an extremely invasive annual herb of the Compositae family, is one of the fastest spreading and most harmful weeds [12] and has caused serious harm to agricultural production, animal husbandry, and biodiversity maintenance [13-15]. This alien weed has strong adaptability [16-18], high interspecific competitiveness [15], high growth rate [19], and large body size. In farmlands, its height reaches over 2.5 m [20], and the individual crown width of a single plant can reach 1.8 m, decreasing illumination for low-growing crops; 8% of farmland coverage by Italian cocklebur was reported to cause 60% of crop yield loss [21, 22].

Oil sunflower is an annual crop of the Compositae family [23]. The linoleic acid content of its seeds is as high as 65.0%, which makes sunflower seed oil a high-quality edible vegetable oil [24], being involved in dissolving excessive cholesterol, softening cardiovascular and cerebrovascular diseases, promoting blood circulation and metabolism, improving immunity, and regulating endocrine [25-27]. Given its high value for human health and strong ecological adaptability [28], oil sunflower is widely cultivated worldwide. However, oil sunflower farmlands are mostly invaded by Italian cocklebur. Although oil sunflower and Italian cocklebur often present a mixed planting pattern in farmlands, the growth of sunflower is inhibited under these conditions, showing thinner and dwarfed stems, smaller capitals, and lower seed yield (Fig. 1). Nevertheless, whether the limitation of sunflower growth is caused by interspecific competition from the exotic Italian cocklebur remains unclear.

Therefore, in this study, we conducted a replacement experiment to compare the interspecific competition intensity between Italian cocklebur and oil sunflower [29], explore the inhibitory potential of Italian cocklebur on sunflower growth, seed yield, and seed oil content, and provide experimental evidence for evaluating the impacts of the invader on the native crop. We hypothesized that when the two species coexist, the interspecific competition from Italian cocklebur significantly hinders sunflower growth and severely reduces the yield and quality of sunflower seeds.

Experimental

Material

One thousand mature seeds of Italian cocklebur of the same size were selected from oil sunflower (*H. annuus*, cultivar "Aidatou") seeds purchased from the

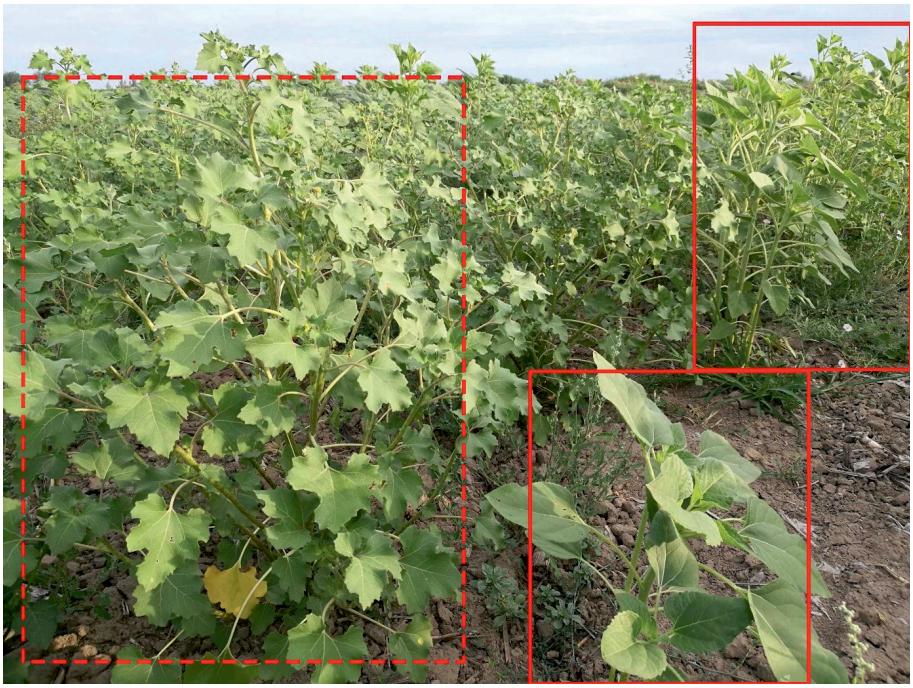

Fig. 1. Actual survey pictures of a farmland. Dotted line: Italian cocklebur; solid line: sunflower.

