OCL 2020, 27, 30
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https://doi.org/10.1051/ocl/2020023

OCL Oilseeds & fats Crops and Lipids
Available online at:
www.ocl-journal.org

REVIEW OPEN ACCESS

Recent progress on sunflower broomrape research in China☆

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Received 19 December 2019 – Accepted 20 April 2020

Abstract – Broomrape (*Orobanche cumana Wallr.*) is a holoparasitic plant which parasites sunflower roots. The infected sunflower plants are smaller, have a reduced kernel/husk ratio and yield decreases dramatically. It has become a severe problem for sunflower production all over the world. In recent years, due to importation of sunflower hybrid seeds, frequent local seed transportation and insufficient plant quarantine, broomrape widely occurs in sunflower production areas of China. This review addresses recent research progress on sunflower broomrape in China, focusing on occurrence, potential damage, seed germination mechanisms, physiological race identification, integrated control and breeding of resistant sunflowers. This review should provide useful reference information for future research and also integrated control of sunflower broomrape.

Keywords: sunflower broomrape / occurrence / seed germination / race identification / integrated control

Résumé – Récents progrès dans la recherche sur l'orobanche de tournesol en Chine. L'orobanche (*Orobanche cumana Wallr.*) est une plante holoparasite qui parasite les racines du tournesol. Les plants de tournesol infectés sont plus petits, présentent un faible rapport entre le grain et la coque, et le rendement diminue de façon spectaculaire. C'est devenu un problème grave pour la production de tournesol dans le monde entier. Ces dernières années, en raison de l'importation de graines de tournesol hybride, du transport fréquent de graines au niveau national et du retard pris par rapport au système de quarantaine des plantes, l'orobanche s'est largement répandue dans les zones de production de tournesol en Chine. Dans cette étude, les progrès récents de la recherche sur l'orobanche du tournesol en Chine seront abordés ; elle se concentrera sur la présence et les dommages potentiels de l'orobanche, le mécanisme de germination des graines, l'identification des races physiologiques, le contrôle intégré et la sélection de tournesols résistants. Cette étude fournira des informations de référence utile pour des recherches futures et la lutte intégrée contre l'orobanche du tournesol.

Mots clés : orobanche de tournesol / présence / germination des graines / identification des races / lutte intégrée

1 Introduction

Broomrape (*Orobanche cumana* Wallr.) is a quarantine weed that parasitizes the root system of sunflower. Due to the lack of chlorophyll, it cannot carry out photosynthesis and completely depends on host plants for its water and essential nutrients. Once attached to the sunflower root, it reduces capitulum size and kernel ratio which leads to a dramatic decrease in yield. It has become a severe problem for sunflower production all over the world (Molinero-Ruiz *et al.*, 2015). In recent years, due to the importation of sunflower hybrid seeds from abroad, frequent seed transportation domestically and insufficient plant quarantine, broomrape has spread widely in most sunflower production areas in China. It has become a serious impediment to the development of the local sunflower industry. In this review, recent progress being made in research on sunflower broomrape will be addressed, it will focus on the occurrence and potential damage caused by broomrape, seed germination mechanisms, physiological race identification, integrated control and breeding of resistant sunflowers. This review will provide useful reference information for future research on the control of sunflower broomrape in China.

2 Occurrence and damage

In China, sunflower production is mainly distributed across Inner Mongolia, Xinjiang, Heilongjiang, Jilin, Shanxi, Shaanxi, Hebei, Gansu and Ningxia provinces. Inner Mongolia is the largest sunflower producing area in China, with a total

☆ Contribution to the Topical Issue "Sunflower / Tournesol".
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Fig. 1. A map indicating the distribution of sunflower broomrape in China. Note: O in the box stands for the abbreviation of *Orobanche cumana* Wallr.

planting area of about 0.40 million ha, accounting for 40.2% of the total sunflower planting area in China (Bai *et al.*, 2013). Sunflower broomrape was first discovered by a farmer in Zhaozhou County of Heilongjiang Province in 1959 (Li *et al.*, 1982). Gradually, it spread to different sunflower planting regions and became a big problem for sunflower production in China (Fig. 1). Here we will review the occurrence of broomrape and its hazard on sunflower production in different regions of China.

