African Journal of Biotechnology Vol. 10(56), pp. 11802-11807, 26 September, 2011
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB11.1758

Review

Phalaris minor control, resistance development and strategies for integrated management of resistance to fenoxaprop-ethyl

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Accepted 1 September, 2011

***Phalaris minor (*Littleseed canary grass*)* is a very important and annual weed of winter cereal crops. It is a very competitive weed of wheat, oat and barley crops in Pakistan. Usually, three aryloxyphenoxypropionate herbicides, fenoxaprop-P-ethyl, diclofop-methyl and clodinafop-propargyl are used as chemical weed control against different grassy weeds like *P. minor, Avena sativa* and *Cyperus rotundus* L. This review describes fenoxaprop-ethyl, a selective chemical herbicide used to control *P. minor* in wheat crop. High production of wheat is associated with its continuous use. But this practice enhances the development of resistant biotypes of *P. minor.* Different management approaches like preference of mechanical weeding over chemical weed control, integration of competitive varietal selection, crop rotation and herbicide rotation can be long duration strategies of resistance management in *P. minor*. However, tillage method, planting time, method of herbicide application, optimum dose, higher seed rate, early sowing, bed planting, stale seed bed and zero tillage are short duration resistance management strategies. Use of water extracts of herbicidal potential (allelopathic) plants can be effective integrated management of herbicide resistant against *P. minor* in wheat and for eco-friendly and sustainable weed management.**

Key words: Control, fenoxaprop-ethyl, management, *Phalaris minor*, resistance, wheat.

INTRODUCTION

Phalaris minor is a monocot plant and graminaceous weeds. Locally, it is called Dumbi sitti, Gullidanda, Sitti, Kanki and Mandusi. It grows in *rabi* (winter) season and found in all parts of the world, especially in tropical and sub-tropical parts of the earth. It is mostly seen in wheat, barley and oat crop fields, waste and fallow lands, along roads, streets, near water channels, poultry sheds, dairy farms, residential colony parks and on sand dunes. Its infestation is common in many wheat growing areas and present in every part of the world, except Antarctica and North Pole (Singh et al., 1999). It resembles wheat plants very much until flowering stage and it is very difficult to distinguish it from wheat plant in its early growth stages (Yasin and Iqbal, 2011). Its stem is erect with distinct nodes and internodes. Branches arise from nodes and leaves are long. Ligules are exceptionally long (about 1 cm) and clasp the stem. Panicles are cylindrical erect. Each canary grass produce 200 to 500 shiny, small, black seeds which can easily be identified by its fox-tail type spike. Its panicles commence maturity at about 2 weeks before wheat harvest (Walia, 2006). Equeous extract of *P. minor* roots and tops cause twisted roots and prevent root hair development. Each plant of canary grass produces about 300 to 460 seeds which contaminate the wheat crop seed (Rammoorthy and Subbain, 2006).

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Control of P. minor by Acetyle CoA carboxylase inhibiting herbicide fenoxaprop-ethyl

Weeds are plants that compete with crops for nutrients, light, space and moisture. Weeds reduce the tillering capacity, kernel size, spike length, grain weight and harvest index of wheat (Zimdhal et al., 1980). Weeds not only lower the market value of the produce but also cause enormous economic losses to the growers (Veleva et al., 1982). There are different methods of weed control which include manual weeding, mechanical weeding, stale seed bed, intercropping and use of herbicides (Mohammad et al., 2001). Over all other weeds control methods, chemical weed control method is preferred because it is quick, more effective and relatively cheaper. Three aryloxyphenoxypropionate (APP) herbicides: fenoxaprop-P-ethyl (FEN), diclofop-methyl (DIC) and clodinafop-propargyl (CLD) are mostly recommended and used as post-emergence to control grass weeds like *Phalaris* spp. and *Avena* spp. in wheat crop (Delye et al., 2002).