Shihezi Academy of Agricultural Reclamation, a suburb of Shihezi, Xinjiang, China (44°23'N, 86°00'E), in October 2019.

One thousand mature seeds of Italian cocklebur (X. italicum Moretti) of the same size of oil sunflower (H. annuus, cultivar "Aidatou") seeds were purchased from the Shihezi Academy of Agricultural Reclamation, located in a suburb of Shihezi, Xinjiang, China (44°23'N, 86°00'E), in October 2019.

Experimental Design and Method

The replacement experiment was performed on the Shihezi University campus (44°19'0"N, 86°0'30"E) from April 2020 to September 2020, at an altitude of 450.8 m and under temperate continental climate, with the annual precipitation being 125.0-207.7 mm.

On April 6, 2019, Italian cocklebur and sunflower seeds were soaked in distilled water at room temperature for 24 h and cultivated in a seedling tray. The cultivation medium was river sand, sowing depth was 1 cm, and sufficient water was provided. After the appearance of the third true leaf, seedlings of the same size were selected and transplanted into plastic pots with a diameter of 25 cm and height of 30 cm, filled with river sand and loam (V:V = 3:7). Two seedlings were transplanted into each pot [30] (Fig. 2). The total nitrogen, phosphorus, and potassium content was 0.268 g kg^{-1}, 0.0855 g kg^{-1}, and 5.72 g kg^{-1}, respectively. The available nitrogen, phosphorus, potassium, and organic matter content was 43.59 mg kg^{-1}, 4.1 mg kg^{-1}, 119.09 mg kg^{-1}, and 5.81 g kg^{-1}, respectively.

Two water-supply conditions were set: low (maintaining the relative soil water content at 40%)- and high (maintaining the relative soil water content at 80%)-water-supply levels. Low- and high-water-level treatments were used to simulate different water-supply conditions in oil sunflower fields [31, 32]. The pots were watered twice daily at 9:00 am and 8:00 pm using the weighing method. All pots were randomly placed in an open area at Shihezi University, and the distance between two adjacent pots was 50 cm to prevent shading from each plant. The positions of the pots were randomly changed once weekly to eliminate the influence of environmental factors. Whole plants were harvested after the seeds matured.

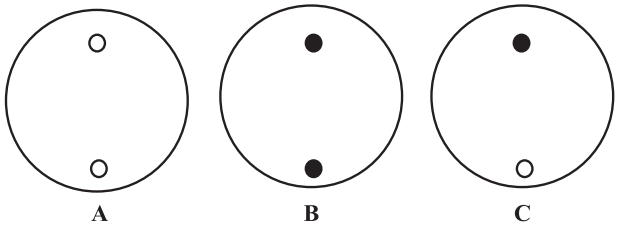

Fig. 2. Diagram of oil sunflower and Italian cocklebur planting. A: monoculture of oil sunflower (MO); B: monoculture of Italian cocklebur (MI); C: interplanting of oil sunflower (IO) and Italian cocklebur (II). Empty small circles: oil sunflower; full small circles: Italian cocklebur.

Measurement Indexes and Methods

Determination of Morphological Indicators

After the plants were harvested, the height, crown width, and base diameter of each plant were measured, and the average values were calculated.

Biomass Measurement

The roots, stems, and leaves of Italian cocklebur and sunflower were separated and dried to constant weight in an oven at 60ºC. The biomass of each part was accurately weighed, and the total biomass was calculated.

Determination of the Yield and Quality of Oil Sunflower Seeds

The sunflower seeds were collected and sundried. Thereafter, the 1000-seed weight and total seed biomass of each pot were determined using an electronic balance (BS423S Sartorius, Beijing, China), and the average values were calculated. The seed oil content for each treatment group was determined using a nuclear magnetic resonance spectrometer (CNMR-1000, Chenmu, Wuhan, China), and the average value was calculated based on three replicates.

