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REVIEW ARTICLE

Broomrape management strategies in tobacco - A review

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ABSTRACT

Broomrape (*Orobanche* spp.) is a complete root parasite that derives total nourishment from host plants. Tobacco is a common crop that is most seriously infected by *Orobanche*, which causes more than 75% yield loss through reduction in above and below ground biomass, leaf yield and quality. Broomrape's idiosyncratic features, such as prolific seed production (more than 5,00,000 seeds per plant), very small seed size, easy mode of seed dispersal, seed viability and longevity, and seed emergence only when a suitable host is present, make parasite eradication strategies ineffective and expensive. Although several potential control measures have been developed over the past few decades for its management, any approach applied alone is often only partially effective, and the results are sometimes inconsistent owing to variable environmental conditions. In addition, broomrape interactions with tobacco are highly specific and complicate the development of selective control methods that do not affect tobacco. Therefore, the only way to achieve effective control of *Orobanche*, especially in tobacco, is through an integrated approach that combines various measures in a concerted manner. Summer ploughing, growing sesame as trap crop preceding to tobacco, application of neem cake 250 kg/ha at 30 days after planting of tobacco and hand weeding are recommended as integrated approach for broomrape management in FCV tobacco under irrigated conditions.

Keywords: Broomrape, Crop loss, Infestation, Integrated, Management, Parasite, Tobacco

INTRODUCTION

Tobacco is one of the most important high-value cash crops in India and ranks third in world tobacco production. It is grown in most of the agro-climatic zones of the country in more than 15 states, but the major tobacco-growing states are Andhra Pradesh, Gujarat, Karnataka, Uttar Pradesh, West Bengal, and Bihar. Presently, tobacco is cultivated in an area of approximately 4.90 lakh hectares, accounting for 0.24% of the total arable land in the country, covering different types of tobacco, *viz*. FCV tobacco, bidi tobacco, chewing tobacco, hookah tobacco, cheroot tobacco, cigar wrapper tobacco, cigar filler tobacco, oriental tobacco, dark fire cured tobacco etc., with an annual production of 800 million kg (Kasturi Krishna *et al*. 2022).

Tobacco is a unique crop in which quality is as important as yield. Hence, in the cultivation of tobacco, attention is paid to reduce the effects of biotic stresses for production of quality tobacco leaf. However, unlike most crops, tobacco is affected by the parasitic flowering plant *Orobanche*, a complete root parasite, commonly known as broomrape. Broomrape (*Orobanche/Phelipanche* spp.) is an obligate, holo-parasitic angiosperm lacking root system and photosynthetic competence, which derives total nourishment from host plants and attacks the roots of economically important crops, such as tobacco, rapeseed and mustard, brinjal, tomato, sunflower and faba bean in the semi-arid regions of the world (Wickett *et al*. 2011). A review on *Orobanche* with special reference to mustard and tomato was done by Punia (2014, 2015). *O. ramosa* and *O. cernua* are two species that commonly parasitize tobacco. The economic production of tobacco is precluded in soils infested with broomrapes, especially *O. ramosa* and *O. cermua* and hence, many of the traditional and best tobacco soils have been abandoned or planted with other crops in many other countries (Lolas 1994). Hence, it is pertinent to review the studies on management strategies for planning effective, safe and economical method of management.

Orobanche and yield loss in tobacco

Among five species of broomrape, *O. cernua* is the major species causing problem to tobacco in India as reported by Krishnamurthy *et al*. (1977a). Eight *Orobanche* isolates collected from five different FCV tobacco growing areas and one each from burley and *bidi* tobacco growing regions in Andhra Pradesh belong to *Orobanche cernua* with 98-100% sequence match. When the conditions are congenial for its

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growth, it causes a yield loss of more than 75% through reduced crop growth, leaf yield and quality (Krishnamurthy *et al.* 1994)

The parasite emerges usually between December and January months after planting and result into reduction of yield and leaf quality in tobacco (Dakshinamurti *et al.* 1964). It is a serious problem on *Bidi* tobacco in Nipani area of Karnataka and Chewing tobacco in Bihar and Uttar Pradesh. In Karnataka, 90% area under tobacco is infested with this weed and reported 50-60% yield losses in some areas (Dhanapal *et al.* 1998). Yield loss due to *Orobanche* infestation in tobacco growing areas of Tamil Nadu, Gujarat and Maharashtra is also reported to be very high. According to Dhanapal *et al.* (1996) and Qasem (2021), the damage caused by *Orobanche* can range from zero to complete crop failure depending upon the extent of infestation, environmental conditions, soil fertility and crops competitiveness.