Compatibility of fenoxaprop-P-ethyl with carfentrazone-ethyl was evaluated for the control *P. minor* at Chaudary Charan Singh Regional Research Station, Haryana Agricultural University, Karnal, India, during *rabi* season of 2005-06 and 2006-07. Maximum number of effective tillers and grain yield were recorded with fenoxaprop + carfentrazone 120 g ha^{-1} (5:1) during both years among all other treatments. It was shown that fenoxaprop was compatible with carfentrazone as tank mixture (Yadav et al., 2009). Jamil et al. (2009) examined eco-friendly and sustainable weeds management practices. He used herbicidal potential of sorghum: the water extract of sorghum alone and in combination with water extracts of other allelopathic plants: sesame, brassica, eucalyptus, tobacco and sunflower, against two serious weeds of wheat crop canary grass (*P. minor*) and wild oat (*Avena fatua*). The results revealed that more effect than all other combination was seen in sorghum and sunflower extracts combination at 12 L ha^{-1} and it reduced canary grass dry matter (36 to 55%) and wild oat dry matter by 42 to 62% with the highest marginal rate of return of 2824%. Inderjit and Kaushik (2009) reported that *P. minor* is a troublesome and nonnative weed, limited to the fields of wheat crop in India. They explained some agro-ecological practices that could influence establishment and survival of *P. minor*.

Although, few experiments were conducted at northwest of Syria, International Center for Agricultural Research in the Dry Areas (ICARDA) in which different herbicides on 2 and 6 rows barley were tested, the results revealed that Puma Super (fenoxaprop-p-ethlyle) was found to be phytotoxic especially at middle post-emergence against 2 and 6 row barley crop (Mona et al., 2003). Kaur and Inderjit, (2004) showed in their study entitled “Phytotoxicity of isoxaflutole to *P. minor* Retz”, that *P. minor* is a serious weed of wheat crop and it has gained resistance against different herbicides like isoproturon but when it is tested against isoxaflutole, a pre-emergence herbicide significantly reduced the shoot height of canary grass (39.6%) as compared to wheat (9.6%). Hassan et al. (2005) carried out field experiment in randomized complete block design (RCBD) with four replications during Rabi season 2003-04 at Malakandher Research Farm, NWFP University Peshawar, Pakistan. Seven herbicides treatments were used these were Affinity (carfentrazone ethyl ester), Pujing (fenoxaprop-p-ethyl), Sencor (metribuzin), WH-01 (clodinofop propargyl), Puma super (fenoxaprop-p-ethyl) Pujing + Sencor (fenoxaprop-p-ethyl + metribuzin), Puma super + Sencor (fenoxaprop-p-ethyl + metriuzin) and weedy check. Wheat variety Ghaznavi-98 was planted and its yield parameters were recorded. Plots treated with Pujing + Sencor produced maximum grain yield (1.51 t ha^{-1}) and it was recommended for the effective management of weeds in wheat. Two years farm experiments were performed to evaluate different post emergence of herbicides and their application on weeds during 2003-04 at Agronomic Research Station Bahawalpur, Pakistan. Treatments Isoproturon 500 WP at the rate of 2 kg ha^{-1} + Buctril-M at the rate of 1 lit ha^{-1} (Sprayed), puma super (fenoxaprop-P) 75 EW 1 lit ha^{-1} (Sprayed), puma super 75 EW at the rate of 1 lit + Buctril-M at the rate of 1 lit ha^{-1} (Sprayed) were applied as post emergent sprays including weedy control. All herbicides significantly decreased weed population over weedy check. Better weeds control was observed in combination of grassy and broad leaf herbicides than their separate application (Cheema and Akhtar, 2005).

