Chapter 2
Wheat Allelopathy for Weed Control

Abstract Wheat (*Triticum aestivum* L.) is among the most important crops of the world and provides food, feed, and several by-products. Other than this, wheat is among the crops that express a strong allelopathic activity. Benzoxazinoids and phenolic compounds are the most important allelochemicals reported in wheat. Allelopathic cultivars of wheat may be grown to suppress weeds in the wheat crop. Allelopathic mulch of wheat can be applied for suppressing weeds both in wheat and other field crops. Several cultivars of wheat with an allelopathic potential have been reported from various countries of the world. Research work conducted to improve the allelopathic potential of wheat has been insufficient. Future research should focus on improving the allelopathic potential of wheat cultivars through conventional and molecular breeding as well as biotechnology.

Keywords Wheat • Allelopathy • Allelochemicals • Phenolic compounds • Benzoxazinoids • Cultivars • Mulch • Weed control

2.1 Introduction

Wheat (*Triticum aestivum* L.) crop is deeply rooted in human culture and civilization. It plays a great role in the global economy and food security. Wheat falls among the three major cereals of the world (two others are rice and maize) that produce the highest quantities of edible grains. Wheat grains provide proteins (~12%), carbohydrates, and several of minerals and vitamins. Flour of wheat is made into breads, while diverse kind of breads are made from wheat flour around the world. Wheat straw is either fed to animal or incorporated as organic manure in the soil, and even used to manufacture several by-products.

Wheat was most probably originated from the Karacadag Mountains located near the Diyarbakar city of Turkey. More than 1000 year old remains of wheat grain have also been found in some old sites that are in Syria and Iraq located near the border of Turkey (i.e., near to Karacadag Mountains). Current global area and grain production of wheat is nearly 222 m ha and 729 m tons, respectively (FAO 2014). More than 40 and 30% of this production comes from Asia and Europe, respectively, while Americas and Africa produce almost 18 and 3% of the total wheat grains in the world (FAO 2014).

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There are a number of social, edaphic, biological, and climatic constraints that hinder the wheat productivity. Weeds are among the most important biological constraint, limiting wheat productivity. Wheat is infested by a high number of weeds; however, most important of these may include: *Avena fatua* L., *Phalaris minor* Retz., *Bromus* species, *Lolium* species, *Cirsium arvense* (L.) Scop., *Veronica* species, *Capsella bursa-pastoris* (L.) Medik., *Lamium* species, *Chenopodium album* L., *Galium* species, etc. The likely grain yield decrease in wheat caused by weeds may have a range of 18–29% (Oerke 2006). Other than causing yield losses, weeds also cause hindrances in agronomic management of wheat and increase its cost of production. Hence, effective weed control is required in order to achieve an optimum and sustainable grain production of wheat. Although cultural practices are also used occasionally, the use of herbicides has been a major method of controlling weeds in wheat. However, during recent times, factors such as herbicide resistance evolution in weeds and environmental pollution caused by herbicides stress the need for weed control methods other than herbicides. Further, there is a demand by organic growers for weed suppressive cultivars. Hence, the phenomenon of allelopathy that can be manipulated to suppress weeds without herbicide application becomes important for weed control in wheat. Wheat plants usually possess a strong allelopathic potential and several allelochemicals have been reported in wheat plants. These are mainly benzoxazinoids and phenolic compounds. Importantly, the allelopathic activity of wheat can be channelized to achieve an environment-friendly weed control (Wu et al. 2003). Hence, the objectives of this chapter are to discuss the wheat as a potential allelopathic crop and the allelochemicals that have been reported in wheat in different regions of the world. The other important aim of this chapter is to discuss the role of wheat for controlling weeds either in wheat (e.g., by growing wheat cultivars with an allelopathic potential) or both in wheat and other crops (e.g., through application allelopathic mulches from wheat residues).