Determination of Interspecific Competitiveness

To compare the interspecific competitiveness of the two species, the relative yield (*RY*) [33] and aggressivity (*A*) [34] were calculated using the following formulas:

$$RY_X = Y_{XH}/Y_{XX}\ ,\ \ RY_H = Y_{HX}/Y_{HH}$$

$$A_X = Y_{XH}/(Y_{XX} \times Z_{XH}) - Y_{HX}/(Y_{HH} \times Z_{HX}),$$

$$A_H = Y_{HX}/(Y_{HH} \times Z_{HX}) - Y_{XH}/(Y_{XX} \times Z_{XH})$$

where *X* represents Italian cocklebur and *H* represents oil sunflower. R_{YX} and R_{YH} are the relative yields of Italian cocklebur and sunflower, respectively, under interplanting conditions. Y_{XX} and Y_{HH} are the average individual yields of Italian cocklebur and oil sunflower, respectively, under monoculture conditions. Y_{XH} and Y_{HX} are the average individual yields of Italian cocklebur and oil sunflower, respectively, under interplanting conditions. Z is the proportion of each species under interplanting conditions ($Z_{XH} + Z_{HX} = 1$, $Z_{XH} = Z_{HX} = 1/2$).

If RY_X is greater than 1.0, the intraspecific competition of Italian cocklebur is significantly greater than the interspecific competition between both species. If RY_X is equal to 1.0, the competitiveness of the two species is equal. If RY_X is lower than 1.0, the intraspecific competition of Italian cocklebur is significantly lesser

than the interspecific competition between the two species.

If A_X is greater than 0, Italian cocklebur is more competitive than oil sunflower and is dominant. If A_X is equal to 0, the competitiveness of both species is equal. If A_X is lower than 0, the competitiveness of Italian cocklebur is significantly lower than that of oil sunflower. The smaller the A_X value, the lower the competitiveness of Italian cocklebur.

Data Analysis

The Statistical Package for the Social Sciences (SPSS) (version 20.0, USA) software was used for statistical analyses. One-way analysis of variance (ANOVA) and nonparametric tests were used to analyze differences in growth-related traits, biomass, yield, and quality of oil sunflower seeds between the monoculture and interplanting conditions. A *t*-test was used to analyze the differences between *RY* and 1, and between *A* and 0.

Results

Effect of the Planting Pattern on the Individual Growth of Italian Cocklebur and Oil Sunflower

Under monoculture conditions, interspecific differences in the growth of Italian cocklebur and oil sunflower were observed, with the body size of Italian cocklebur being larger than that of oil sunflower. The plant height, crown width, base diameter, and root, stem, leaf, and total biomass of Italian cocklebur were 1.20, 1.56, 1.19, 1.90, 1.56, 1.11, and 1.23 times higher than those of oil sunflower, respectively, under low-water-supply conditions but 1.23, 1.63, 1.18, 1.59, 1.48, 1.11, and 1.12 times higher, respectively, under high-water-supply conditions (Fig. 3).

The planting patterns significantly affected the growth of both species ($P<0.05$). Compared with those under monoculture conditions, the plant height, crown width, base diameter, and root, stem, leaf, and total biomass increased by 27.95%, 16.86%, 25.45%, 33.64%, 30.09%, 21.27%, and 26.43%, respectively, for Italian cocklebur and decreased by 14.67%, 13.31%, 9.86%, 27.67%, 34.49%, 19.96%, and 22.48%, respectively, for oil sunflower under interplanting and low-water-supply conditions. Under interplanting and high-water-supply conditions, the plant height, crown width, base diameter, and root, stem, leaf, and total biomass increased by 23.78%, 21.29%, 30.95%, 64.34%, 26.81%, 20.06%, and 35.83%, respectively for Italian cocklebur and decreased by 12.86%, 15.82%, 13.67%, 26.79%, 18.12%, 11.58%, and 15.80%, respectively, for oil sunflower relative to those under monoculture conditions.

Under interplanting conditions, larger interspecific differences were observed in the individual growth of Italian cocklebur and oil sunflower. The plant height, crown width, basal diameter, and root, stem, leaf, and total biomass of Italian cocklebur were 1.79, 1.56, 1.65, 3.50, 3.74, 1.67, and 2.01 times higher, respectively, under low-water-supply conditions and 1.74, 1.63, 1.78, 3.57, 2.30, 1.51, and 1.81 times higher, respectively, under high-water-supply conditions than those of oil sunflower (Fig. 3).