In spite of all these facts, many researchers described the distribution, biology, agro-ecology and control of *P. minor.* Facts showed that the herbicides resistant biotypes of *P. minor* were epidemic in India. These biotypes caused great impact on economics, culture and social aspect of India and also opened new scientifice dimentions, trends and debates on modren agriculture (Singh et al., 1999). Hassan et al. (2006) carried out a field experiment using RCB design having three replications at Distract Karak, North West Frontier Province, Pakistan, during 2004-05 to evaluate the effect of different herbicides for controling noxious weeds in chickpea. The experiment comprised of nine herbicides and a weedy Duel gold. The herbicides used in the experiment, were Guel gold at the rate of 5.31 kg a.i ha^{-1}, Isoproturon (pre) at the rate of 4.5 kg a.i ha^{-1}, Isoproturon (post) at the rate of 4.5 kg a.i ha^{-1}, Stomp (pre) at the rate of 3.7 kg a.i ha^{-1}, Stomp (post) at the rate of 3.7 kg a.i ha^{-1}, Sencor (pre) at the rate of 2.45 ha-1 a.i ha^{-1}, Sencor (post) at the rate of 2.4.5 kg a.i ha^{-1}, Puma super at the rate of 1.87 kg a.i ha^{-1} and Topik at the rate of 0.16 kg a.i ha^{-1}. Puma super 75 EW provided best weeds control results, giving only 20.70 weeds m^{-2} as compared to 31.23 weeds m^{-2} in weedy check plots. Again, Hassan et al. (2008) initiated an experiment to find out the efficacy of different herbicides alone and in mixture to control weeds present in wheat crop. The seven treatments were Isoproturon at the rate of 4.5 kg ha^{-1}, Affinity at the rate of 4.9kg ha^{-1}, Sencor at the rate of 2.45 kg ha^{-1}, Puma super + 2,4-D at the rate of 1.875 + 2.0 kg ha^{-1}, Puma super + Buctril-M at the rate of 1.875 + 1.6 kg ha^{-1}, Topik + 2,4-