2.2 Wheat Allelopathy and Allelochemicals

Wheat is among the crops that possess a strong allelopathic activity against other plants (Macías et al. 2005). Lodhi et al. (1987) elaborated the presence of phenolic compounds in wheat (see Table 2.1) and the phytotoxic effects of wheat extracts (obtained from soil under wheat cropping or wheat mulch) on germination and growth of radish, cotton, and *Triticum vulgare* Vill. A study from Canada evaluated the allelopathic activity of winter wheat by either applying the wheat straw over soil surface or mixing it in the soil (Opoku et al. 1997). The control treatment was not applied with wheat straw. Highest quantities of total phenolics were noted in soil that was applied with wheat straw (Opoku et al. 1997). Similarly, autotoxicity of the allelopathic wheat cultivars has also been reported from Australia (Wu et al. 2007). The aerial parts of wheat have been found to possess the highest allelopathic activity followed by whole plant (i.e., roots + shoots) and roots, respectively (Zuo et al. 2005). According to Mathiassen et al. (2006), hydroxamic acids were among the

Table 2.1 Allelochemicals reported in wheat from various parts of the world

Allelochemicals	Region	References
Vanillic acid, ferulic acid, *p*-hydroxybenzoic acid, *p*-coumaric acid, syringic acid	Pakistan	Lodhi et al. (1987)
p-Coumaric acid	USA	Blum et al. (1991)
MBOA	USA	Blum et al. (1992)
Vanillic acid, *o*-coumaric acid, scopoletin	Iran	Baghestani et al. (1999)
Syringic acid, *trans*-ferulic acid, *p*-hydroxybenzoic acid, *cis*-*p*-coumaric acid, *cis*-ferulic acid, *trans*-*p*-coumaric acid, vanillic acid	Australia	Wu et al. (2000a)
DIMBOA, *p*-hydroxybenzoic acid, *cis*-ferulic acid, vanillic acid, *cis*-*p*-coumaric acid, *trans*-ferulic acid, syringic acid, *trans*-*p*-coumaric acid	Australia	Wu et al. (2000b)
2,4-Dihydroxy-1,4-benzoxazin-3-one (DIBOA), DIMBOA	Germany	Belz and Hurle (2005)
Syringoylglycerol 9-*O*-*β*-D-glucopyranoside, L-tryptophan	Japan	Nakano et al. (2006)
Ferulic acid, L-tryptophan	Japan	Nakano (2007)
DIMBOA, MBOA	China	Lu et al. (2012)
DIMBOA	China	Zhang et al. (2016)
MBOA, HMBOA, HBOA	Denmark	Krogh et al. (2006)
DIBOA, BOA, 2-aminophenoxazin-3-one (APO)	Spain	Macías et al. (2005)

important allelochemicals present in wheat plants. These included: 2,4-dihydroxy-7-methoxy-1,4-benzoxazin-3-one (DIMBOA), 6-methoxy-2-benzoxazolinone (MBOA), and benzoxazolin-2-one (BOA). Krogh et al. (2006) reported that MBOA were the major allelochemicals found in wheat leachates, while 6-methoxybenzoxazolin-2-one (HMBOA) and 2-hydroxy-1,4-benzoxazin-3-one (HBOA) being the other allelochemicals noted in comparatively less concentrations.

Allelopathic potential of wheat can contribute to weed management in different cropping systems (Wu et al. 2003). For example, in a study from Canada, the germination of weeds (*Setaria viridis* (L.) P. Beauv. and *Amaranthus retroflexus* L.) was decreased significantly through application of allelopathic extracts from wheat plants (Flood and Entz 2009). In another study, *Lolium rigidum* Gaudin received a significantly negative impact on its growth (particularly the root growth, including the root surface area and its length) from allelopathic wheat plants (Li et al. 2011). In a study from India, the wheat straw was found phytotoxic against *Lolium perenne* L. (Al Hamdi et al. 2001). Two allelochemicals (i.e., syringoylglycerol 9-*O*-β-D-glucopyranoside and L-tryptophan) and an ~80% reduction in the roots growth of lettuce and garden cress were noted by Nakano et al. (2006). Importantly, the recent research indicates that a positive feedback exists between the soil microbial communities and the allelopathic activity of wheat (Zuo et al. 2014).

