REVIEW

Review of research on weed management of chickpea in Iran: challenges, strategies and perspectives

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Abstract

Weeds are one of the most important limiting factors in the production of chickpea (*Cicer arietinum*) in Iran, especially in autumn sown chickpea. Weed density and biomass in autumn chickpea are seven and two and a half times higher than the spring chickpea, respectively. The weed damage to chickpea in Tabriz, Kermanshah and West Azerbaijan was estimated at 48.3, 57 and 36%, respectively. Sixty-four weed species were identified in chickpea fields. *Convolvulus arvensis* L. and *Galium tricornutum* Dandy have the highest presence in chickpea fields. Pyridate and linuron are the only herbicides registered for use in chickpea fields in Iran. However, research results show that fomesafen and isoxaflutole are the most appropriate herbicides for chickpea fields. Oxyfluorfen, imazethapyr, metribuzin, trifluralin, simazine, terbutryn and pendimethalin are the major herbicides studied in weed control research. The combination of herbicides and mechanical control is one of the effective methods to reduce weeds. Hand weeding and cultivation between rows are the most effective mechanical methods of weed control. High nitrogen enhances weed dry weight. Safflower and barley residues reduce weed populations and biomass. Barley-chickpea and wheat-chickpea intercropping systems increase chickpea yield together with proper weed control. In future research, more attention should be paid to surfactants to reduce the use of herbicides, rotation crops and integrated weed management in chickpea.

Keywords: herbicide, intercropping system, mechanical management, weed flora

Introduction

Chickpea (*Cicer arietinum* L.) is suitable for rotation with wheat, and the highest wheat grain yield has been observed in wheat-chickpea rotation (Parpinchi *et al.* 2013). Iran is the fourth largest chickpea producer in the world after India, Turkey and Pakistan (Upadhyaya 2007). Worldwide the average grain yield of chickpea is 965.1 kg · ha^{-1}. In Asia, it is 919.7 kg · ha^{-1} and in Iran it is 443.2 kg · ha^{-1} (FAOSTAT 2018). To a large extent part of the fluctuations in the production of this product is due to competition with weeds and non-principled management (Williams and West 2000). Chickpea has hardly any ability to compete with weeds due to its relatively slow growth in the early growing season. Weeds affect not only chickpea yield, but also make mechanized harvesting difficult (Karimi Torki *et al.* 2012). One of the main reasons for the low yield of rain-fed chickpea in the Zagros region of Iran is weed interference (Ahmadi *et al.* 2013). Increasing the period of weed interference with chickpea reduces seedling dry weight (Mohammadi *et al.* 2005). Obviously, achieving the highest chickpea production and easy harvesting requires careful attention to weed interference and the use of appropriate management methods to remove or reduce the interference (Plancqaert *et al.*

1990; Mousavi *et al*. 2007). Chickpea yield reduction has been reported to be up to 90% due to the presence of weeds (Knott and Halila 1988) and in some cases up to 94% (Knights 1991; Saxena *et al*. 1996). In Iran, this damage has been reported in Tabriz, Kermanshah, and West Azerbaijan (48.3, 57, and 36%, respectively) (Ahmadi *et al*. 1997; Mohammadi *et al.* 2005; Jalilian and Heydarzadeh 2017). During chickpea cultivation in spring, plowing before planting controls a lot of weeds. However, reduced rainfall during spring in recent years has increased the tendency of autumn and winter crops to use the rainfall in these seasons. Farmers, on the other hand, are less interested in this type of farming system because of the high weed population. One of the major problems in chickpea is how to employ different strategies for managing weeds in autumn and winter sown chickpea. The mean weed density in autumn chickpea cultivars has been estimated to be three times higher than the winter variety and more than seven times higher than the spring type. The biomass of the autumn crop was more than two and a half times greater than winter and spring crops (Mousavi *et al.* 2007). In autumn sown chickpea, different scenarios of integrated weed management (mechanical, chemical and farming practices) are currently being investigated in Iran.

Weed flora

Structure of the weed population includes life cycle, species diversity, species composition, dominance and stability against the weeds' environmental, temporal and spatial changes. The difference in weed population structure is due to differences in weed management (Poggio *et al*. 2004). Of various agricultural inputs, the use of herbicides is the most important factor in a crop system that affects the weed population (Andreasen *et al.* 1996).