D at the rate of 0.168 + 2.0^{-1} kg ha^{-1}, Topik + Buctril –M at the rate of 0.168 + 1.6 kg ha^{-1} and weedy check. Puma super + Buctril-M had maximum weed control (2.00) weeds m^{-2} and grain yield (3194 kg ha^{-1}) as compared to minimum (20.80) weeds m^{-2} and grain yield (614 kg ha^{-1}) in weedy check plot. Ali et al. (2004) compared efficacy and economics of six herbicides: Chlodenafop (Topic), Isoproturon + Carfentrazone (Affinity), Isoproturon (Arelon), Fenoxaprop (Puma super), Metribuzin (Sencor) and Isoproturon+Diflufenicon (Panther) during 2000-2003 at Adaptive Research Farm Vehari, Pakistan on clay loam soil. Fenoxaprop and Chlodenafop had best control against *P. minor* with 86.76 and 85.52% mortality, respectively. However, maximum cost benefit ratio (4.08) was obtained with Chlodenafop. Sherawat et al. (2005) carried out a field trial to determine the efficacy of six herbicides at Adaptive Research Farm Sheikhupura, Pakistan. The herbicides Atlantus 3.6 WG at the rate of 400 g ha^{-1}, Isoproturon 50 WP at the rate of 2.0 kg ha^{-1}, Metribuzin 70 WP at the rate of 247 g ha^{-1}, Topik 15 WP at the rate of 247 g ha^{-1}, Puma super 75 EW at the rate of 1.0 l ha^{-1} and Affinity 50 WP at the rate of 2.0 kg ha^{-1} gave 100.00, 96.61, 86.84, 77.50, 77.14 and 63.26% control of *P. minor* Retz., respectively. Shahid et al. (2007) applied aqueous extract of sorghum (*Sorghum bicolor*), johnson grass (*Sorghum helepense*), eucalyptus (*Eucalyptus camaldulensis*), sunflower (*Helianthus annuus*), neem (*Azadirachta indica*) and acacia (*Acacia nilotica*) to control weeds of wheat, alone and in combination with three herbicides: Buctril M40 EC (Bromoxynil+MCPA), Puma super 75 EW (fenoxapop-p-ethyl) and Affinity 50WDG (Carfentrazone-ethyl ester) 30 and 50 days after sowing. It was shown that combination of sunflower water extract with half dose of Affinity provided better control of weeds, returns and environmental protection. Seven herbicides: clodinafop at the rate of 0.05 kg a.i ha^{-1}, 2.4-D at the rate of 0.7 kg a.i ha^{-1}, bromoxynil + MCPA at the rate of 0.49 kg a.i ha^{-1}, isoproturon at the rate of 1.0 kg a.i ha^{-1}, carfentrazone-ethyl at the rate of 0.02 kg a.i ha^{-1}, terbutryn + triasulfuron at the rate of 0.16 kg a.i ha^{-1} and fenaxaprop-p-ethyl at the rate of 0.93 kg a.i ha^{-1} and a weedy check were tested to control weeds in wheat crop at Barani Research Station, Kohat, Pakistan. All herbicides significantly reduced weed populations (Marwat et al., 2005). Ashiq et al. (2006) investigated the efficacy of two herbicides: fenaxaprop (Puma super 75 EW, Graminicide 69 EW and Brake 10 EC at the rate of 426 g a.i. ha^{-1}) and clodinafop (Topik 15 WP and Topcide 15 WP at the rate of 37.05 and 44.46 g a.i. ha^{-1}) against monocot weeds in wheat. All herbicides suppressed weeds but Topcide 15 WP proved to be best by giving 36% more grain yield over weedy check. Ranjit and Suwanketnikom (2003) performed an experiment, the treatments used were unweeded control, handweeding one, post emergence application of sulfosulfuron at the rate of 28 g a.i ha^{-1}, post emergence application of fenoxaprop-P-ethyl at the rate of 100 g a.i ha^{-1}, and rice straw mulch at the rate of 4 t ha^{-1} + sulfosulfuron at the rate of 26 g a.i ha^{-1}. Fenoxyprop-P-ethyl suppressed narrow leaf weeds. Khan et al. (2008) sprayed different post emergence herbicides to control weeds in canola crop. All herbicides together with Puma super 75 EW (fenoxaprop-p-ethy) at the rate of l 0.75 kg a.i ha^{-1} significantly reduced weeds biomass.

Recently, Yasin and Iqbal (2011) recommended fenoxaprop-p-ethyl (Puma Super-75 EW) at 45 g a.i. ha^{-1} to be very effective herbicide against *P. minor* and provided highest biological yield of 7.54 t ha^{-1} and harvest index of 55.96% in the plots treated with fenoxaprop-p-ethyl (Puma Super-75 EW) at 45 g a.i. ha^{-1} as compared to weedy check plots in wheat crop. Fenoxaprop-p-ethyl (Puma Super-75 EW) at 45 g a.i. ha^{-1} can be used for control of narrow leaved weeds in wheat under Faisalabad condition of Pakistan. Abbas et al. (2010) evaluated different post emergence herbicides on narrow leave weed (*A. fatua*) in wheat crop in an experiment conducted at Adaptive Research Farm, Karor (District Layyah), Pakistan during 2007-2008. Treatments included Topik at the rate of 300 g ha^{-1}, puma super at the rate of 625 ml ha^{-1}, Pujing at the rate of 625 ml ha^{-1} and fenoxaprop at the rate of 625 ml ha^{-1} and weedy check. Maximum grain yield (4167 kg ha^{-1}) was obtained by the Topik at the rate of 300 g ha^{-1} followed by Puma super at the rate of 625 ml ha^{-1} (4100 kg ha^{-1}). Topic and Puma super at the rate of 300 g and 625 ml ha^{-1}, respectively were recommended for the control of narrow leave weeds of wheat. Yasin et al. (2010) performed an experiment to check the effect of herbicides on narrow leaved weeds and yield of wheat. Five herbicides: clodinafop (Topic-15 WG) at the rate of 37 g a.i. ha^{-1}, clodinafop (Topaz-15 WG) at the rate of 45 g a.i. ha^{-1}, fenoxaprop-p-ethyl (Puma Super-75 EW) at the rate of 45 g a.i. ha^{-1}, fenoxaprop-p-ethyl (Gramicide-6.9 EW) at the rate of 85 g a.i. ha^{-1}, fenoxaprop-p-ethyl (Chinlima-6.9 EW) at the rate of 85 g a.i. ha-1 and a weedy check were compared. Plots treated with fenoxaprop-p-ethyl (Puma Super-75 EW) at the rate of 45 g a.i. ha-1 produced less weed biomass, more plant height, number of spike bearing tillers, number of grains per spike,1000-grain weight and grain yield (4.20 t ha^{-1}).