Effect of the Planting Pattern on the Yield and Quality of Oil Sunflower Seeds

Compared with those under monoculture conditions, the seed yield, seed oil content, and 1000-seed weight of oil sunflower decreased by 37.75%, 23.48%, and 13.86%, respectively, under interplanting and low-water-supply conditions and by 19.85%, 24.36%, and 16.19%, respectively, under interplanting and high-water-supply conditions (Fig. 4).

Comparison of the Competitive Ability between Italian Cocklebur and Oil Sunflower

Under both water-supply conditions, RY_X was greater than 1.0, whereas RY_H was lower than 1.0 ($P<0.05$) (Table 1), indicating that the intraspecific competition of Italian cocklebur is significantly greater than the interspecific competition from oil sunflower and that the intraspecific competition of oil sunflower is significantly lower than the interspecific competition from Italian cocklebur. A_X was greater than 0, and A_H was lower than 0, indicating that the interspecific competitiveness from Italian cocklebur is significantly greater than that of oil sunflower ($P<0.05$).

Discussion

Plant competition is one of the major forces that configure the morphology and life history of plants,

Table 1. Competition indexes of Italian cocklebur and oil sunflower under two water-supply conditions.

	RY_X	RY_H	A_X	A_H
Low water supply	1.264±0.008*	0.775±0.02*	0.978±0.018**	–0.978±0.018**
High water supply	1.324±0.009*	0.786±0.027*	1.073±0.034**	–1.073±0.034**

Data are presented as average±standard error.
* RY_X and RY_H are compared to 1 (*t*-test, $P<0.05$).
** A_X is compared to 0 (*t*-test, $P<0.05$, n = 2).

and that affect the structure and dynamics of plant communities [35]. The competition intensity between species depends mainly on the similarity of their niches. The more similar their ecological habits and the greater the niche overlap, the more intense the competition between species and the greater the replacement of less competitive individuals by more competitive ones [36]. When plants with similar niches coexist, they often compete for limited environmental resources such as soil moisture, mineral nutrition,