2.3 Allelopathic Wheat Cultivars for Weed Control

Growing allelopathic wheat cultivars can help to achieve eco-friendly weed control (Jabran et al. 2015). This is particularly important for the organic growers, who demand for wheat cultivars with a potential to suppress weeds. Other than weed control, allelopathic wheat cultivars have also been used to suppress wheat diseases (Schalchli et al. 2012). There have been efforts to evaluate and improve the allelopathic potential of wheat germplasm (Bertholdsson 2005, 2010; Wu et al. 2000d). More than 200 recombinant inbred lines were produced through a cross of wheat genotypes including 22 Xiaoyan and 92517-25-1 (Zuo et al. 2012). Multiple genes were found to control the allelopathic potential of wheat genotypes, while chromosome 1A and 2B were containing the 75% and 25% genes of allelopathy, respectively (Zuo et al. 2012).

Considerable research work has been conducted in order to evaluate the allelopathic activity of existing wheat germplasm. Moreover, there have been efforts to improve the allelopathic potential of wheat through breeding and molecular genetics. According to Zuo et al. (2007), allelopathic potential of wheat possesses a high level of heritability and a linear relation with production traits. Wheat cultivars with low (Swedish origin) and high (Tunisian origin) allelopathic potential were crossed; an increase of 20% was noted in the allelopathic activity of three lines (F6 and F7 generations), with a subsequent 19% decrease in weed biomass (Bertholdsson 2010). Out of 813 wheat cultivars in Sweden, several expressed an inhibitory activity to *L. perenne* (Bertholdsson 2010).

In a study from Iran, out of nine popular wheat cultivars, cultivar Azar2 expressed the highest allelopathic activity against *Secale cereale* L. (Mardani et al. 2014). Among the 11 wheat cultivars in India, most allelopathic against *P. minor* were WH533 and WH542 that caused 30 and 21% decrease in germination of this weed (Om et al. 2002). Similarly, among the ten wheat genotypes in Pakistan, Shafaq-06 expressed the highest allelopathic activity against *P. minor* (Kashif et al. 2015). This was the result of highest total phenolics production in Shafaq-06 compared with other wheat genotypes in the study (Table 2.2). Interestingly, the production of phenolic compound in all the genotypes in the experiment was increased when *P. minor* was present in the surroundings (Kashif et al. 2015). The research work of Lu et al. (2012) follows a similar pattern where proximity of two weeds (*Descurainia sophia* (L.) Webb ex Prantl and *A. fatua*) increased the synthesis of allelochemicals (DIMBOA and MBOA) in wheat seedlings. Weed infestation (with weeds such as *Digitaria sanguinalis* (L.) Scop. and *A. retroflexus*) was found to increase the production of allelochemicals (DIMBOA) in wheat (Zheng et al. 2010).

More than 450 wheat genotypes obtained from different parts of the world (50 countries) were evaluated for their allelopathic activity again *L. rigidum* (Wu et al. 2000c). A great variability (10–91% inhibition of a weed species) was noted in the allelopathic potential of these cultivars. There were more than 60 wheat genotypes that had a high allelopathic potential; these genotypes decreased the root growth of

Table 2.2 Wheat cultivars/genotypes with allelopathic properties reported from different regions of the world