Information about models of weed distribution in an area can help with the choice of the best weed management method, reduce the rate of herbicides in agricultural ecosystems and increase their efficiency (Amini *et al.* 2015). During weed management, the composition of the weed population should be shifted to the least invasive species that can easily be controlled (Liebman 2001). The effect of herbicides on certain weeds may lead to the dominance of other weed species. For instance, imazethapyr, with the control of *Solanum nigrum* L. (SOLNI) increases *Chenopodium album* L. (CHEAL) (Abbassian *et al.* 2016). On the other hand, the composition of the weed flora in the crop system changes due to seasonal changes, crop rotation, and long-term environmental changes such as soil erosion and climate changes (Amini *et al*. 2015). The grassy weeds of chickpea fields are usually seen in winter, and these grasses are often referred to as C_3 plants.

In Kurdistan, *Galium tricornutum* Dandy (GALTR) and *Torilis arvensis* (Huds.) link (TORAR) are frequent in the autumn crop. TORAR and *Geranium molle* L. (GERMO) are frequent in winter, while *Convolvulus arvensis* L. (CONAR) is frequent in spring (Fathi *et al*. 2016). *Carthamus oxyacantha* M.B. (CAROX), GALTR, *Vaccaria pyramidata* Medik. (VACPY) and CONAR are the most dominant weed species of the autumn chickpea crop in Lorestan. In another study, the mean weed densities in spring, autumn and winter chickpea crops have been calculated at 25.8, 18.8 and 13.5 plant · m^{-2}, respectively (Mousavi *et al*. 2007).

CONAR and *Glycyrrhiza glabra* L. (GLYGL) are the most important permanent weeds in the chickpea fields of Kermanshah Province (Chalechale *et al.* 2014) (Table 1). The problematic broadleaved species in chickpea mainly belong to families such as Brassicaceae, Asteraceae, Chenopodiaceae, Fabaceae, and Polygonaceae (Bhan and Kukula 1987). *Hordeum vulgari* L. (HORVU) is the main weed of autumn crops in Lorestan (Mousavi *et al.* 2007). Chalechale *et al.* (2014) stated that if the dominant species of the chickpea fields in Kermanshah Province was transferred to areas with similar ecological needs, it could contaminate those places. The response of weed populations to chickpea planting date and cultivars was evaluated at 91.8% in the presence of high weed densities (Mousavi *et al.* 2007). The most frequent among 70 weed species were GALTR and *Vicia villosa* L. (VICVI) in Khorramabad (Ahmadi and Mousavi 2017). CHEAL, SOLNI and *Amaranthus retroflexus* L. (AMARE) were dominant in the north of Khorasan (Vesal *et al.* 2004), and AMARE, CHEAL, *Polygonum aviculare* L. (Table 1). (POLAV), SOLNI, *Salsola rigida* Pall. (SALRI) and CONAR were frequent in Karaj (Yousefi *et al.* 2006). The dominant grass weeds of autumn chickpea fields in Kermanshah include *H. spontaneum* C. Koch. (HORSP), *Phalaris minor* Retz. (PHAMI) and *Lolium* spp. (LOLSP) (Nosrati *et al.* 2017b). The most important weeds in the harvesting of chickpea are GALTR. CONAR (Nosrati *et al*. 2017b) and CAROX (Ahmadi *et al*. 2017) (Table 1).

Orobanche crenata Forsk. (OROCR) was observed for the first time in 2013 in chickpea fields in Saqez, Kurdistan (Hossieni *et al*. 2015). *Cuscuta campestris* Yunck. (CUSCA) was the dominant weed of chickpea in Tabriz (Shamsi *et al.* 2015).

Chemical management

Herbicides play an important role in weed management because of their efficiency and cost-effectiveness (Mckay *et al*. 2002). Herbicides used to control chickpea weeds have been restricted in the world (Datta *et al*. 2007), including Iran. Herbicides that satis-