It is obvious that 1/5 to 1/8 of the three major nutrients are removed by broomrape. Broomrape contains about 9% reducing sugars and the large depletion of sugars affects tobacco leaf quality (Prasada Rao and Murty 1976). In another study by Murthy and Nagarajan (1986) at Rajahmundry, Andhra Pradesh, broomrape infestation reduced the plant height (52.3%), number of leaves (34.3%), shoot fresh weight (40.3%), shoot dry weight (39.5%), root fresh weight 62.0% and root dry weight (53.7%). It was also reported that *Orobanche* infestation caused reduction in uptake of nutrients N (53.3%), P (77.8%), K (82.6%), Ca (54.9%) and Mg (65.9%). The capacity of infested plants for uptake of nutrients was reduced by 50%. Leaf samples from broomrape infested tobacco plants showed a decrease in P, K, total sugars, reducing sugars, total reducing substances, polyphenols and chloride contents and an increase in total N, Ca, nicotine, total volatile bases and petroleum ether extractives. Physical characters, *viz.* EMC, shattering index and leaf thickness reduced considerably while filling value increased in the broomrape affected tobacco leaf. Nutrient removal by the parasite from the host plant ranged between 20-25% that of healthy plants in case of major nutrients i.e. N, P and K. Further, broomrape was found to contain higher amounts of potassium and protein nitrogen (Murthy *et al.* 1977). Broomrape acts as a strong sink, depriving the host from water, mineral, and organic nutrients with the consequent negative impact on the growth of the host plant (Joel 2000, Abbes *et al.* 2009)

Life cycle of broomrape

Thorough knowledge on life cycle of broomrape is necessary to control the parasite at its vulnerable stage. *Orobanche* infestation and parasitisation processes takes place underground, so damage to the crop occurs prior to the emergence of the parasite and diagnosis of infestation. The germination of broomrape seeds is triggered by the interplay of three factors, *viz.* root exudates of host/ trap crop, low soil temperature and high soil moisture.

After germination in response to specific chemicals released by the host plant, the broomrapes seedlings attach to the host roots by the production of specialized feeding structures, described as 'Haustoria' that form a functional bridge into their hosts. Once vascular connections are formed, the parasite starts extracting water, nutrients, and photosynthates from the host vascular tissues (Fernandez-Aparicio *et al.* 2011). Haustoria penetrate the host tissues until they reach the vascular system for uptake of water, nutrients and assimilates and grow at the expense of the host plant's resources (Joel *et al.* 2007). After the vascular connection between haustorium and root of the host is established, the part of the broomrape seedling that remains outside the host root tissue swells to form the tubercle. In 1 to 2 weeks a shoot bud on tubercle differentiates and develops slowly into a shoot that emerges above the soil surface. The emerged ground shoot elongates to produce the flowering shoot in about 4 to 5 days. The seed ripen after another 20 to 25 days. Thus, the life cycle of parasite is completed in about three months after planting of tobacco (Krishnamurthy *et al.* 1977b). The seed germination stage, infection stage and shoot emergence and succulent stage above ground are considered as the vulnerable stages to combat the parasite.

Spread of *Orobanche* in tobacco growing areas

During field preparation, the *Orobanche* seeds spread by the movement of farm machinery and vehicles from infested fields to the other fields. Due to anticipated economics and limited scope for continued leased in cultivation, farmers cultivating tobacco in leased fields are not showing much attention towards physical removal of *Orobanche* prior to its flowering ,seed shattering and for its proper disposal. In general, after removal of *Orobanche* shoots, farmers are disposing them at field corners/ road side areas/ canals which are places for uncontrolled movement of grazing animals.