2.1 Inner Mongolia region

In 1980, the general survey of quarantine diseases was conducted in Inner Mongolia region, broomrape was found in the Chayouhouqi and Liangcheng counties of Wulanchabu region (Li, 1981). In 2003, the total area of farms covered with sunflower broomrape in Inner Mongolia region was about 0.13 million ha (Li *et al.*, 2004). In 2009, a larger area of sunflower broomrape was recorded in Inner Mongolia, causing serious yield loss of sunflower. According to a 2010 publication, the parasitic rate of broomrape in Wengniuteqi of Chifeng city was 87%, resulting in a decrease in sunflower production of about 21%; in 2011, nearly 0.07 million ha of sunflower farms in Xixiaozhao town of Wulateqianqi had no harvest; in the same year, the infection area of broomrape in Baotou city was nearly 13.3 thousand ha with a parasitic rate between 10–35%, and in severe cases in plots along the Yellow River, the parasitic rate was about 75% (Bai *et al.*, 2013). In 2013, in Bayannur county, the infection area reached 0.12 million ha. In some severe cases, the parasitic rate was more than 90%, and the average yield decreased by about 50%. Broomrape occurred increasingly when several sunflower crop were grown successively, the parasitic rate was up to 100% resulting in no yield at all (Sun, 2017). At present, sunflower broomrape has a high occurrence rate in Inner Mongolia region, and most severe infection occurs in Wulanhot, Tongliao, Chifeng, Wulanchabu, Hohhot, Baotou, Bayannur, and Erdos etc., covering almost all sunflower planting regions in Inner Mongolia.

2.2 Xinjiang region

In Xinjiang region, sunflower broomrape is mainly distributed in Altay, Tacheng, Ili, Shihezi, Bayingolin, Changji, etc. (Wu and Qiang, 2006). Zhao *et al.* (2007) investigated the occurrence of broomrape in Yili district, and that found it caused 30–35% reduction in sunflower yield. Zhang *et al.* (2011) reported that, from 2007 to 2013, sunflower broomrape was found in 31 towns and 2 state farms in Yili district. The average number of broomrape shoots on a single sunflower plant was 38. Capitulum diameter, average plant height and stem diameter of the sunflower plants were reduced by more than 58%, and the average weight of 1000 seeds was reduced by more than 55%. In Atlay district, due to the lack of resistance to broomrape, the most elite landrace of sunflower "Sandaomei" was only planted in fields with no history of sunflower cultivation. Many other sunflower plots with serious infection of broomrape had to be rotated with non-host crops of broomrape (Chen *et al.*, 2014).

2.3 Northeast region

In 1979, sunflower broomrape was first reported in Changling, Qian'an, Qianguo, Fuyu, Da'an and Tongyu counties of Jilin Province (Zhao and Yan, 1983). The average number of broomrape shoots on a sunflower plant in Changling county, Jilin province could reach up to 51; the average density of shoots was 36.7/m^2 (Zhou *et al.*, 1980). In 1980, Li *et al.* (1982) investigated the occurrence of sunflower broomrape in Zhaozhou county, Heilongjiang province. Among the 289 plots investigated, broomrape was found in 150 plots, with an estimated area of 630 ha, accounting for 44% of the investigated area. In 1981, according to the research data obtained from Heilongjiang Agricultural Bureau, the total area of sunflower broomrape occurrence in Heilongjiang reached more than 0.14 million ha. From 2003 to 2005, Guan *et al.* investigated the occurrence of broomrape in Heilongjiang province, and found that sunflower planted in Lanxi, Qinggang, Zhaozhou, Fuyu, Mingshui, Baiquan and Yi'an counties suffered from serious damage due to broomrape; the number of broomrape shoots on a single sunflower plant varied from 6 to 215. Broomrape was also found mainly on the lateral roots of sunflower at a depth of 5–10 cm (Guan, 2007).