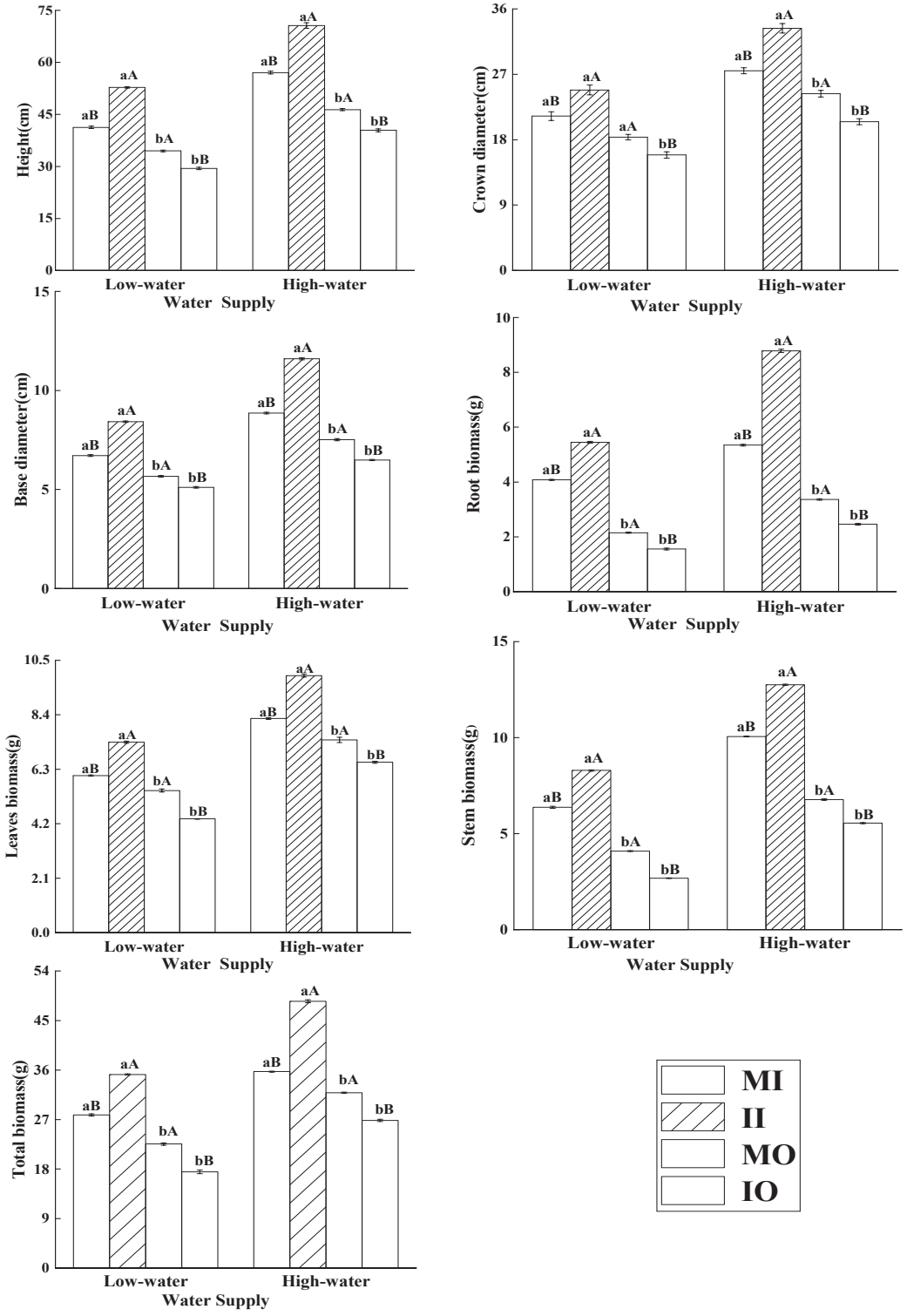

Fig. 3. Vegetative growth-related parameters of Italian cocklebur and oil sunflower (mean±standard error). Different uppercase letters: significant differences between the same plant under monoculture and interplanting conditions; different lowercase letters: significant differences between the two plants under the same planting conditions (P<0.05). MI: monoculture of Italian cocklebur; II: interplanting of Italian cocklebur; MO: monoculture of oil sunflower; IO: interplanting of oil sunflower.

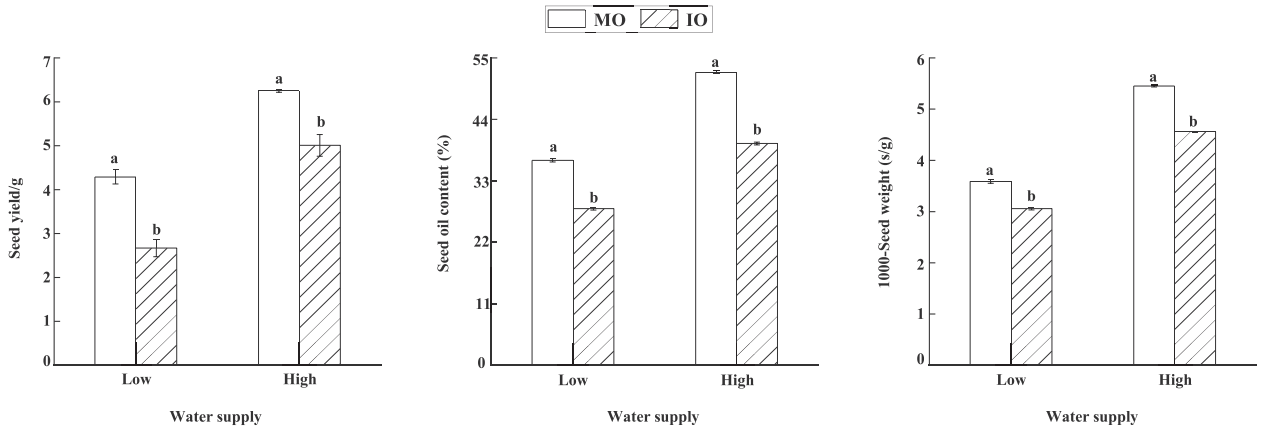

Fig. 4. Oil sunflower seed yield and quality (mean ± standard error). Auto-cDifferent lowercase letters: significant differences between planting conditions (P<0.05). MO: monoculture of oil sunflower; IO: interplanting of oil sunflower.