In addition, *Orobanche* shoots are good feed stuff to the sheep and goats. The excreta/ manure of those grazing animals act as the reservoir of *Orobanche* seed and also spreads the infestation. Farmers are growing tobacco year after year without following crop rotation and by not growing promising trap crops. As a result, the existing *Orobanche* seed reservoir in the soil is increasing and causing severe damage to the tobacco crop. The use of organic manure from livestock fed with contaminated hay is a cause of further seed dispersal, since the parasite seeds do not lose their viability while passing through animal's digestive systems (Jacobsohn *et al.* 1987).

Management strategies

Over decades, a great deal of research on *Orobanche* in many crops including tobacco yielded vast scientific knowledge on myriad aspects of parasite's life cycle covering seed phase, parasitic phase, emergence and reproductive phase. Based on understanding the points of vulnerability in parasite's life cycle, several management strategies were developed to minimise the loss of yield and quality of the host crops across the world.

a) Management of seed phase of *Orobanche*

Orobanche species are annuals that reproduce by seed. Viability of seeds in the field also varies with *Orobanche* species and environmental conditions. Seed longevity of 12 to 13 years or up to 20 years has been reported in the literature for *O. ramosa* (Puzzilli 1983), and 3 years for *O. Cernua* (Parker and Riches 1983). A simple technique to germinate *Orobanche* in the presence of live host seedlings under controlled conditions was developed by Pathak and Kannan (2014). This seed stage of the parasite is managed by summer ploughing, soil solarisation, crop rotation, intercropping, herbicide application etc.

Cultural practices

Summer ploughing: Summer ploughing at soil depth of more than 20 cm for several years in areas of heavy infestation will reduce *Orobanche* seed bank by exposing the parasite seed to the high temperatures and bring seeds of parasite to a depth of less oxygen availability and resulting in less germination. Deep inversion ploughing after tobacco harvest is the most efficient and cheapest method of control. Trench ploughing45-50 cm deep with a mouldboard plough reduced *O.ramosa* by 80-90% in tobacco fields of Eastern Europe by burying seed to depths where it is unlikely to germinate (Habimana *et al.* 2014). Summer deep ploughing reduced the broomrape incidence upto 59.2% and also increased the yield of in *Bidi* tobacco India (Khot *et al.* 1987).

Soil solarisation: Mulching soil with transparent polyethylene sheets for 4-6 weeks during summer months kill *Orobanche* seeds in the upper soil layers by increasing soil temperature. The temperatures of 45-60°C kill *Orobanche* seeds that are in the imbibed state; therefore soil must be wet at the time of treatment. Soil solarization has eliminated *Oroobanche* and other weeds from the treated plots and black plastic much is effective in controlling *O. Cernua* in tobacco (Meti and Hosmani 1994). Solarisation for 40 days reduced the number and dry weight of broomrape shoots resulting 78% broomrape control in *Bidi* tobacco (Meti 1993). The seed germinability, which was originally 77.5%, decreased as the period of solarisation increased and was completely lost after 7 days of solarisation. The biggest limitation to this method, however, is the high cost of the polyethylene (Krishnamurthy and Raju 1993). Experiments conducted in Vertisols at ICAR-CTRI, Rajahmundry, showed that soil solarisation alone reduced 22% and with mulching it reduced 54% *Orobanche* infestation in tobacco field crop (CTRI 2019).

Crop rotations: Planting non host plants in broomrape infested field is beneficial in terms of preventing new seed production and allowing natural decline of broomrape seed bank in the soil. Rotation with trap crops can stimulate germination of broomrape seeds, but are not themselves parasitized.

Many crops and wild species have been identified in the field and laboratory as trap-crops for *O. ramosa (Phaseolus, Sinapis, Sorghum, Maize, Fenugreek*) and O. *Cernua, (Sorghum, Chickpea, Linum, Soybean, Lucerne)*. Flax, fenugreek and Egyptian clover are established to be successful trap crops for *O. crenata (*Haidar and Sidahmad 2000). Trap crops like black gram, green gram, sesame and sun hemp, when grown in broomrape infested fields, have reduced the incidence of the parasite in the succeeding tobacco (Hosmani 1985). In Nipani (Karnataka), sunhemp and green gram proved to be promising trap crops for *Orobanche cernua* control where tobacco is grown in long growing (*Kharif* and *rabi*) seasons (Dhanapal *et al.* 1996). Broomrape infestation in tobacco was significantly lower (1.75%) in succeeding maize when compared to sole tobacco (21.54%) in Vertisols (Kasturi Krishna *et al.* 2007). Trap crops, *viz.* green gram, sesame and sorghum in one year rotation reduced the incidence of *Orobanche* in succeeding tobacco by 22%, 29% and 28.67%, respectively when compared to sole tobacco rotation under Vertisols.

