

RESEARCH ARTICLE

Effectiveness of ten commercial maize cultivars in inducing Egyptian broomrape germination

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Abstract Egyptian broomrape (EB), *Phelipanche aegyptiaca*, is a devastating root parasite, causing enormous crop losses around the world. Maize has the potential to influence the growth of other plants through releasing certain allelochemicals and is able to induce germination of at least three broomrape species. To determine whether maize could be used as a trap crop for EB, 10 maize cultivars were tested for their ability to induce EB germination. The results showed that maize cultivars can induce EB germination, and that germination rates in a cut-root experiment and a hydroponic experiment were consistent. Maize cvs Changcheng 799 and Zhengdan 958 induced the highest EB germination rates, while cvs Luyu 13 and Zhengyu 203 were the least effective. These four maize cultivars were further studied in a pot experiment. Rhizosphere soil, rhizosphere soil extracts, root extracts and shoot extracts from these cultivars were all able to induce EB germination, with cv. Changcheng 799 inducing the highest germination rates. Root extracts generally induced higher germination rates than shoot extracts. It is suggested that Changcheng 799 could be planted as a trap crop for control of EB.

Keywords allelopathy, Egyptian broomrape, maize, seed germination, trap crop

They can heavily infest many important crops with negative impact on crop yield and quality, causing economic losses worldwide^[2–4]. In China, there are about 20 broomrape species, of which Egyptian broomrape (*Phelipanche aegyptiaca*), sunflower broomrape (*Orobancha cumana*) and *O. ramosa* are the most common species and have the widest host range^[5]. In China, Egyptian broomrape was first reported infesting melon and tomato in 1964 in the Xinjiang Uygur Autonomous Region. The fields had been continuously cropped for 3 to 5 years, and had an average parasitism rate of 31%–54%, with some areas up to 100%^[6]. Egyptian broomrape is mainly found in Xinjiang and causes heavy and direct damage to some important crops such as eggplant, melon, potato, tobacco, tomato and watermelon. Every year, 1500–2000 hm² of melon suffer complete yield loss due to the infestation of Egyptian broomrape, and 3500–5500 hm² have severe yield loss. The area of tomato parasitized by Egyptian broomrape is about 7000 hm², with a yield loss between 30%–80%^[7,8].

Seeds of Egyptian broomrape need to be preconditioned (i.e., exposed to water and suitable temperatures for several days) before they will start to germinate in response to chemical stimuli from host or non-host roots^[9–13]. The seedlings infect host roots by developing a haustorium that penetrate host roots and then develop tubercles, with adventitious roots and a shoot. When a host is not present, the seedling will die. A crop which can induce broomrape seed germination, but is not parasitized, is known as a trap crop.

Broomrapes are extremely difficult to control because of their specialized biology and their direct connection with host roots. Methods such as manual weeding, plant quarantine, resistant cultivars and biochemical methods have been used for broomrape control. However, these methods are not particularly effective and cannot eliminate

1 Introduction

Broomrapes (*Orobancha* spp.) are holoparasitic weeds that completely depend on their hosts for water and nutrients^[1].

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the problem, because the majority of the damage occurs before the parasite emerges from the soil^[4,14,15]. The use of trap crops, on the other hand, offers a promising option for broomrape control. Trap crops can reduce broomrape seed banks and improve crop production. The benefit of trap crops can be enhanced by combination with the other methods of control.

Maize is known to induce the germination of *O. ramosa* and *O. minor*^[2,3,16] and recently, we found that maize can also be used as trap crop for sunflower broomrape^[17]. There is no report that maize could be parasitized by Egyptian broomrape and we have planted maize in the soil containing Egyptian broomrape seeds and find that no parasitism occurred. Therefore, we studied the potential of maize cultivars to induce germination of Egyptian broomrape. The purpose of this study was to screen commercial maize cultivars for their effectiveness in inducing Egyptian broomrape germination. Cut-root and root exudate assays and hydroponic and pot experiments were used to identify maize cultivars that induced the highest germination of Egyptian broomrape. These data will provide a basis for field control of Egyptian broomrape using maize as a trap crop.

2 Materials and methods

2.1 Preparation of seeds and chemicals

Seeds from 10 commercial maize cultivars were obtained from Sanqin seed company (Yangling, Shaanxi, China) (viz. Changcheng 799, Changdan 48, Luyu 13, Nongda 364, Shandan 2001, Tiancheng 288, Yuyu 22, Zhengda 12, Zhengdan 958 and Zhengyu 203). These cultivars are adapted for the region where Egyptian broomrape occurs in China. Seeds of Egyptian broomrape were collected from infested melon fields in the Xinjiang, China. A standard germination stimulant for Egyptian broomrape, GR24 (a synthetic strigolactone analog), was provided by Prof. Binne Zwanenburg, University of Nijmegen, the Netherlands.

Seeds were surface-sterilized before use. Maize and Egyptian broomrape seeds were immersed in 1% (v/v) sodium hypochlorite for 3 min followed by soaking in 75% (v/v) ethanol for 3 min. The seeds were then rinsed with sterile distilled water and air-dried on a clean bench.