Wheat cultivars/genotypes	Weed/test species	Country	References
Tasman, Triller, Wilgoyne, Meering, 3-J 27, Nabawa, Sunstar, 3-J 67, CH 31, AUS#375	*L. rigidum*	Australia	Wu et al. (2000c)
Karcagi 21	*L. rigidum*	Hungary	Wu et al. (2000c)
Castaño, Oracle, Tukan	*L. rigidum*	Chile	Bensch et al. (2009)
Shafaq-06	*P. minor*	Pakistan	Kashif et al. (2015)
Lumai168, Nongda211, Duokang1	*A. fatua*, *D. sophia*	China	Lu et al. (2012)
Azar2	*S. cereale*	Iran	Mardani et al. (2014)
WH533, WH542	*P. minor*	India	Om et al. (2002)
22 Xiaoyan, 6 Lankao	*L. rigidum*	China	Zuo et al. (2007)
Yecora Rojo	Lettuce	USA	Schuerger and Laible (1994)
22 Xiaoyan, No 131 Chanowu	Potato	China	Zuo et al. (2008)
Stakado	–	Denmark	Krogh et al. (2006)
Triller, Currawong	Wheat (autotoxicity)	Australia	Wu et al. (2007)
Ritmo, Astron	–	Spain	Macías et al. (2005)

L. rigidum by >81% (Wu et al. 2000c). It was observed that multiple genes were involved in the expression of allelopathic potential of wheat genotypes. The wheat genotypes from countries such as Hungary, Peru, Germany, Bangladesh, etc. were those with a highest allelopathic potential (Wu et al. 2000c). In another study, Wu et al. (2000d) evaluated the allelopathic potential of 92 wheat genotypes against *L. rigidum*. The experiment was designed to avoid the effects of microorganisms and crop competition in order to ensure that weed inhibition was purely due to allelopathic effects of wheat cultivars. A significant difference was noted among the weed suppressive ability (24–99%) of wheat cultivars through their allelopathic activity, while 22 genotypes were consistent (over the years) for expressing an allelopathic activity against *L. rigidum* (Wu et al. 2000d). Further, Wu et al. (2000a, b) reported DIMBOA and seven phenolic acids from 58 wheat genotypes; these allelochemicals were usually having a higher concentration in wheat roots than shoots. Moreover, wheat genotypes with higher concentration of allelochemicals in roots were having a high allelopathic activity against *L. rigidum* (Wu et al. 2000a, b). Further, this research showed that root exudation was the major way of allelochemicals' secretion from wheat seedlings, while wheat plants could retain allelochemicals once synthesized in the plant body (Wu et al. 2000b).

2.4 Allelopathic Wheat Mulch for Weed Control

Residues or straw of wheat with allelopathic properties can be used for controlling weeds in wheat or even the other field crops (Farooq et al. 2011a, b; Jabran and Farooq 2013). In addition to allelopathic suppression, some physical suppression of weeds may also be achieved if the allelopathic residues are utilized for managing weeds (Li et al. 2005). The allelopathic residues from wheat plants caused a ~70–85% reduction in the fresh weight of a wheat weed *Aegilops cylindrica* Host (Anderson 1993). *Digitaria ciliaris* (Retz.) Koeler, an important maize weed in China, was suppressed significantly (a 78–96% decrease in weed density and biomass) through residues application from wheat (0.75 kg/m^2) (Li et al. 2005). The authors concluded that this weed suppression was the result of both the allelopathy and physical effects of wheat straw (Li et al. 2005).

T. portulacastrum is an important weed that severely infests several of summer crops. Recently, this weed has also been noted in some spring or autumn crops. Allelopathy has provided some promising results regarding control of this weed. For example, allelopathic wheat straw mulch (4–8 g/kg of soil) helped to decrease the germination, chlorophyll and soluble protein contents, biomass, seedling growth, leaf area, leaf number, and root growth of this weed over control (Khaliq et al. 2011). In summary, the residues from wheat possessing an allelopathic activity may be applied to control weeds in various agricultural systems.

2.5 Conclusions

Wheat possesses an inevitable role in global food security. Weeds are among the most important causes of yield decline in wheat. ‘Growing of wheat cultivars with an allelopathic activity’ may be used as a method of cultural weed control in wheat crop. This can provide environment-friendly weed suppression and requires no extra inputs or expenditures. The other way is to apply the allelopathic residues from wheat as a mulch for controlling weed in wheat as well as other crops. The future research may include improving the allelopathic potential of wheat germplasm through conventional and modern breeding tools as well as converting the allelopathic residues of wheat into a portable weed control product.

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