2.4 Other regions

The average annual area of sunflower broomrape occurrence in the northwest of Hebei province from 1989 to 1991 was around 12.0 thousand ha, accounting for one third of the planting area of sunflower, and the infection area expanded gradually (Ren *et al.*, 1992). In 2003, Wang *et al.* (2003) reported the occurrence of sunflower broomrape in Shilou, Shanxi province, with the trend spreading to neighboring counties in the province. In 2002, sunflower broomrape was reported in Wuqing District of Tianjin, the infection area was 1.33 ha and increased to 6.67 ha in 2003. Tianjin Plant Protection Station made great efforts in controlling the rapid spread of broomrape, this limited the infection area to 6.67 ha in 2008 (Wang *et al.*, 2008). In Dingbian, Shaanxi province, the infection area was up to 64% of the total sunflower planting area, and yield reduction ranged from 15–50% (Chen, 2010). Yan *et al.* (2014) reported the occurrence of sunflower broomrape in Zhangjiakou, Hebei province, where the average yield reduction in infected plots was about 30%, and there was almost no yield in severely infected areas. At present, Xuanhua, Shangyi, Yangyuan, Huai'an, Wanquan, Huailai and Pingxiang are the main counties with large occurrence of broomrape in Hebei province (Han, 2018).

3 Broomrape seed germination

The germination of broomrape seeds requires pre-culture under specific temperature and humidity conditions, and also the stimulation of nutrients from host roots (Amsellem *et al.*, 2001). He *et al.* (2012) collected root exudates from sunflower plants at seedling stage by a hydroponic method, for analysis and identification of the constituents in the root exudates using GC-MS. Several chemicals such as dehydrochloride could induce the germination of broomrape seeds. When the concentration of dehydrochloride reached a certain level around the rhizosphere of sunflower roots and the environmental conditions such as soil temperature and humidity were suitable, broomrape seeds could germinate along the whole growth stage of sunflower. Ren (2012) found that the amount of germination stimulants secreted by roots of sunflower was varying at the seedling stage among different varieties, and showed different resistance levels among tested varieties. Jun *et al.* (2014) studied the effect of root exudates of three different sunflower varieties on the germination of broomrape seeds. The results showed that both root exudates of susceptible variety "Xinghuodabaibian" and resistant variety "Baikuza 9" could stimulate the germination of broomrape, and the allelopathic effects showed "low promoting, high inhibiting" tendencies. Root exudates of an immune variety "MGS" could also stimulate seed germination, but the germination rate was significantly lower than that of the other two varieties tested.

Soil conditions could affect the germination and parasitism of broomrape. Results from Dinesha and Dhanapal (2013) showed that broomrape survives easily in alkaline soil (pH $>$ 7.0), and the occurrence rate was less in acidic soil (pH $<$ 7.0). Shi *et al.* (2018) reported that sandy-loamy soil with temperature around 25–30 °C, humidity of 60–70%, and soil pH value of 8 could facilitate the parasitism and development of broomrape. Di *et al.* (2017) concluded that both organic matter and sufficient nitrogen in soil promoted the occurrence of sunflower broomrape, but the presence of phosphorus in the soil inhibited parasitism. Lu *et al.* (2019) developed a water-soluble fluoroline nano preparation system (tf-or-cc) that could effectively inhibit the germination of sunflower broomrape seeds. Both actinomycete (*Streptomyces fusarius sveshnikova*) and *Penicillium griseofulvum dierckx* were screened out based on their ability to strongly inhibit the broomrape seed germination (Chen *et al.*, 2016). Further studies revealed that patulin, a secondary metabolite produced by *P. chrysanthum,* could inhibit the germination of broomrape seeds (Chen *et al.*, 2017).

