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Role of allelopathic crop mulches and reduced doses of tank-mixed herbicides in managing herbicide-resistant *Phalaris minor* in wheat

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ABSTRACT

Widespread resistance in *Phalaris minor* is a major challenge for sustainable wheat production. Recently, multiple resistance and cross resistance in this weed increased the concerns of wheat growers. The use of potential integrated resistance management strategies including allelopathic crop mulches and herbicide mixtures is crucial in assuring sustainable production. A two-year field trial was conducted during 2014–15 and 2015–16 in wheat to evaluate the efficacy of allelopathic mulches of sunflower, rice, maize, and sorghum alone and in combination with three types of herbicide mixtures. Post-emergence herbicide mixtures used in this study were clodinafop –propargyl plus metribuzin, sulfosulfuron plus clodinafop-propargyl, and pinoxaden plus sulfosulfuron at 50% of recommended doses. Integrated use of allelopathic crop mulches and herbicide mixtures provided effective control of *P. minor* in wheat. However, application of allelopathic mulches and herbicide mixtures alone did not provide a satisfactory control of *P. minor*. In addition, the application of allelopathic mulches caused a significant decay (23–52%) of soil weed seed bank. The integrated use of mulches and herbicide mixtures consistently enhanced the wheat yield by 23–39% and 24–35% during 2014–15 and 2015–16, respectively. These findings, as the first indication of the potential integration of allelopathic mulches and post-emergence herbicide mixtures to manage *P. minor* in wheat fields, would help control resistant *P. minor* and delay further herbicide resistance in this weed.

1. Introduction

Widespread herbicide resistance in *Phalaris minor* Retz., the most troublesome weed in the top wheat producing countries, is a major challenge for sustainable wheat production (Travlos, 2012; Heap, 2016). Recently, herbicide resistant *P. minor* has been reported in all major cropping systems of Punjab, Pakistan (Abbas et al., 2017a). The repeated use of herbicides with the same mode of action (MOA) is the largest contributing factor in the fast evolution of herbicide resistance (Beckie, 2006; Norsworthy et al., 2012). Controlling weeds in the field using herbicides with different MOAs in rotations, mixtures, and sequential applications can avoid and delay the development of herbicide resistance (Norsworthy et al., 2012). To manage and delay resistance development, combinations of herbicides must have different MOAs. Reducing the herbicide selection pressure is key to delay resistance (Beckie, 2006; Norsworthy et al., 2012). Herbicide rotations with different MOAs are beneficial to delay resistance, but not effective, because they include a single MOA at a time (Wrubel and Gressel, 1994) which allows resistant plants to survive, obtain more resistance through gene flow, and produce seeds before the next herbicide application (Powles et al., 1997; Beckie and Reboud, 2009). Therefore, annual herbicide rotations and sequential applications with different herbicide MOAs may cause multiple resistance long term. However, application of herbicide mixtures with different MOAs on multiple selection pressures simultaneously would theoretically allow rare individuals to survive that already had evolved multiple resistance to the MOAs used in mixtures (Diggle et al., 2003; Beckie and Reboud, 2009; Abbas et al., 2016a). For

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example, Wrubel and Gressel (1994) reported that mixtures of triazine and chloroacetamide herbicides were effective to prevent resistance for a 20-year duration in *Chenopodium album* L. and *amaranthus* species, while application of herbicides alone caused widespread resistance in the weed species.

To maximize benefits, the mixtures should have herbicides with different MOAs and similar efficacy against the target weed. Preferably, the mixtures would have similar persistence and different degradation mechanisms (Powles et al., 1997; Wrubel and Gressel, 1994). Some herbicide mixtures act synergistically; the combine effect of herbicides in mixtures is greater than the individual effect of each herbicide (Woodyard et al., 2009). Such types of mixtures may be used at lower doses than the field rate of each herbicide to achieve effective weed control. Higher cost and crop phytotoxicity are two major constraints in the use of herbicide mixtures. The dose of herbicide mixtures can be lowered by integrating herbicide mixtures with other non-chemical weed control methods like allelopathic crop mulches (Jabran et al., 2010b).

The use of herbicides in conventional agriculture is not only insecure due to the rapid increase in herbicide resistance, but they are also dangerous to health and destructive to the environment. Allelopathic applications, such as straw mulching, provide sustainable weed management (Jabran et al., 2015). Mulches inhibit weeds in several ways as they reduce light interception, alter soil temperature, physically hinder emergence (Bond and Grundy, 2001), and through the release of phytotoxic chemicals (allelopathy). Allelopathic mulches increased the weed control efficacy by releasing phytotoxic chemicals. Phytotoxins released by mulches act as natural herbicides and offer environmentally safe alternatives to chemical herbicides because they are decomposable, rarely contain halogenated atoms and are safe for the environment (Duke et al., 2000; Petroski and Stanley, 2009). Inhibition of *P. minor* due to allelopathic mulches has been reported in previous findings (Batish et al., 2007). Moreover, straw mulch can improve the soil organic matter content and increase soil fertility. Cheema et al. (2000) reported that sorghum mulch can be successfully used to control weeds in cotton, with 97% reduction in weed dry weight.