To break dormancy, Egyptian broomrape seeds were preconditioned. First, a piece of filter paper was placed in each Petri dish and moistened with 1.5 mL of distilled water. Then about 150 disks of glass fiber filter paper (7 mm Whatman GF/A, Whatman Plc., Little Chalfont, England) were placed on the moistened filter paper and 20–50 Egyptian broomrape seeds were spread on the surface of glass fiber filter paper. Finally, the dishes were sealed and incubated at 25°C for 3 days.

2.2 Cut-root assay

A cut-root assay was conducted to determine the effect of maize roots on Egyptian broomrape germination^[18,19]. Briefly, 10 surface-sterilized maize seeds of each cultivar were placed in sterile Petri dishes lined with moistened filter paper. The dishes were covered with aluminum foil and incubated at 25°C for 4 days. Seedlings were removed from the Petri dishes and the roots cut into 0.5 cm segments (about 0.5 g), which were placed in the center of Petri dishes lined with filter paper (one segment per dish). Twenty to 50 Egyptian broomrape seeds were arranged in three concentric circles around each root segment. These circles were 10, 20 and 30 mm away from the root segment and are hereafter referred to as the inner, middle, and outer circles, respectively. Aluminum foil rings were used to enclose each root segment to ensure there was no direct contact with the broomrape seeds. Sterile distilled water (1.5 mL) was slowly poured over the top of the root segment. The water ran down the segment and then spread out evenly across the bottom of the dish. The dishes were sealed with parafilm, wrapped in aluminum foil, and incubated at 25°C in the dark. GR24-treated (20 µL of 0.1 mg·L⁻¹ GR24 per disk) and water-treated disks were used as positive and negative controls, respectively. Each treatment had three replicates. After 10 days, each Egyptian broomrape seed was examined under a microscope for the emergence of a germ-tube, which indicated that the seeds had germinated.

2.3 Root exudates assay

After the maize seedlings were removed from the Petri dishes in Experiment 1, 16 glass fiber filter paper disks (7 mm diam.) with Egyptian broomrape seeds (20–50 per disk) were placed in the area where the maize roots had grown. These dishes were sealed, wrapped, incubated and assessed as describe for cut-root assay.

2.4 Hydroponic experiment

2.4.1 Collection of maize root exudates

Surface-sterilized maize seeds were germinated in the dark on moistened filter paper in Petri dishes at 25°C for 48 h. After germination, 150 seedlings were transferred to a sieve (33 cm × 26 cm × 8 cm, 10 mm mesh) lined with a sheet of gauze moistened by placing it in a slightly larger container (42 cm × 30 cm × 11 cm) containing 4 L of tap water. This arrangement was transferred to a growth chamber with a 12 h photoperiod at 120 µmol·m⁻²·s⁻¹ photons at 25°C. The tap water was replaced every 2 days. On day 10, the tap water was replaced with half-strength Tadano and Tanaka (TT) medium (Tadano & Tanaka, 1980). The pH of the culture media was adjusted to 6.0

with NaOH. The TT medium was replaced every 2 days. On day 14, the TT medium was replaced with tap water containing $1 \text{ mmol} \cdot \text{L}^{-1}$ CaCl_2 . The tap water plus CaCl_2 medium was circulated through an activated charcoal filter with an aquarium pump. The maize was grown on this medium for 1 week and the charcoal filter was replaced every 2 days.

Root exudates adsorbed onto the activated charcoal filters were eluted with acetone. The acetone was removed by vacuum evaporation in a rotary evaporator at 40°C . The residue was dissolved in 50 mL distilled water, and then extracted three times with 50 mL ethyl acetate. These extracts were combined, dried over anhydrous NaSO_4 , and then evaporated to dryness under vacuum at 40°C using a rotary evaporator. The residues were dissolved in 5 mL acetone and then stored in sealed glass vials at 4°C .

2.4.2 Assay of root exudates

The stored root exudates were diluted with distilled water to final concentrations of 1, 10 and $100 \text{ mg} \cdot \text{L}^{-1}$. Aliquots ($20 \mu\text{L}$) of these aqueous test solutions were applied to glass fiber filter paper disks (7 mm) in Petri dishes and air-dried. A 7 mm disk with Egyptian broomrape seeds was put on top of each disk and then moistened with $40 \mu\text{L}$ distilled water. Each test solution had three replications. The treated seeds were incubated in the dark at 25°C for 10 days and germination assessed under a microscope. The preconditioned Egyptian broomrape seeds treated with GR24 ($10^{-4} \text{ mol} \cdot \text{L}^{-1}$) and distilled water were used as positive and negative control, respectively.

2.4.3 Assay of maize plants

Maize roots and shoots were collected after being cultured hydroponically for 25 days. The samples were freeze-dried, milled and passed through a 0.35 mm sieve. One milliliter aliquots of distilled water or methanol were added to 1.5 mL centrifuge tubes containing the milled samples (100 mg). The samples were ultrasonically treated for 30 min and then centrifuged at $6400 \text{ r} \cdot \text{min}^{-1}$ for 2 min (Millipore N8JMB042A, Nihon Millipore LTD. Yonezawa, Japan). These solutions were diluted 10- and 100-fold and then were used in Egyptian broomrape seed germination tests as described above.