4 Races type identification

Sunflower broomrape is both self- and cross-pollinated, thus facilitating generation new races. Several races have been identified based on their response to differential lines which contain different resistance genes (Or1-Or7) (Kaya *et al.*, 2004). At present, eight races have been identified as A, B, C, D, E, F, G and H worldwide (Dicu *et al.*, 2011; Shindrova and Penchev, 2012). The first report on race identification in China dates back to 1996. Dong and Sha (1996) used five differential lines which were requested from Spain to identify the race types of broomrape samples collected from three areas in Jilin Province. The results indicated that three samples were identified as race A. Ma and Wan (2015) used the same differential lines to identify the race types of broomrape which were collected from different areas in China. The results indicated that the races B, D and F were identified in Inner Mongolia region; E, F in Xinjiang region; A, B, E, F in Gansu province; A, C, D, E in Jilin province, and A, E in Heilongjiang province. Shi *et al.* (2015, 2016a, b) successfully identified the race types of 32 broomrape samples collected from different provinces in China using the differential lines provided by

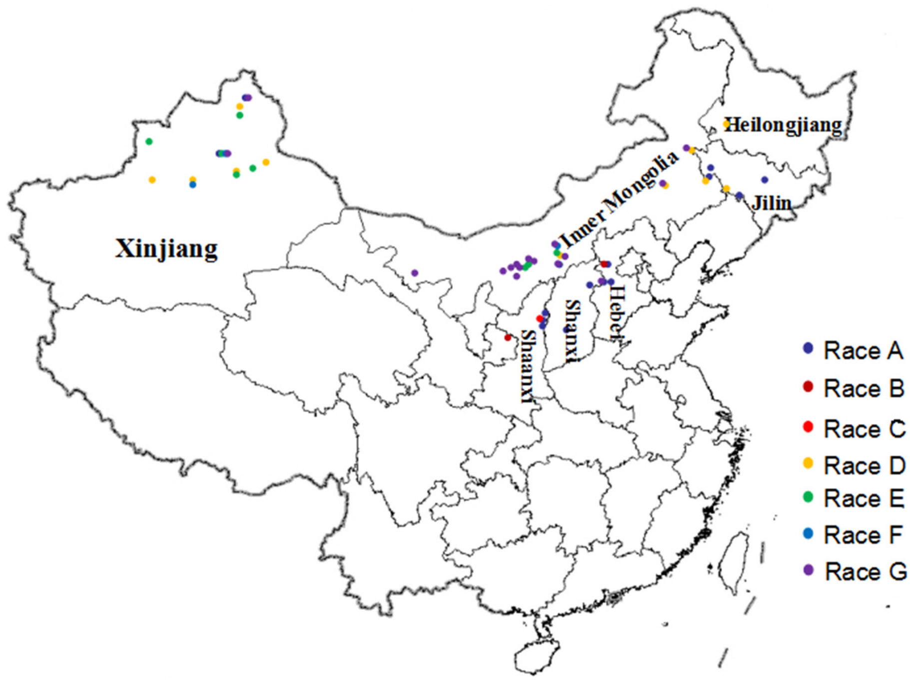

Fig. 2. Distribution of different race types of Sunflower broomrape in China.

Dr. Dragan Skoric. The results suggested that five races including A, D, E, F and G were identified in different provinces of China and D was the dominant race. Liu *et al.* (2019) identified broomrape race types collected from ten different places in Xinjiang and Inner Mongolia region with differential lines requested from Romania. Race D, E, F and G were identified among the collected samples, and the most striking result was two samples collected from Wuyuan county and Shuanghe town of Bayannur city, that could overcome the resistance controlled by Or7, indicating the race type of these two samples was higher than G, it was labeled as G^+. However, considering the sampling information, the distribution frequency of races in different regions was found to be variable. Inner Mongolia region possessed the most diverse races (A, B, D, E, F, G and G^+) and race G was dominant; whereas, in Xinjiang region, races D, E, F were identified and race E was dominant. Jilin province contained A, C, D and E; Gansu province contained A, B, E and F; Heilongjiang province contained A and E; Hebei and Shanxi province possessed the most basic race type, race A only (Figs. 2 and 3).