Table 1. Dominant weeds in chickpea fields in Iran

Scientific name	Family	Kermanshah			Lorestan		Mashhad		Kurdestan	Maragheh
		rain-fed spring chickpea	rain-fed spring chickpea	irrigated spring chickpea	rain-fed spring chickpea	authumn-sown chickpea	irrigated spring chickpea	rain-fed spring chickpea	rain-fed spring chickpea	rain-fed spring chickpea
		Chalechale *et al.* (2014)	Amini *et al.* (2015)	Amini *et al.* (2015)	Ahmadi *et al.* (2013)	Ahmadi *et al.* (2017)	Vesal *et al.* (2003)	Vesal *et al.* (2003)	Mansourian *et al.* (2017)	Poorsatari *et al.* (2017)
1	2	3	4	5	6	7	8	9	10	11
Acroptilon repens (L.) DC.	Asteraceae							*		
Adonis aestivalis L.	Ranunculaceae									
Alhagi persarum Boiss. & Buhse	Papilionaceae							*		
Amaranthus retroflexus L.	Amaranthaceae						*			
Anthemis cotula L.	Asteraceae	*				*				
Apocynum venetum L.	Apocynaceae		*							
Aristolochia spp.	Aristolochiaceae					*				
Artemisia annua L.	Asteraceae						*			
Avena fatua L.	Poaceae			*						
Avena ludoviciana Dur.	Poaceae		*			*				
Bromus spp.	Poaceae					*				
Cardaria draba (L.) Desv.	Brassicaceae									*
Carthamus oxyacantha M.B.	Asteraceae	*		*	*					
Carthamus tinctorius L.	Asteraceae					*				
Centaurea spp.	Asteraceae				*	*				
Cephalaria syriaca (L.) Roem. & Schult.	Caprifoliaceae									
Cerastium dichotomum L.	Caryophyllaceae				*					
Cerastium tomentosum L.	Caryophyllaceae					*				
Chenopodium album L.	Chenopodiaceae						*			
Cichorium intybus L.	Asteraceae	*								
Cirsium arvense (L.) Scop.	Asteraceae			*						
Conringia orientalis (L.) Dumort.	Brassicaceae	*			*	*				
Convolvulus arvensis L.	Convolvulaceae	*	*	*			*	*	*	*
Cynodon dactylon (L.) Pers.	Poaceae									
Echinocloa crus-galli (L.) P. Beauv.	Poaceae						*			
Euphorbia bungei Boiss.	Euphorbiaceae							*		
Euphorbia cyparissias L.	Euphorbiaceae									
Euphorbia helioscopia L.	Euphorbiaceae	*			*					*
Falcaria vulgaris Bernh.	Apiaceae									

Table 1. Dominant weeds in chickpea fields in Iran – *continuation*

1	2	3	4	5	6	7	8	9	10	11
Fumaria parviflora Lam.	Papaveraceae						*			
Galium aparine L.	Rubiaceae								*	
Galium tricornutum Dandy	Rubiaceae	*			*	*				*
Geranium tuberosum L.	Geraniaceae					*				
Glycyrrhiza glabra L.	Fabaceae		*	*						
Hordeum murinum L.	Poaceae		*							
Hulthemia persica Bornm.	Rosaceae							*		
Lactuca serriola L.	Asteraceae				*					
Lactuca orientalis (Boiss.) Boiss.	Asteraceae									
Lathyrus aphaca L.	Fabaceae		*	*		*				
Lathyrus sativus L.	Fabaceae	*	*							
Malcolmia africana (L.) W.T. Aiton	Brassicaceae						*			
Neslia apiculate Fisch., C.A. Mey. & Ave'-Lall	Brassicaceae				*					
Papaver dubium L.	Papaveraceae									
Picnomon acarna (L.) Cass	Asteraceae									
Polygonum aviculare L.	Polygonaceae		*				*	*		
Prosopis farcta (Banks & Sol.) J.F. Macbr.	Fabaceae							*		
Ranunculus arvensis L.	Ranunculaceae				*					
Rumex acetosella L.	Polygonaceae						*			
Scandix pecten-veneris L.	Apiaceae					*			*	
Silene conoidea L.	Caryophyllaceae				*					
Sinapis arvensis L.	Brassicaceae	*			*					
Solanum luteum Mill.	Solanaceae						*			
Solanum nigrum L.	Solanaceae						*			
Sonchus asper (L.) Hill.	Steraceae						*			
Sophora alopecuroides L.	Fabaceae									*
Sorghum halepense (L.) Pers.	Poaeaec									
Torilis arvensis (Huds.) Link.	Apiaceae		*	*						
Tragopogon graminifolius DC.	Asteraceae								*	*
Tragopogon collinus DC.	Asteraceae									
Tragopogon major DC.	Asteraceae	*								
Turgenia latifolia Hoffm.	Apiaceae							*	*	
Vaccaria hispanica Mill.	Caryophyllaceae					*				
Vaccaria pyramidata Fish. ex Dc. Jaub. & Spach	Caryophyllaceae	*			*					