2.5 Pot experiment

A pot experiment was conducted at the Institute of Soil and Water Conservation, Yangling, Shaanxi, China in April 2012. Eight kilogram of soil was put into plastic pots (25 cm height, 20 cm diam.). The soil, which was collected from a cultivated field near the research institute, is classified as silty loam. The soil tests gave the following

mean values: pH 7.98; organic matter content $14.0 \text{ g} \cdot \text{kg}^{-1}$; $\text{NO}_3\text{-N}$ $48.3 \text{ mg} \cdot \text{kg}^{-1}$; Olsen P $24.2 \text{ mg} \cdot \text{kg}^{-1}$; and ammonium acetate extractable K $166 \text{ mg} \cdot \text{kg}^{-1}$. Ten maize seeds were sown per pot and after germination thinned to four uniformly sized seedlings per pot. Each maize line was replicated three times. Changcheng 799, Zhengdan 958, Luyu 13 and Zhengyu 203 were used in this experiment to study the stability of their induction of Egyptian broomrape germination. Maize plants were sampled at the four-, six-, and eight-leaf stages. Samples of rhizosphere soil were collected at the same time as the plant samples.

2.5.1 Assay of rhizosphere soil

Five gram of rhizosphere soil and 1.5 mL distilled water were added to Petri dishes (35 mm diam.). Five disks of glass fiber filter paper (7 mm Whatman GF/A) with 20–50 Egyptian broomrape seeds were placed on the surface of the soil. The dishes were sealed and incubated in the dark at 25°C for 10 days. The germination of Egyptian broomrape was assessed under a microscope.

2.5.2 Assay of rhizosphere soil extracts

Five gram of rhizosphere soil samples were ultrasonically treated for 30 min in 10 mL of distilled water or methanol and then filtered. These solutions were diluted 10- and 100-fold for use in Egyptian broomrape seed germination tests as described above.

2.5.3 Assay of root and shoot extracts

The method for assay of root and shoot extract was as described above for maize plants in the hydroponic experiment.

2.6 Statistical analyses

SPSS 10.0 software was used to perform one-way analysis of variance. Treatment means were compared using least significant difference tests at the 5% level of probability.

3 Results

The mean germination rate of Egyptian broomrape induced by GR24 was 81.9%. Distilled water induced no significant germination. Thus, the Egyptian broomrape seeds used in this study were viable.

3.1 Cut-root assay for germination-promoting ability

All the maize cultivars tested, except for Luyu 13, induced

Egyptian broomrape to germinate. However, there were significant differences between the germination rates induced by individual cultivars.

Germination rates of Egyptian broomrape ranged from 0 to 40% (Fig. 1), and showed an increasing trend as the distance between the Egyptian broomrape seed and the maize root segment increased. Among the maize cultivars, Changcheng 799 generally induced the highest germination rates (12.7%–40.6%) followed by Zhengdan 958 (16.9%–30.8%). Changdan 48 and Zhengda 12 also induced moderate germination rates (16.5%–27.2%, 8.2%–29.4%). Zhengyu 203 induced lower germination rates of less than 10%. Luyu 13 did not induce germination of Egyptian broomrape and other maize cultivars induced germination rates of 10%–20%.

3.2 Analysis of germination-promoting ability by root exudate assay

Root exudates of 10 maize cultivars induced Egyptian broomrape germination. Changcheng 799 induced the highest germination rate (38.4%) followed by Zhengdan 958 (37.2%) (Fig. 2), however, these rates were not significantly different. Zhengyu 203, Yuyu 22 and Luyu 13 induced lower germination rates (< 15%). The other maize cultivars induced germination rates that were intermediate between the above cultivars (20%–30%) (Fig. 2).

3.3 Assay of root exudates from hydroponic culture

The root exudates of 10 maize cultivars induced Egyptian broomrape to germinate, and there were significant differences between rates comparing extracts from different cultivars (Table 1). At a concentration of $100 \text{ mg} \cdot \text{L}^{-1}$, Changcheng 799 induced the highest germination rate (41.4%) followed by Zhengdan 958 (29.9%) and Yuyu 22 (29.6%), which were not significantly different. The germination rates of Egyptian broomrape induced by Zhengyu 203 and Luyu 13 were 11.3% and 13.3%, respectively, and germination rates induced by the other cultivars were about 20%. At concentrations of 1 and $10 \text{ mg} \cdot \text{L}^{-1}$, Changcheng 799 also induced the highest germination rates (5.3% and 21.8%) and Luyu 13 induced the lowest germination rate (< 10%) (Table 1). Generally speaking, the germination rates declined as the concentration of root exudates decreased, which showed that the activity of root exudates depended on the concentration.