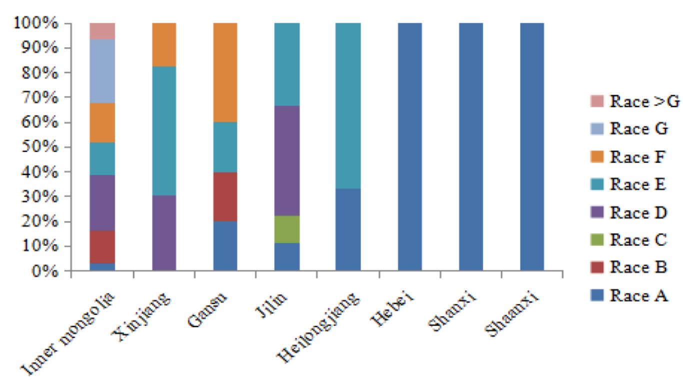

Fig. 3. Distribution frequency of broomrape race types in different regions of China.

5 Resistance breeding

The most economical and effective way to control broomrape is to generate resistant varieties (Škorić and Pacureanu, 2010), but for this, identification and selection of resistant breeding materials are necessary.

5.1 Identification of resistant varieties in the field

Wang *et al.* (2007) screened confectionery sunflower varieties from a field in Shanxi province, and identified one immune variety and two highly resistant varieties. At the same time, they also screened 11 resistant germplasm materials. In 2010, Wang (2010) also screened 41 sunflower breeding materials from Heilongjiang province, and 24 immune and 4 highly resistant materials were identified. The resistance level of oilseed sunflower was much higher than that of the confectionery sunflower varieties; and the resistance level of hybrid varieties was significantly higher than that of landraces, no landrace showed immunity to broomrape. Zhang *et al.* (2012) screened 25 sunflower hybrids collected from Inner Mongolia region, varieties T423, 135 and 9091 showed immunity to broomrape collected from Shanxi province. Niu *et al.* (2010) evaluated the resistance level of 52 sunflower varieties in Jilin province, and 40 varieties showed resistance to broomrape, including hybrids, inbred lines and sterile lines. By using a pot inoculation system, Zhang *et al.* (2013) declared that different sunflower varieties showed significantly different resistance level to broomrape. Among all the tested materials, oilseed sunflower varieties “To12244” and “MGS” were classified as immune and “S31” and “Baiza 9” were highly resistant, while "Xinghuodabaibian" and "Baiza 6" were susceptible. Dong *et al.* (2016) identified the resistance level of different sunflower varieties from Altai in Xinjiang and Wulatqianqi in Inner Mongolia in 2012 and 2013–2014 respectively. The results showed that, in Altai area, 16 oilseed varieties were identified as immune, including Longkuzha1, F08-1 and Liaofeng F53; and only one immune variety (JK106) was identified in the confectionery group. In Wulateqianqi, Inner Mongolia, 2 immune varieties and 4 highly resistant oilseed varieties and 2 resistant confectionary varieties were identified. Comparing the results from two different locations, there were more varieties classified as immune and highly resistant in Altai, Xinjiang than in Wulateqianqi, Inner Mongolia, indicating that the race in Wulateqianqi may be more virulent than it in Altai. Liu *et al.* (2017) identified the resistance level of varieties in a nursery plot in Linhe district, Bayannur city. They identified TP3313 as immune, with a yield of 3.9 t/hm^2, TP3314 as a highly resistant variety, and 8 others, including SH361 and SH338 were classified as moderate resistance to broomrape. Zheng *et al.* (2019) also identified the resistance level of 13 sunflower varieties in the natural disease nursery plot, and identified 2 immune varieties (TP3313, TP3314) and one highly resistant variety (T261). In Beitun city, Xinjiang, Shen *et al.* (2019) identified 6 oilseed and 8 confectionery resistant varieties in the field, also with high yield production. In conclusion, we recommended Gufeng No. 1, TP3313, TP3316, SH361 and Xinnong177 as the elite broomrape resistant varieties for planting in these regions.