Resistance development in *P. minor* against Acetyle Coenzyme A Carboxylase (ACCase) inhibiting herbicide fenoxaprop-ethyl

Herbicides resistance was first reported in 1957 (Hilton, 1957). Confirmed report of herbicide resistance was reported in 1968 from U.S.A. against triazine herbicide in common groundsel (*Senecio vulgaris*) (Ryan, 1970). The continue application of same herbicide enhances the development of resistant biotypes of *P. minor.* Resistance to ACCase inhibiting herbicides like fenoxaprop-P in sprangletop (*Leptochloa chinensis)* was reported and it was concluded that after the eight time application of fenoxaprop-P on sprangletop, it became ineffective (Maneechote et al., 2005). Aryloxyphenoxypropionate herbicides inhibit the chloroplastic acetyl coenzyme A carboxylase (ACCase) action in the Poaceae family, preventing fatty acid synthesis and reducing the production of the phospholipids that are used in the membranes (Delye et al., 2002). Chlorosis, necrosis and finally the death of plant tissue occur after applying these herbicides (Ball et al., 2007).

PCR based RAPD technique were used to detect the viability at DNA level between two susceptible and two resistant biotypes of *P. minor* to isoproturon. Amplified DNA segment size ranged from 105 to 1020 base pair (bp) and mean dissimilar value for these biotypes was 0.19, while primer 20 A0 expressed maximum polymorphic value of 1.0 between susceptible and resistant biotypes (Dhawan et al., 2005). Gharakhlou et al. (2008) conducted seed bioassay and ACCase enzyme assay at Weed Science Laboratory, Ferdwosi University of Mashhad during 2005-2006 to study the resistance of *P.* minor to aryloxyphenoxy-propionate (app) inhibitors. An herbicide-resistant ACCase enzyme in the AR, MR4 and SR3 populations were found in *in-vitro* enzyme assays. The findings revealed that the mechanism of resistance to APP herbicides relates to an altered ACCase in the three most resistant populations (AR, MR4 and SR3). Uludag et al. 2(007) detected fenoxaprop resistance in sterile wild oat (*Avena sterilis*) in wheat fields in Turkey. They examined seven population of wild oat (AKR1; AKR2; DZC; GKY1; GKY3; KMP; KMT) and showed that all were resistant against fenaxaprop. These populations were also found to have cross resistant against clodinafop too. Hassan et al. (2005) conducted an experiment that consisted of 7 biotypes of wild oat during 2004 at Weed Science Research Laboratory, Department of Weed Science, North West Frontier Province, Agriculture University Peshawar, Pakistan. Treatments were Topik 15 WP (clodinafop-propargyl) and Puma super 75 EW (fenoxaprop-p-ethyl), each at 4 rates with untreated check. D.I.Khan white biothye was the only one which had tolerance against both herbicides and more dose of herbicides is required to control it. Shamsi et al. (2006) studied three poaceous weeds viz., *P. minor, A. fatua* and *Lolium temulentum*, and evaluated their control and resistance against herbicides Isoproturon, Topik (Clodinafop-p) and Puma Super (Fenoxaprop-p). Results reveal that *P. minor* had lowest mortality (only 17.7%) as compared to other two weeds and was the most resistant weed. Rastgoo et al. (2006) applied clodinafop propargyl, diclofop methyl and fenoxaprop-P-ethyl at recommended rates of 64, 900, and 75 g ai ha^{-1}, respectively on 46 wild oat populations collected from seven different sites of provinces Ahvaz, Andimeshk, Shush, Shushtar, Ramhormoz, Susangerd (Dashte Azadegan) and Dezful in Iran, to check herbicide resistance against these populations. Results reveal that wild oat seed populations collected from Khuzestan Wheat Fields showed resistance to these herbicides. Rolston et al. (2003) undertoke a field experiment to evaluate the grassy weeds, espacially *P. minor* tolerence to herbicide in creals (wheat and barley). Eleven cultivars were evaluated and results revealed that good tolerence were found in all cultivars.