The aqueous extracts of maize roots and shoots grown under hydroponic conditions also induced Egyptian broomrape germination (Fig. 3) with the 100-fold dilutions inducing higher germination rates than the 10-fold dilutions (Fig. 3). The aqueous shoot extracts of Changcheng 799 induced the highest germination rate (25.8%) followed by Zhengdan 958 (23.3%). Nongda 364 also induced a high germination rate (21.7%). Zhengyu 203 and

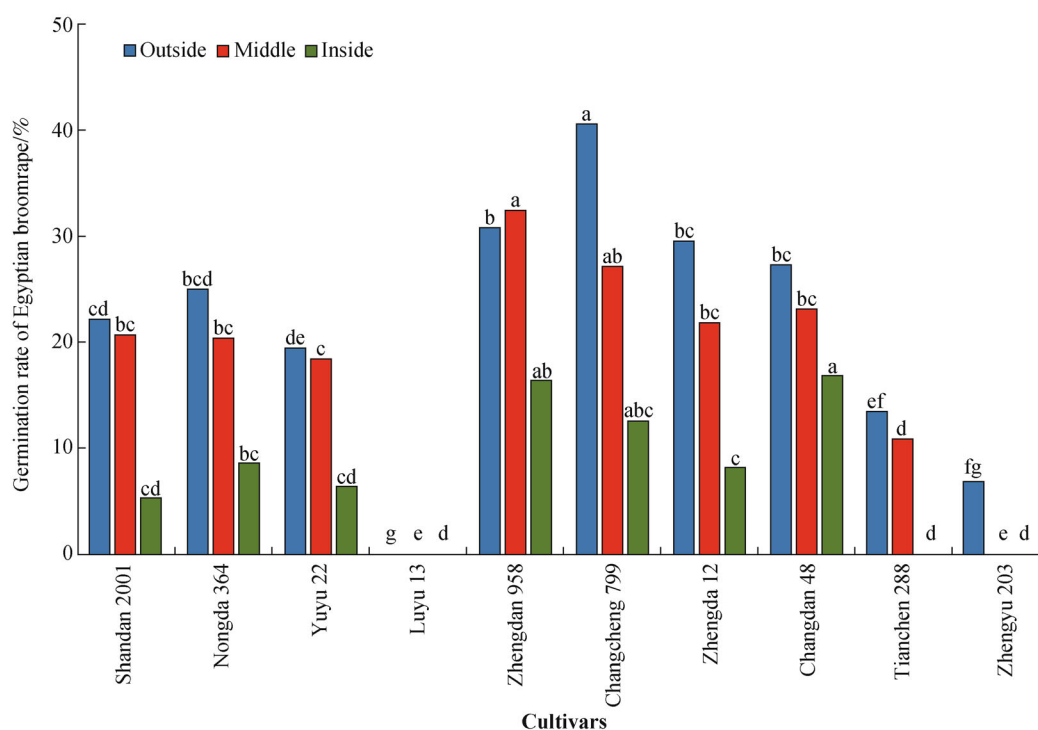


Fig. 1 Germination rates of Egyptian broomrape seeds in the cut-root assay. Seeds were placed in concentric circles 1, 2 and 3 cm (inside, middle and outside, respectively), from root segments of maize seedlings. Significant differences at 5% level (LSD, $P < 0.05$) are indicated by lowercase letters.

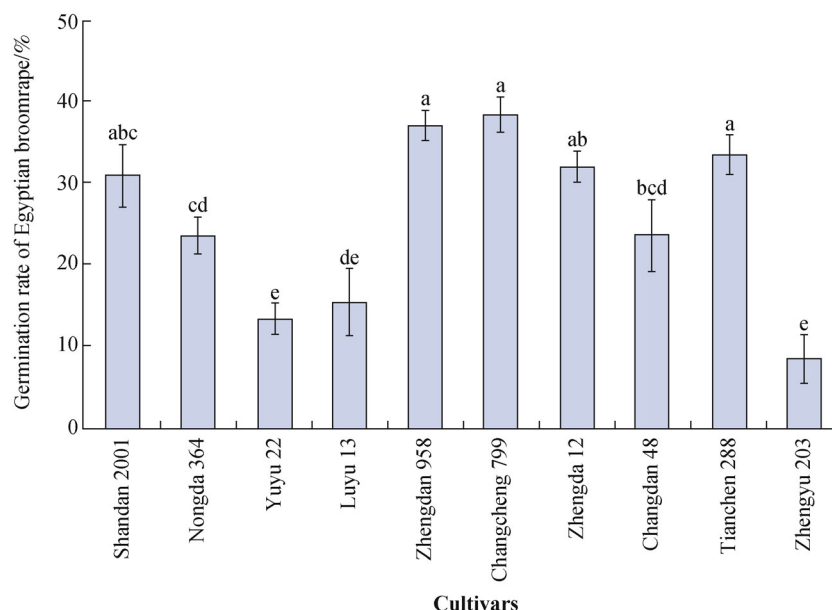


Fig. 2 Effect of root exudates from ten maize cultivars on Egyptian broomrape germination. Egyptian broomrape seeds were germinated in filter paper-lined Petri dishes where maize seedlings had been growing for 96 h. Significant differences at 5% level (LSD, $P < 0.05$) are indicated by lowercase letters.