5.2 Identification of resistant varieties under laboratory conditions

Niu *et al.* (2010) established a set of method for identifying broomrape resistance under laboratory conditions, which mainly includes mixing broomrape seeds with soil, sowing sunflower seeds in this mixed soil and then seedling management. The resistance levels of breeding materials tested were classified according to the tubercle number on sunflower roots. Wang (2013) analyzed the resistance of 41 sunflower resources with this pot inoculation system. Results showed that 25 were identified as immune, including 8604, SF187 and Longshiza 1, which are oilseed varieties and hybrids, but no immune material was identified in local sunflower resources. Zhao's team developed parasitic growth *in vitro* in both plastic cups and petri-dishes. Based on the resistance level of varieties identified in the field, they defined resistance criteria in petri-dishes with average tubercle number per petri-dish (Shi *et al.*, 2016a, b; Xu, 2017). Shi *et al.* (2016a, b) evaluated the resistance level of sunflower varieties using an *in vitro* plastic cup system. He identified 3 immune genotypes (Baikuiza 6, Xinkuiza 23, AR7-1614) among oilseed varieties, but only one confectionery sunflower was highly resistant (H76/702), indicating that the resistance level of oilseed sunflower is higher than that of confectionery. Using the petri-dish system, Xu (2017) identified the resistance level of sunflower varieties against race G. The results revealed that the resistance levels could be divided into three groups: highly resistant (Chiky11-46, Chiky11-23, Chiky-52 and Xinkuiza 2); moderately resistant (JK105, JK108 and Bakui 138) and highly susceptible (Longshikui 2, Gankui 2 and LD5009). Shi (2018) evaluated the resistance level of 80 sunflower varieties using the petri dish method. Fourteen varieties were identified as immune, comprising of 11 oilseed and 3 confectionery varieties; 25 showed a high resistance level including 14 oilseed and 11 confectionery; whereas, 22 varieties showed moderate resistance, 12 were susceptible and 7 varieties were highly susceptible.

5.3 Resistance breeding

Many genetic studies on the sunflower resistance carried out in many countries indicated that sunflower resistant to broomrape is controlled by either a single dominant gene (Burlov and Kostyuk, 1976; Pogorletsky and Geshele, 1976; Ish-Shalom-Gordon *et al.*, 1993) or multiple genes. Velasco *et al.* (2012) also confirmed that dominant alleles in sunflower controlled the resistance against race G. However, some results indicated that the sunflower resistance to broomrape was controlled by multiple genes, for example two recessive genes or6 and or7 control resistance to race F (Cubero, 1991; Pérez-Vich *et al.*, 2004; Hladni *et al.*, 2012; Louarn *et al.*, 2016). In China, Zhang *et al.* generated three combinations using a resistant line P1 and a susceptible line P2, and identified the resistance and susceptible separation ratio in F1, F2 and BC1 population (P2), they concluded that sunflower resistance to broomrape was controlled by a pair of dominant alleles; hence proposed a breeding procedure to improve the resistance level of new varieties (Zhang *et al.*, 2006). Reseacher also selected resistant plants from the landrace "Sandaomai", and generated the resistant variety "Sandaomai 622" by pure inbreed lines in Xinjiang (Chen *et al.*, 2014). The confectionery hybrid "Xinnong177" generated using R1040 as the male parent and A1347 as the female parent showed immune to all the broomrape races in Xinjiang and Inner Mongolia regions (Su *et al.*, 2018).