Recently, Gherekhloo et al. (2011) confirmed resistance to aryloxyphenoxypropionate herbicides in *P. minor* populations in Iran. Thirty-four *P. minor* populations with suspected resistance were tested against Diclofop-methyl, fenoxaprop-P-ethyl, and clodinafop-propargyl. Fourteen populations were found to be resistant to fenoxaprop-P-ethyl and enzyme assay confirmed the existence of modified ACCase in these populations.

Strategies for integrated management of resistance to fenoxaprop-p-ethyl

Chhokar and Malik, (2002) performed pot, laboratory and field experiments in India to quantify different levels of isopro-turon resistance in littleseed canary grass to alternate herbicides. Based upon their experiments results, it was recommended that the growers should follow herbicide and crop rotation if they want to avoid herbicides resistance in near future and prefer mechanical weed control for long term strategy for resistance management. Singh (2007) showed that in Indo-Gangetic Plains of Pakistan, India, Nepal and Bangladesh, the *P. minor* (canarygrass) is a major weed of winter-season crops and it showed resistance against photosystem II–inhibiting herbicide isoproturon and other herbicides like clodinafop, fenoxaprop-P and sulfosulfuron. It was due to resistance mechanism metabolic degradation, mediated by P-450 monooxygenase enzymes, continuous use of these herbicides in monoculture rice–wheat-cropping systems, inexpensive and their broad-spectrum weeds control characteristics. Author agreed that herbicides sequences, rotations and mixtures are useful against weeds control, but only for short duration of time. An integration of varietal selection, crop rotation, tillage method, planting time, method of herbicide application and its optimum dose are very important in managing herbicide-resistant in canarygrass. Chhokar et al. (2008) investigated herbicide resistance in littleseed canarygrass *P. minor*. He found that *P. minor* has developed multiple resistances to 3 modes of action (photosynthesis at photosystem II site A, ALS inhibitor and ACCase). He suggested the use of weed free crop seeds, weed free manures, herbicides rotation and crop rotation as long term strategies and agronomic tactics like competitive variety, higher seed rate, early sowing, stale seed bed, zero tillage, etc. for short term measures towards effective integrated management of herbicide resistant against *P. minor* in wheat. Chhokar et al. (2008) showed that to obtain better control against *P. minor,* herbicide resistance zero tillage, early sowing, bed planting technique, crop rotation, herbicide rotation, use of competitive variety, stale seed bed technique and higher seed rate are suggested.

CONCLUSION

Fenoxaprop-ethyl is an excellent herbicide to control grassy weeds and especially against *P. minor*. But it continuous use develop resistance biotypes of *P. minor*. We can assess herbicide resistance in canary grass by visual diagnosis, bioassay, plant assay, dose response experiment, single dose resistance assay and specific discrete test. Different types of herbicides resistance management practices can be adopted like herbicide rotation with different target sites, crop rotation, integrated cultural practices and use of herbicides resistant crops to impede the resistance evolution. The spray of short residual herbicides also reduces selection pressure for herbicide resistance.

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