Inter cropping: Intercropping is already used in regions of Africa as a low-cost technology of controlling the broomrapes (Oswald *et al.* 2002). Sowing of fenugreek on both sides of FCV tobacco after establishment recorded only 3.2% *Orobanche* infestation. Trigoxazonane was identified in the root exudates of fenugreek which may be responsible for the inhibition of *O. crenata* seed germination (Evidente *et al.* 2007). Intercropping in berseem with *legumes* (broad bean and pea) reduced the intensity of *Orobanche crenata* (Fernandez-Aparicio *et al.* 2010). Though, lower percentage of infection recorded by planting marigold in between the tobacco plants, it is suppressing the tobacco crop as well (CTRI 2022).

Chemical methods

Herbicides: Different herbicides and fungicides have been tested for control of broom rape in the field but none proved effective or realistic to become a common practice especially for tobacco (Puzzilli 1983). Chlorsulfuron and imazapyr were also tested as pre-emergence herbicides to affect the *Orobanche* seed germination in FCV tobacco and showed 50% control of broom rape with significant adverse effect on tobacco yield. Pre-emergence application of alachlor and pendimethalin reduced the incidence of *Orobanche* by 46.3% and 36.0% when compared to control in FCV tobacco in Vertisols by killing the imbibed seed of the parasite (CTRI 2014-15).

Good control has been reported for MH, glyphosate, sulfosate, imazaquin and imazapyr. Use of plant hole application of neem cake at 200 kg/ha at 30 DAT and post-emergence application of imazethapyr at 30 g/ha at 55 DAT has been suggested to control *Orobanche* in tobacco under Western zone of Tamil Nadu in India (AICRPWC 2013). Application of neem cake at 25-30 days after planting reduced up to 40% incidence of *Orobanche*. It can be applied in the final field preparation in Vertisols (2.5 q/ha) or during fertiliser application in irrigated Alfisols. Punia et al. (2016) have worked on the use of herbicides in tomato and their residual effect on succeeding crops.

b) Management of parasitic phase

Seeds of the different *Orobanche* species do not germinate unless they are found in the vicinity, about 1 to 2 cm, of roots of the suitable host and under appropriate climate conditions (Temperature, moisture and light). Germination is induced in response to stimulation by a chemical released from the roots to host. Germinating *Orobanche* seeds produce a radical, referred to as “germ tube”, which can grow to a length of 3 to 4 mm. On elongation, the radical contacts of host root and attaches to it mainly in the zone of root elongation and absorption. The radical then thickens, by rapid cell division; to form the haustorium. This stage can be managed by early planting dates, fertilisation, mulching, herbicide application *etc*.

Planting date: The degree of infestation by broomrapes is closely related to the date of sowing of the host crop. Early planting reduce the parasite infestation as the crop growth will be completed by the time the parasite infests the crop there by reducing the effect on yield of the crop (Krishnamurthy *et al.* 1994). However, early planted crop *i.e*. tobacco plantings in second fortnight of October to first fortnight of November escaped the parasite competition for acquisition of host nutrients due to the early growth and utilization of nutrient by the host and noticed less damage to the tobacco crop. Delaying the planting date affects *Orobanche* more than its hosts (Habimana *et al.* 2014).