6 Integrated control of broomrape

6.1 Agricultural control measures

In addition to sunflower, the root exudates of capsicum, mung bean, alfalfa and other crops can also induce germination of broomrape seeds, but with no parasitic structures such as tubercles developing in the roots of these plants, hence, resulting in "suicide germination" of broomrape. These crops were named as "trapping crops" (Ma *et al.*, 2012, 2013). Crop rotation with trapping crops could effectively decrease the occurrence of broomrape in sunflower fields. Here listed some publications related to trap crops of broomrape. Jia *et al.* (2016) showed that six kinds of Chinese herbal medicines such as *Artemisia annua*, Snow ginseng, *Caulis spatholobi*, Blue orchid, *Pinus sylvestris* and Angelica in Qinghai could secrete high concentration of chemicals from roots, thus increasing broomrape seed germination ratio to over 20%. These plants can be used as trapping crops for controlling broomrape. Wang *et al.* (2016) showed that root exudates of wheat and broad bean can also stimulate the broomrape seed germination. Yu and Ma (2014) concluded that a methanol extract of hemp can also induce germination. Lang and Ma (2011) showed that the methanol extract from the soil rhizosphere and roots of cotton seedling had a strong inducing effect on the germination of sunflower broomrape seeds. Dong (2013) reported that some genotypes of winter wheat can also stimulate the germination of broomrape seed, hence winter wheat can be a rotation crop for sunflower to trap the broomrape. Jia (2013) used maize inbred lines and hybrids as experimental materials to study the induction efficiency of root exudates on broomrape seeds germination. It was found that both root system and the above ground part of maize could stimulate the broomrape seeds germination, and the F1 hybrid 3255 × 335 and their parent lines were suitable to plant as "trapping crops" to control broomrape. Bai *et al.* (2019) revealed that broomrape occurrence rate decreased when oat and sunflower were rotated, indicating that oat could be used as a trapping crop in Inner Mongolia region. Wang *et al.* (2019) studied the control effect of different crop rotation systems on broomrape and found rotation with beet, wheat and capsicum reduced infection by 60%. Although the use of "trapping crops" can reduce the number of broomrape seeds in the soil, a long rotation cycle is necessary to exterminate broomrape completely. Chen *et al.* (2014) also studied the effect of sowing date on the occurrence of sunflower broomrape in Xingjiang region and found that delayed sowing can reduce broomrape occurrence considerably.

6.2 Chemical control measures

Herbicide control is a widely used method at present in China. 0.2% 2,4-D butyl ester solution can be sprayed on broomrape shoots or the soil surface, but the application can only be carried out when the diameter of sunflower head is more than 10 cm, otherwise, it leads to side effects such as leaf or stem deformity, flower head development inhibition (Pang *et al.*, 2012). Glyphosate is a good pesticide against sunflower broomrape especially spraying with a combination of 2.4-D butyl ester (Ren *et al.*, 1992). Li *et al.* (1992) sprayed metolachlor and glyphosate on broomrape as a control measure and death rate was up to 100% seven days after application. Duan *et al.* (2010) used 48% butralin emulsion for soil treatment to control broomrape, giving 75.1% positive result, with no side effect on sunflower. Before emergence of seedlings, 48% butralin emulsion was sprayed on the soil surface, in another setting 10% nitramine was used to irrigate roots before the flowering period of broomrape, a substantial control effect on broomrape was observed in field (Wang *et al.*, 2015). Xu *et al.* (2016a) observed that the number of sunflower broomrape shoots on tobacco could be reduced effectively by soil treatment with spermiopropylamine and butralin. Two kinds of herbicides were selected and used, the results showed that the most effective combination was 41% glyphosate isopropylamine salt 12 L/hm^2 + 57% 2.4-D butyl emulsion 1.2 L/hm^2, 41% glyphosate isopropylamine salt 12 L/hm^2 + 96% fine isopropylamine emulsion 1.2 L/hm^2 (Zhang *et al.*, 2011). Using 48% butralin emulsion and 33% dimethylpentyl could also effectively control broomrape without causing any damage to sunflower, and the recovered yield losses were 30.5% and 25.0% respectively (Leng *et al.*, 2014). Bai *et al.* (2018) studied a new sunflower variety, Xinshi 1, which is resistant to imidazolinone herbicide. The results showed that the control effect could reach up to 100% by spraying 5% imidazole ethylnicotinic acid and 4% methoxyimidazol nicotinic acid at the V6-V8 stage of sunflower development, with a dosage of 750 mL/hm^2. Yun *et al.* (2018) showed that IR-18, a plant inducer, showed a significant inhibitory effect on the occurrence of broomrape on sunflower and the control effects of IR-18 was confirmed *in vitro* using the petri-dish system.