Table 1 Germination rate of Egyptian broomrape induced by maize root exudates in the hydroponic experiment %

Maize cultivars	Concentration of root exudates/(mg·L ⁻¹)		
	100	10	1
Changcheng 799	41.4 b	21.8 a	5.3 a
Changdan 48	22.5 cde	8.6 bc	0.0 c
Luyu 13	13.3 ef	3.0 bc	1.1 bc
Nongda 364	17.3 ef	4.8 bc	1.2 ab
Shandan 2001	28.7 cd	21.7 a	3.5 abc
Tiancheng 288	18.0 def	7.7 bc	0.0 c
Yuyu 22	29.6 c	4.7 bc	0.0 c
Zhengda 12	14.3 ef	8.6 bc	3.2 abc
Zhengdan 958	29.9 c	10.6 b	2.9 abc
Zhengyu 203	11.3 f	10.2 b	4.2 ab
Distilled water	0.0 g	0.0 c	0.0 c

Note: Values that are significantly different at 5% (LSD, $P < 0.05$) level in the same column are marked by lowercase letters.

Luyu 13 induced the lowest germination rates (< 10%) (Fig. 3a). The aqueous root extracts of Changcheng 799 also induced the highest germination rate (28.0%) followed by Zhengdan 958 (27.8%). Zhengyu 203 and Luyu 13 induced the lowest germination rates (7.2% and 11.7%) (Fig. 3b).

The methanol extracts of maize roots and shoots produced under hydroponic conditions also induced Egyptian broomrape germination (Fig. 4), with the 100-fold dilutions inducing higher germination rates than the 10-fold dilutions (Fig. 4). The methanol shoot extracts of Changcheng 799 induced the highest germination rate

(23.0%) followed by Zhengdan 958 (20.6%). Zhengda 12 and Tiancheng 288 induced similar germination rates (18.2% and 18.1%). Zhengyu 203 and Luyu 13 induced lower germination rates (8.3% and 10%) (Fig. 4a). The methanol root extracts of Changcheng 799 again induced the highest germination rate (32.6%) followed by Zhengdan 958 (31.3%), whereas Zhengyu 203 and Luyu 13 induced the lowest germination rates (13.6% and 14.8%) (Fig. 4b).

3.4 Effect of rhizosphere soil from maize grown in pots

Results from the previous experiments demonstrated that Changcheng 799 and Zhengdan 958 induced the highest Egyptian broomrape germination rates, while Zhengyu 203 and Luyu 13 induced the lowest germination rates. Therefore, they were used for further analysis by growing them in pots and subsequent testing of the effectiveness of the pot soil in stimulating germination.

Rhizosphere soil collected at all growth stages induced Egyptian broomrape germination. Changcheng 799 and Zhengdan 958 induced higher germination rates than Zhengyu 203 and Luyu 13 at all growth stages, and there were significant differences (Fig. 5).

Aqueous extracts of rhizosphere soil collected at all growth stages also induced Egyptian broomrape germination. Changcheng 799 induced the highest germination rates, whereas Luyu 13 induced the lowest germination rate (Table 2).

Methanol extracts of rhizosphere soil collected at all growth stages induced Egyptian broomrape germination.