Fertilization: Nutrient status of soil has been observed to affect the infestation of broomrape and its parasitism on host plants. *Orobanche* tends to be associated with less fertile soil conditions. Nitrogen in the ammonium form is more inhibitory than nitrate and reductions in radicle length were observed when ammonium solutions were applied during either preconditioning or germination periods. For germinating seeds, exposures to ammonium sulphate of 4 to 8 h (depending on the species) reduced radicle elongation by half, indicating a relatively rapid inhibition (Westwood and Foy 1999). The activity of glutamate Synthetase is very low in broomrape and therefore carries a reduced ability to detoxify the ammonium.Nitrogen in ammonium form negatively affects broomrape germination and/or elongation of the seedling radical. In addition, manure fertilization augments the killing effect of soil solarization on *O.crenata* seeds (Haidar and Sidahmad 2000).

Mulching: Transparent poly mulch increased the temperature by 10-12-^{0}F in the soil which is not congenial for broomrape seed germination for further infestation to the host plant as low temperatures are prerequisite for its germination. *Orobanche* infestation was not recorded under white polythene mulch but under mulching sheet it was 14% and it was 21% under no mulch (CTRI, 2019). But high cost of polyethylene, appropriate machinery and cloud-free sunny days may restrict its use on larger scale (Foy *et al.* 1989).

Irrigation: Drip irrigation reduced the *Orobanche* infestation and dry weight by 70-76% and appears to be a promising cultural practice in management of *Orobanche ramose* in tobacco under Mediterranean conditions of Greece as reported by Karkanis *et al.* (2007).

Bio-control measures

Biological control is particularly attractive in suppressing root parasitic weeds in annual crops because the intimate physiological relationship with their host plants makes it difficult to apply conventional weed control measures. F. *oxysporum* f.sp. orthoceras, fungus decreased *Orobanche* infestation to tobacco by 75.23% and increased crop yield by 80.5% (Mazaheri *et al*, 1991). Pathogens can be used as sole agents or as part of a complex integrated control strategy (Sauerborn *et al.* 2007). Chandrashekharagowda *et al.* (2018) suggested that AM fungal colonization likely induces resistance to plant parasitism by reducing the exudation of strigolactones from the host roots simultaneously influencing the stimulation of physiological and biophysical attributes of tobacco. The development of fungal inoculate application through drip irrigation system developed in Bari, Italy, opens new horizons in biological control methodology (Hershenhorn *et al.* 2006). Kannan *et al.* (2014) reported natural incidence of the oligophagous fly *Phytomyza orobanchie* on *Orobanche crenata* in brinjal in the farmers' field in India. This fly has also been reported and worked for biological control of *Orobanche* in tobacco worldwide with limited success because of predator and parasites (Habimana *et al.* 2014).

c) Management of emergence and reproductive phase

During the epigeal stage the emerged tubercle above the ground elongates to produce the flowering shoot in about 4 to 5 days. The seed ripen after another 20 to 25 days. Studies of Dinesha *et al.* (2012) on biology of *O. cernua* revealed that broom rape spikes started emerging above ground from 43-58 days after transplanting, flowering was completed in 7-13 days after emergence while stem drying was completed by 26-38 days after emergence of spike and it completed its life cycle by 37-50days after emergence.

Hand weeding: It was the most common method in the past and it is still practised by small farmers where the labour is cheap. It is important that pulled plants are removed from the field and destroyed before seed matures and falls on the ground. Frequency of pulling must be every one week. Weekly pulling of tender *Orobanche* spikes before they set seed, has reduced the original stand by 85% after 2 years and by 96% after 4 years. Periodical hand pulling carried out meticulously by every grower in a large block for at least 4 years will give adequate control of this menace. An alternative to hand-pulling is the "spear "which consists of an iron blade 16 cm long, 8 cm wide and 0.5 cm thick, attached to a bamboo stick about 2 m long which is operated manually to cut unflowered broomrape shoots up to 5 cm deep or more in the soil (Krishnamurthy and Raju 1993)

Oils: Application of 2-3 drops of oil kill the bud portion of young shoots and stem portion before seed portion. Different oils, *viz.* pongamia, rice bran, soybean were tested against broom rape on tobacco and these oils killed the parasite shoots effectively (Krishnamurthy *et al.* 1994). Repeated applications on emerging shoots at an interval of 4-5 days is required for its effective control.Post emergence application of Neem oil and Soybean oil at weekly intervals reduced the incidence of *Orobanche* by 40.6% and 31.5% when compared to control. Neem cake application at 30 days and Neem oil to *Orobanche* spikes reduced the infestation of *Orobanche.*

Considerable work has been done on various aspects of Orobanche in tobacco and in other crops. In spite of the extensive studies on the parasite, its control aspect presents considerable difficulties, still eradication is extremely difficult, practically impossible, mainly because of the large number of seeds produced by a broomrape plant and the long viability of the seeds in the soil. Hence preventing the parasite from spreading to parasite-free areas is the most crucial step in broomrape management.