6.3 Biological control measures

Biological control aims at diseases control *via* antagonist effects of other microorganisms. Louarn *et al.* (2012) found that applying arbuscular mycorrhiza (AM) isolates to soil could inhibit broomrape seed germination, thus reducing damage to a certain extent. In China, Kong *et al.* (2006) isolated *Fusarium* spp. from a diseased broomrape in the field and named it L2. It was found that the crude toxin of L2 could inhibit the germination of broomrape. Field experiments were carried out using L2, and results showed that control could reach 92.4%. Ding *et al.* (2012) also isolated and identified pathogens from diseased broomrapes samples as *Fusarium* spp which was the main pathogen causing the basal stem rot of broomrape in Xinjiang region. Wu *et al.* (2011) reported that application of *Fusarium* spp. and adjusting soil pH with sulphur could delay broomrape emergence, with 62.4% control effect. The microbial fertilizer developed by a company from Chengdu, Sichuan province, could control broomrape effectively. The above product not only decreased damage caused by broomrape, but also promoted sunflower growth, with a yield increase of more than 10% (Li *et al.*, 2013). Guo (2018) studied control effects of three biocontrol agents, *Penicillium griseofulvum* (CF3), *Actinomycete streptomyces* (509) and *Streptomyces pactum* (Act12) on the occurrence of broomrape on sunflower. The results showed that after pretreatment with both CF3 and Act12, the number of broomrape shoots decreased and sunflower stem heights increased significantly compared with the control setup.

7 Other aspects of broomrape

To unravel the cross infection ability of broomrape on sunflower and other hosts such as tobacco and tomato, Zhao's team performed a cross-infection study using both petri-dish and plastic cup methods *in vitro*. The results suggested that sunflower broomrape does not only parasitize on sunflower, but also on tobacco and tomato, but the parasitic effect is varying. Xu *et al.* (2016b) first reported on broomrape wilt caused by *Plectosphaerella cucumerina* in Inner Mongolia, China, and found *P. cucumerina* is much more aggressive on broomrape than it is on sunflower. Zhang *et al.* (2018) firstly reported the stem rot of sunflower broomrape caused by *Sclerotinia minor* Jagger in Inner Mongolia, China, this finding may broaden our knowledge on both *S. minor* and *O. cumana*. To clarify the genetic relationship between broomrape isolates, 96 samples were collected from different provinces in China, 12 ISSR markers were selected based on their polymorphism and used to study population genetic diversity. The results showed a total of 147 bands were amplified by PCR, of which 90 were polymorphic accounting for 61.2%. Shannon information index and Nei′s diversity index on broomrape populations from different locations increased with the increase in population sample size. Genetic clustering results revealed that the samples from 6 different provinces could be divided into 2 sub-groups. Shanxi, Hebei and Shaanxi samples were clustered into one sub-group; and those from Jilin, Xinjiang and Inner Mongolia were clustered into another sub-group. Broomrape samples between Hebei and Shaanxi had the closest genetic distance, whereas, samples from Xinjiang and Hebei had the farthest genetic relationship. Among them, broomrapes form Xinjiang region showed much higher genetic variation than samples collected from Inner Mongolia region (Shi *et al.*, 2019).

8 Conclusion

At present, sunflower broomrape has become a bottleneck in sunflower production in China and has attracted the attention of local researchers. According to current research statistics, the best way to reduce damage due to broomrape is to generate resistant sunflower varieties which can survive against the different races. Several key goals need to be set up in the coming future. First, it is essential to identify all races of sunflower broomrape continually with the same set of differential lines all over the country and determine the composition and distribution map of race type of broomrape. Secondly, it will be useful to exchange resistant breeding materials with sunflower breeding teams in other countries in order to generate resistant confectionery sunflower varieties. Thirdly, molecular studies on the interaction between broomrape and sunflower are also required to unravel the mechanism of broomrape pathogenesis and also host resistance. Finally, a set of integrated control techniques to control sunflower broomrape need to be organized and put into practical application.

Acknowledgement. This work was funded by China Agricultural Research System (CARS-14), Inner Mongolia Scientific Major Project, Inner Mongolia Scientific Plan Project (201802072), Inner Mongolia Academician Station Specific Project (201803048) and Xinjiang Province Scientific Plan Project (2018Q043).

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Cite this article as: Shi B, Zhao J. 2020. Recent progress on sunflower broomrape research in China. *OCL* 27: 30.