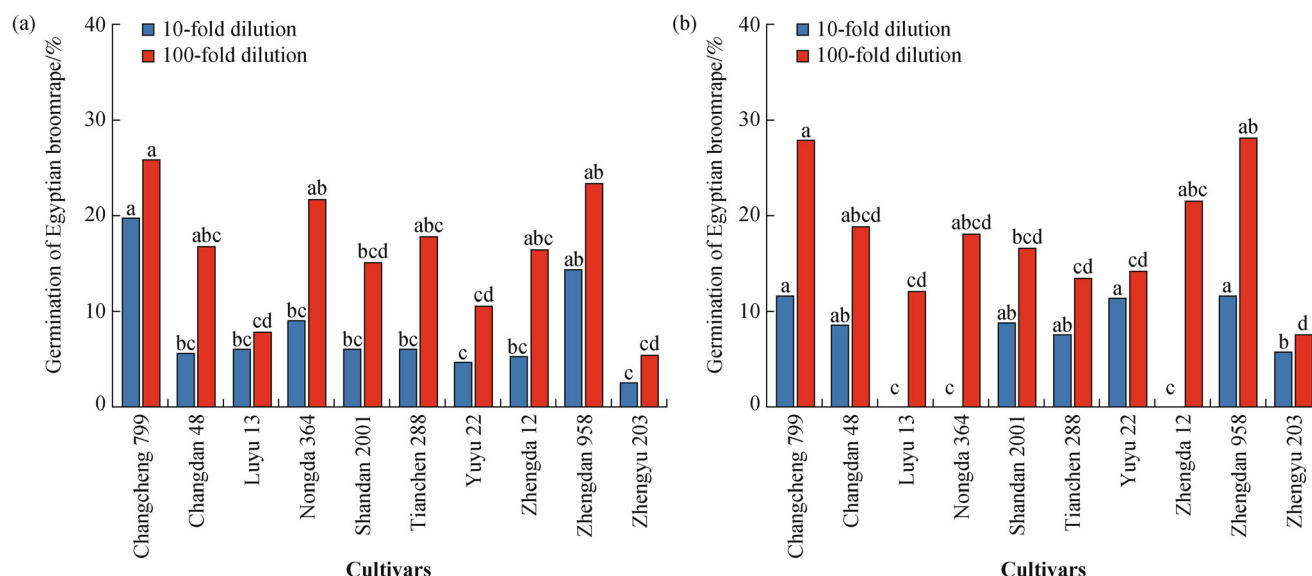


Fig. 3 Effect of shoot (a) and root (b) water extracts from ten maize cultivars on Egyptian broomrape germination in a hydroponic experiment. Significant differences at the 5% level (LSD, $P < 0.05$) are indicated by lowercase letters.

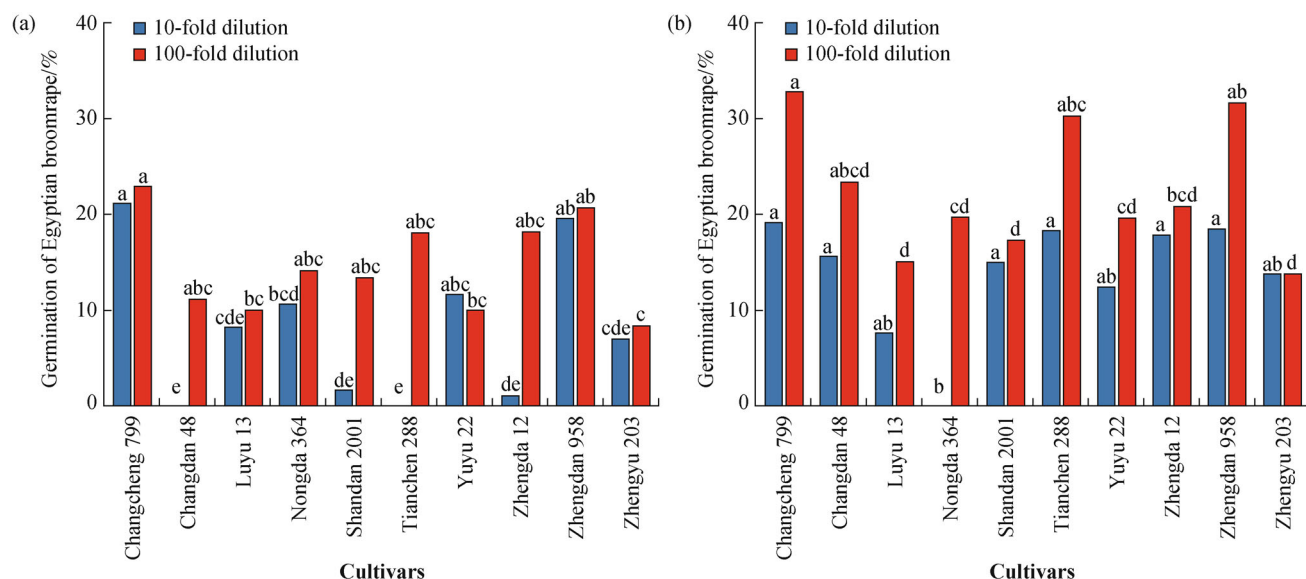


Fig. 4 Effect of shoot (a) and root (b) methanol extracts from ten maize cultivars on Egyptian broomrape germination in a hydroponic experiment. Significant differences at the 5% level (LSD, $P < 0.05$) are indicated by lowercase letters.

Changcheng 799 induced the highest germination rates at all growth stages, followed by Zhengdan 958, and Zhengyu 203 and Luyu 13 induced the lowest germination rates (Table 2).

Maize aqueous root extracts induced Egyptian broomrape germination, with Changcheng 799 inducing the highest germination rates. The germination rate induced by Changcheng 799 was 38.8% at the eight-leaf stage. Zhengyu 203 and Luyu 13 induced lower germination rates (Table 3). The methanol extracts generally induced

higher germination rates than the aqueous extracts, and the effectiveness of methanol root extracts in inducing germination initially increased with growth stages and then decreased (Table 3). At the six-leaf stage, root extracts of Changcheng 799 induced the highest germination rate (52.6%), followed by Zhengdan 958 (41.6%). Zhengyu 203 and Luyu 13 induced the lowest germination rates (about 20%) (Table 3).