In previous studies, allelopathy was used for weed management in several crops including wheat (Cheema and Khaliq, 2000). Several potential allelopathic crops including sorghum (*Sorghum bicolor* L.), sunflower (*Helianthus annuus* L.), rice (*Oryza sativa* L.), and maize (*Zea mays* L.) have been used for weed management (Cheema et al., 2009; Jamil et al., 2009; Jabran et al., 2010a). These crops contain allelochemicals that act as natural herbicides to control various weed species (Kato-Noguchi, 2000; Ahn et al., 2005). However, information pertaining to weed control efficacy of allelopathic crop mulches to manage *P. minor* in wheat is lacking. First author and farmer observations revealed that wheat crop grown after sorghum, sunflower, and maize showed less infestation of *P. minor*. It may be due to the exposure of *P. minor* seeds in the soil seed bank to the allelochemicals released by the roots and stubbles of these crops in the cropping system. Targeting soil weed seed bank is a major component of sustainable and effective weed management (Hossain and Begum, 2015). In the scenario of widespread resistance in *P. minor* (Heap, 2016; Abbas et al., 2016b), allelopathy may offer a sustainable alternative to manage herbicide resistance (Duke et al., 2000; Vyvyan, 2002).

Integrating allelopathic crop mulches with reduced doses of herbicide mixtures may provide an effective control of resistant *P. minor* in wheat (Jabran et al., 2010b). Furthermore, it will reduce the cost and phytotoxic effect of herbicide mixtures which are the two major constraints in using herbicide mixtures at recommended doses of herbicides. Integration of allelopathy and chemical weed control helped reduce herbicide doses without reducing weed control efficacy (Jabran et al., 2010b; Iqbal et al., 2009; Shah et al., 2013). It was hypothesized that allelopathic crop mulches in combination with reduced doses of herbicide mixtures can be used to manage and delay resistance in *P. minor* without reducing the weed control efficacy. Therefore, a two-year field study was conducted to evaluate the integrated effect of four allelopathic crop mulches and reduced doses of three types of herbicide mixtures on *P. minor* and wheat yield. In addition, the potential role of allelopathic mulches in decaying *P. minor* soil seedbank was also studied.

2. Material and methods

To assess the effect of allelopathic crop mulches and herbicide mixtures alone and in combination with *P. minor* in wheat crop, a field study was conducted at Agronomic Research Area, University of Agriculture (UAF), Faisalabad, Pakistan, for two consecutive years (2014–15 and 2015–16). The allelopathic crops used in this study were maize, rice, sorghum, and sunflower. Three types of herbicide mixtures were used including clodinafop-propargyl plus metribuzin, sulfosulfuron plus clodinafop-propargyl and pinoxaden plus sulfosulfuron at 50% of recommended doses. Recommended doses of clodinafop-propargyl (55 g a.i. ha^{-1}), metribuzin (425 g a.i. ha^{-1}), sulfosulfuron (50 g a.i. ha^{-1}) and pinoxaden (45 g a.i. ha^{-1}) were considered as 100% dose. Wheat fields were exposed to treatments including mulches alone, herbicide mixtures alone, and their combinations (Table 1). A randomized complete block design with three replicates was used. The soil textural class of the field was clay-loam with a slightly alkaline reaction (pH 8.5) and organic matter of 0.71%. Total nitrogen, available phosphorus, and available potassium contents were 0.44%, 5.12 ppm, and 127 ppm, respectively. Each plot size was 6 m × 2.5 m having 11 rows of wheat sown at 22.5 cm row spacing. Wheat (cv. Glaxy-2013) was sown in the third week of November with a manual drill using a seed rate of 125 kg ha^{-1}. All other recommended agronomic practices were kept constant for all plots. Naturally occurring broad-leaved weeds were controlled by using bromoxynil plus MCPA at 490 g a.i. ha^{-1}. Treatments were applied at the 4 or 5-leaf stage of *P. minor*. The herbicide mixtures were sprayed with a knapsack hand sprayer using a T-Jet nozzle at a pressure of 207 kPa. During both years, metrological data regarding temperature and rainfall was obtained from AgroMet Observatory, Department of Crop Physiology, UAF (Fig. 1).

Phalaris minor mortality percent was taken after 21 days of treatment application while dry biomass (g m^{-2}), the number of

Table 1
Mulches and herbicide mixtures treatments used during 2014–15 and 2015–16.

Treatment	Mulches (8 t ha^{-1})	Herbicide mixtures (50% of recommended)
H_1	Weedy check	
H_2	Sunflower	–
H_3	Rice	–
H_4	Maize	–
H_5	Sorghum	–
H_6	No mulch	Clodinafop –propargyl + metribuzin
H_7	Sunflower	Clodinafop –propargyl + metribuzin
H_8	Rice	Clodinafop –propargyl + metribuzin
H_9	Maize	Clodinafop –propargyl + metribuzin
H_{10}	Sorghum	Clodinafop –propargyl + metribuzin
H_{11}	No mulch	Sulfosulfuron + clodinafop –propargyl
H_{12}	Sunflower	Sulfosulfuron + clodinafop –propargyl
H_{13}	Rice	Sulfosulfuron + clodinafop –propargyl
H_{14}	Maize	Sulfosulfuron + clodinafop –propargyl
H_{15}	Sorghum	Sulfosulfuron + clodinafop –propargyl
H_{16}	No mulch	Pinoxaden + sulfosulfuron
H_{17}	Sunflower	Pinoxaden + sulfosulfuron
H_{18}	Rice	Pinoxaden + sulfosulfuron
H_{19}	Maize	Pinoxaden + sulfosulfuron
H_{20}	Sorghum	Pinoxaden + sulfosulfuron
H_{21}	Weed-free	

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