and light. Plant size (height, crown width, and biomass) plays an important role in resource competition and affects the growth rate [37]. Italian cocklebur and oil sunflower are sunny annual herbs of the Compositae family that present tall stems, broad leaves, and shallow roots. They have similar niches, and therefore, there is potential interspecific competition between them. The results of our study showed that the plant height, crown width, base diameter, and root, stem, leaf, and total biomass of Italian cocklebur were greater than those of oil sunflower under the same planting pattern and both low- and high-water-supply conditions. Broad ecological amplitude [16], high phenotypic plasticity [38], and rapid growth characteristics improve the ability of alien plants to live in complex and variable environments. Therefore, the interspecific competition intensity from Italian cocklebur was significantly higher than that from oil sunflower, indicating that the former intercepts more light from the canopy and reduces the light intensity reaching the lower layer of the sunflower crop [30], which inevitably reduces the net photosynthetic rate and further biomass accumulation in oil sunflower. In addition, under low- and high-water-supply conditions, the root biomass of Italian cocklebur was significantly higher than that of oil sunflower, indicating that the roots of the former are more developed than those of the latter. A more developed root system reflects a better moisture and mineral absorption capacity of Italian cocklebur than that of oil sunflower, which enables the first to obtain more moisture and mineral nutrition from the limited soil resource pool, demonstrating strong interspecific competitiveness and, thus, negatively affecting oil sunflower growth.

Exotic plants invade more successfully when there is a lack of strong native resource competitors or sufficient available resources in the community [39]. Both under low- and high-water-supply conditions, the plant height, crown width, base diameter, and root, stem, leaf, and total biomass of Italian cocklebur under interplanting conditions were significantly higher than those under monoculture conditions, indicating that the intraspecific competition intensity of the alien weed is significantly higher than the competition suppressed in oil sunflower. However, for oil sunflower, these parameters were significantly lower under interplanting conditions than under monoculture conditions, indicating that the intensity of intraspecific competition of oil sunflower is significantly lower than the interspecific competition from Italian cocklebur. These results suggest that interplanting these species is beneficial to the accumulation of biomass in Italian cocklebur, which enhances the relative competitiveness of the weed and has a significant inhibitory effect on the growth of oil sunflower.

Invasive weeds rapidly reduce the yield and quality of crops due to competition for environmental resources [15, 40]. Italian cocklebur is a highly competitive weed in farmlands, and 8% of farmland coverage by Italian cocklebur can cause a crop yield loss of approximately 60% [21, 22]. The results of our study showed that the seed yield, seed oil content, and 1000-seed weight of oil sunflower were reduced by 19.85%, 24.36%, and 16.19%, respectively, under high-water-supply conditions and by 37.75%, 23.48%, and 13.86%, respectively, under low-water-supply conditions when interplanted with Italian cocklebur. The sharp declines in seed yield and seed oil content reflect a significant decrease in sunflower seed oil production [34], which would inevitably impact the economic benefits of farmers and oil-extracting factories. Noteworthily, the oil stored in seeds is an important material and energy source for germination and seedling growth. When interplanted with Italian cocklebur, the oil content of oil sunflower seeds decreased by almost a quarter under both water-supply conditions, which would negatively affect seed germination and seedling survival and, subsequently, the oil sunflower yield in the next growing period.

RY and A are often used to characterize the niche similarity between two coexisting species and relative intensity of their interspecific competitiveness [33].

This study showed that the relative yield of Italian cocklebur was greater than 1.0, whereas that of oil sunflower was lower than 1.0. This indicates that the two species have similar niches, and that Italian cocklebur has a stronger interspecific competitive ability than oil sunflower (A_X>0) and a significant inhibitory effect on the growth of the latter, which is consistent with the findings of Xu and Ma [15] and Funk and Vitousek [41]. A higher interspecific competitive ability of Italian cocklebur may explain the suppressed growth of oil sunflower after the introduction of the invasive weed into its habitats.

Conclusions

The niches of Italian cocklebur and oil sunflower are similar, and the interspecific competitiveness of Italian cocklebur is significantly higher than that of oil sunflower in both relatively arid and humid habitats, which significantly inhibits the vegetative growth of oil sunflower, hinders its biomass accumulation, and strongly impedes its reproduction and growth. Under low-water-supply conditions, the sunflower seed yield and oil content decreased by approximately 40% and 1/4, respectively, severely weakening the yield and quality of the economically exploited organs of oil sunflower.

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Conflict of Interest

There are no conflicts of interest to declare.

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