Maize aqueous shoot extracts induced Egyptian broomrape germination, and the effectiveness of maize shoot

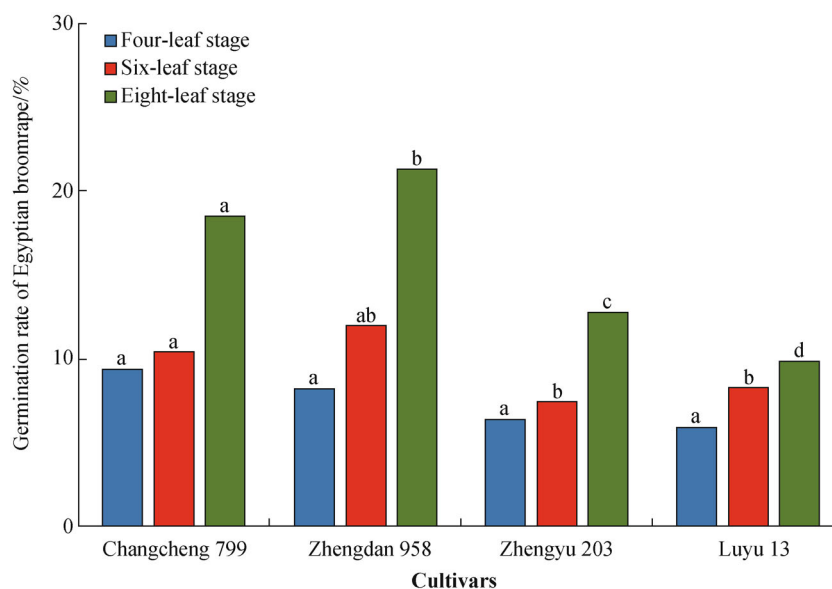


Fig. 5 Effect of rhizosphere soil from four maize cultivars on Egyptian broomrape germination in the pot experiment. The rhizosphere soil was collected at the four-, six-, and eight-leaf stages. Significant differences at 5% level (LSD, $P < 0.05$) are indicated by lowercase letters.

Table 2 Germination rate of Egyptian broomrape induced by maize rhizosphere soil extracts collected at different leaf stages in the pot trial %

Extracts	Maize cultivar	Undiluted extracts			10-fold dilution			100-fold dilution		
		Four-leaf stage	Six-leaf stage	Eight-leaf stage	Four-leaf stage	Six-leaf stage	Eight-leaf stage	Four-leaf stage	Six-leaf stage	Eight-leaf stage
Aqueous	CC	10.5 d	25.4 a	30.9 a	27.3 a	30.9 a	33.8 a	23.1 a	23.2 a	35.8 a
	ZD	19.0 a	22.9 a	26.3 b	20.7 b	22.9 b	26.3 bc	18.0 a	20.5 ab	29.6 b
	ZY	14.9 b	15.3 b	17.6 c	19.7 b	21.4 b	24.4 c	19.4 a	20.4 ab	25.8 bc
	LY	12.8 c	13.9 b	21.4 c	19.0 b	21.1 b	27.0 b	18.0 a	18.1 b	24.0 c
Methanol	CC	9.2 b	12.5 a	16.5 a	14.2 a	21.1 a	22.5 a	16.4 a	18.2 a	15.0 a
	ZD	11.5 a	13.6 a	14.5 a	16.3 a	18.3 ab	20.0 a	15.3 ab	17.5 a	18.4 a
	ZY	8.6 b	11.7 a	12.9 a	12.8 a	17.1 ab	15.3 b	11.6 b	15.1 a	13.0 a
	LY	8.7 b	12.1 a	14.2 a	13.4 a	15.0 b	16.5 b	11.3 b	15.5 a	14.5 a

Note: Values that are significantly different at 5% (LSD, $P < 0.05$) level in the same column are marked by lowercase letters. CC, Changcheng 799; ZD, Zhengda 12; ZY Zhengyu 203; LY, Luyu 13.

Table 3 Germination rate of Egyptian broomrape induced by maize root extracts collected at different leaf stage in the pot trial %

Extracts	Maize cultivar	10-fold dilution			100-fold dilution		
		Four-leaf stage	Six-leaf stage	Eight-leaf stage	Four-leaf stage	Six-leaf stage	Eight-leaf stage
Aqueous	CC	17.6 a	16.3 b	23.7 a	20.5 b	25.5 a	32.3 a
	ZD	17.4 ab	21.7 a	19.4 b	24.5 a	22.5 a	28.6 b
	ZY	14.1 c	17.0 b	12.7 c	15.4 c	19.1 b	18.7 d
	LY	14.9 bc	15.9 b	12.9 c	16.3 c	17.0 b	23.0 c
Methanol	CC	30.1 a	33.3 a	29.5 a	35.9 a	35.3 a	39.8 a
	ZD	20.3 b	26.1 b	24.4 a	26.8 b	32.7 ab	34.4 b
	ZY	16.1 c	23.9 b	15.5 b	19.6 c	25.5 bc	22.4 c
	LY	22.3 b	14.0 c	16.1 b	23.9 bc	21.2 c	24.7 c

Note: Values that are significantly different at 5% (LSD, $P < 0.05$) level in the same column are marked by lowercase letters. CC, Changcheng 799; ZD, Zhengda 12; ZY Zhengyu 203; LY, Luyu 13.

extracts to induce germination tended to increase as the plants matured (Table 4). The germination rates were generally more than 20%. Changcheng 799 induced the highest germination rate at the eight-leaf stage (39.8%). Zhengyu 203 and Luyu 13 induced lower germination rates (Table 4). The methanol extracts generally induced higher germination rates than the aqueous extracts, and the effectiveness of methanol shoot extracts in inducing germination tended to increase as the plants matured. Changcheng 799 induced the highest germination rate, while Zhengyu 203 and Luyu 13 induced the lowest germination rates (Table 4).