Phyto-sanitary measures

- Prevent the spread of seeds by restricting the movement of infested soil by farm machinery and vehicles. Clean all the tools and implements after their use in the infested fields.
- Prevent grazing on infested plant material/ *Orobanche* spikes
- Use certified crop seeds collected from non-infested fields and avoid using seeds obtained from infested fields.
- In *Orobanche* sick fields, growing specific host crops for one or two seasons is to be skipped.
- Burning of residue from infested crops can reduce carryover of broomrape seeds back to the soil.
- Prevention of erosion and water runoff from an infested farm to adjacent, non-infested farms

Integrated approach: Farmers rotating the tobacco with recommended trap crops are maintaining their fields with very meagre infestation. In general, farmers who are following crop rotation, balanced fertilization and manual removal of *Orobanche* shoots as and when it appears in the field are facing less problem of infestation. Hence, the only effective way to counteract parasitic weeds problems is to apply an integrated approach (Rubiales and Fernández-Aparicio 2012) through a combination of all possible weed control methods and tools. These include preventive, cultural; mechanical; Physical; biological; and future research and biotechnologies and chemical methods. Several feasible methods/options can be integrated to form a workable integrated weed management (IWM) module including *Orobanche* or certain problematic perennial weeds (Kumar *et al.* 2012) in a specific area or crop for a long-term basis.

Dhanapal (1996) suggest the following package to obtain higher tobacco yields and minimize the *Orobanche cernua* population in the soil for the Nipani tobacco area and areas of similar conditions. 1. Grow trap crops (sunhemp or greengram) in the early spring and incorporate in-situ at 45 days after sowing. 2. Take up general weeding within 45 days after transplanting (DAT). 3. Apply glyphosate 0.50 kg/ha (or less) at 60 DAT.4. Remove the remaining few broomrape spikes by hand or apply plant oils to prevent seed formation.

Kasturi Krishna *et al.* (2019) recommended Summer ploughing, growing sesame in *Kharif* season preceding to tobacco, neem cake 250 kg/ha application at 30 days after planting to tobacco and hand weeding as integrated measures for broomrape management in FCV tobacco under irrigated conditions.

Use of plant hole application of Neem cake at 200 kg/ha at 30 DAT and post-emergence application of Imazethapyr at 30 g/ha at 55 days after planting has been suggested to control *Orobanche* in tobacco under Western zone of Tamil Nadu in India (Chinnusamy 2012).

In highly infested fields of *Orobanche* in tobacco, integration of trap crops of sorghum and sesame, rotation for two years with hand weeding for *Orobanche* management in Vertisol grown tobacco in Andhra Pradesh (Kasturi Krishna *et al.* 2022).

Under Bihar conditions neem cake application at sowing 200 kg/ha followed by metalaxylMZ 0.2% at 20 DAP was recommended for effective management of Orobanche in tobacco (Roy *et al.* 2024)

Conclusions

Several strategies for the control of these parasitic weeds have been studied however, none of them could provide fool-proof protection against *Orobanche* infestation to the host crop. Effective broomrape control strategies should target the underground mechanisms of crop parasitism in order to meet both the short-term productivity expectations of the farmer and reduction of soil bank in the long run. Therefore, an integrated management strategy is the best perspective to control broomrapes combining various methods for control of broomrape menace in tobacco with an aim to reduce seed bank in the soil, infection to host and seed production. Different integrated measures suggested for different tobacco is by researchers and followed in the field are given.

Future research on the critical elements of long-term integrated strategy for *Orobanche* should focus on:

(a) Reducing seed bank in soil while avoiding fresh additions

(b) Identification and timely application of parasite life-cycle phase specific cultural practices and

(c) Community approach to implement integrated strategies for effective control of broomrape.

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