4 Discussion

Results from the four experiments showed that maize can induce seeds of Egyptian broomrape to germinate, and that significant differences in effectiveness existed between the maize cultivars. Maize is a host plant for *Striga*. Some researchers have identified two kinds of strigolactones, strigol and 5-deoxystriol in the root exudates of maize, which are potent germination stimulants for broomrape^[12,20]. So, it is consistent that maize induces the germination not only of *O. minor*, *O. ramosa* and sunflower broomrape, but also Egyptian broomrape^[17,21,22]. Our study found two maize cultivars that were able to induce high germination rates of Egyptian broomrape seeds and another two maize cultivars that induced low germination in cut-root and hydroponic experiments. Each of these four cultivars showed the same trend in the pot experiments, showing that the differences in induction of germination were stable across a range of conditions.

All 10 maize cultivars induced germination of Egyptian broomrape in the cut-root assay. This shows that maize produces germination stimulants at an early growth stage. It has been reported that maize produces more than three different kinds of germination stimulant after 5 days

growth and has the allelopathic potential of cress (*Lepidium sativum*)^[23].

We found that maize induced high germination rates of Egyptian broomrape seeds in a hydroponic experiment, and that the germination rates declined as the concentration of root exudates decreased.

Changcheng 799 and Zhengdan 958 induced high germination rates of Egyptian broomrape seeds, and Luyu 13 and Zhengyu 203 induced low rates in the cut-root and hydroponic experiments. So, these four maize cultivars were selected for the pot experiment, and the results were consistent with those of the cut-root and hydroponic experiments. The former two maize cultivars also showed high germination stimulation. These findings justify future testing of the cultivars in the field.

We found that root extracts generally induced higher germination rates than shoot extracts. This finding is consistent with the report that strigolactones were mainly synthesized in the roots and transported to the shoots; a finding further confirmed in our earlier study^[17,24]. It has been reported that maize exudates contain 5-deoxystriol^[12], which is one of the strigolactones. It was also reported that a maize cultivar resistant to *Striga* mainly produces sorghumol, whereas susceptible cultivar mainly produces 5-deoxystriol^[25]. These strigolactones are liposoluble. We also observed that methanol extracts generally induced higher germination rates than distilled water extracts. Furthermore, we found that some extracts at 100-fold dilution induced higher germination rates than at 10-fold dilution, which shows that the concentration of germination stimulants in maize are high or have high activity.

This study demonstrated that Changcheng 799 had the strongest stimulation of Egyptian broomrape. Therefore, using it as trap crop could be feasible. Other researchers who engaged in studies of broomrape control have found that selected alfalfa, green bean, hot pepper and sweet potato can be used as trap crops for Egyptian broomrape, with sweet potato being the most effective^[26].

Table 4 Germination rate of Egyptian broomrape induced by maize shoot extracts collected at different leaf stage in the pot trial %

Extracts	Maize cultivar	10-fold dilution			100-fold dilution		
		Four-leaf stage	Six-leaf stage	Eight-leaf stage	Four-leaf stage	Six-leaf stage	Eight-leaf stage
Aqueous	CC	14.6 b	26.8 b	22.6 b	20.2 ab	36.0 a	38.8 a
	ZD	14.6 b	33.9 a	27.0 a	14.5 b	31.7 a	32.6 ab
	ZY	21.9 a	21.8 b	20.8 b	22.2 a	25.7 b	27.7 b
	LY	12.2 c	11.9 c	21.9 b	15.7 b	17.0 c	28.4 b
Methanol	CC	31.6 a	52.6 a	32.2 a	35.1 a	39.2 a	34.7 a
	ZD	34.3 a	41.6 b	28.2 b	31.9 a	34.1 b	28.7 b
	ZY	21.7 b	24.3 c	22.6 c	27.2 b	27.5 c	22.4 c
	LY	22.7 b	23.5 c	17.7 d	28.4 b	26.3 c	22.0 c

Note: Values that are significantly different at 5% (LSD, $P < 0.05$) level in the same column are marked by lowercase letters. CC, Changcheng 799; ZD, Zhengda 12; ZY Zhengyu 203; LY, Luyu 13.

5 Conclusions

The use of false hosts (trap crops), which offer the advantage of stimulating broomrape germination without being parasitized, can be effective to some extent in reducing the EB infection. In this study, a set of trials demonstrated the potential of appropriate maize cultivars to induce high EB germination. Accordingly, maize can be used as a trap crop as part of EB management and this may lead to an integrated, biologically based strategy for EB control. Further study is needed to investigate the impact of maize on the EB soil seed bank and to explore the efficiency of maize in reducing parasitism of subsequent crop under field conditions.

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