factorily control the weeds of chickpea fields impose a high cost to the farmers. Moreover, herbicides that are effective for controlling the weed spectrum in one chickpea production system in a particular geographic area may be completely worthless against weeds in another production system or limited in their use due to soil persistence. Thus, discussing specific herbicides across the board is pointless as recommendations for one country may be ineffective or illegal in another country, or even in different regions of the same nation (Yenish 2007). Crop safety is often limiting with post-emergence broadleaf herbicides in chickpea. Because of the sensitivity of chickpea to herbicides, most effective are the pre-emergence herbicides, and choices for post-emergence herbicides are limited. The pre-emergence herbicides are effective in controlling weeds at early stage of seedling growth, but weeds germinating after crop emergence become dominant in the field and cause substantial yield loses (Gaur *et al.* 2013). Pyridate and linuron are herbicides that were registered for chickpea in Iran, but linuron is not currently used (Zand *et al.* 2017). Pyridate was registered in Iran for chickpea in 1998 (Veisi *et al.* 2003). In many studies, the application of pyridate caused the highest grain yield and reduction of weed biomass (Veisi *et al.* 2003; Seyed Sharifi *et al.* 2008; Sarparast and Shaykh 2010; Naghashzadeh and Beyranvand 2015; Ahmadi *et al.* 2017; Izadi Darbandi *et al.* 2017). However, because it is so expensive, its use is not recommended for farmers.In recent years, in an attempt to replace the appropriate herbicide with pyridate several studies have been carried out in Iran. The most important herbicides proposed are as follows: isoxaflutole, fomesafen, flumetsulam, and oxyfluorfen (Veisi *et al.* 2019).

Isoxaflutole is a herbicide for broadleaf and grass weed control in corn and sugarcane which acts by inhibiting the enzyme 4-hydroxyphenylpyruvate dioxygenase (HPPD). In plants and soil, isoxaflutole is rapidly converted to a diketonitrile derivative (DKN) which is the active herbicide principle (Viviani *et al.* 1998). The mode of action of isoxaflutole is suggested to be due to an indirect inhibition of phytoene desaturase resulting from the absence of plastoquinone, an essential cofactor for the desaturase (Pallett *et al.* 1998). Isoxaflutole caused the highest reduction in weed density after hand weeding at three experimental locations (Kermanshah, West and East Azerbaijan) and was more effective in the spring crop than the autumn crop (Shimi *et al.* 2004). Merlin® Flex was evaluated in 2017 with the new formulation to which cyprosolphamide was added in order to reduce crop damage. In these studies, isoxaflutole reduced up to 75% of total weed populations in autumn chickpea (Veisi *et al.* 2019) and 80.5% in spring chickpea (Veisi *et al.* 2018). The wide range of weed control of pyridate and isoxaflutole eliminates the need for inter-row cultivating of chickpea (Ahmadi *et al.* 2017). Crop injury due to isoxaflutole is found in soils with low organic matter content and high pH (Wicks *et al.* 2000).

Flumetsulam belongs to group B of Herbicide Resistance Classification (HRAC) that inhibits plant amine acid synthesis – acetohydroxy acid synthase AHAS (Roberts *et al.* 1998). Veisi *et al.* (2019) reported that post-emergence flumetsulam increased grain yield in autumn chickpea (45%).

Mousavi *et al.* (2010) stated that pre-emergence application of fomesafen, with relatively good control of weeds (88%), did not have any obvious phytotoxicity effects on the chickpea, but this herbicide is not available in Iran (Table 2). Ahmadi *et al.* (2017) and Mitkov *et al.* (2017) reported that corum (imazamax + + bentazon + methyl ester) controls broadleaf and grassy weeds between 55 and 90%, and with regard to damaging chickpea by 20 to 30%.

On the other hand, herbicides such as pendimethalin, from which chickpea is protected, do not have a positive effect on weed density reduction (Ahmadi *et al.* 2017). Veisi *et al.* (2019) showed that metribuzin, despite proper weed control, causes severe phytotoxicity on chickpea and imazethapyr makes the stems and leaves long and narrow (Table 2). It also reduces pods of the autumn chickpea (Molaie *et al.* 2017). Yousefi *et al.* (2006) stated that post-emergence use of oxyfluorfen and paraquat damages chickpea production (Table 2). In another study cyanazine + terbuterin was the best treatment in terms of weed reduction and increasing grain yield (Veisi 2016).

Pre-emergence simazine, prometryne, cyanazin, and metribuzin are also used in some countries for weed control in chickpea (Whish *et al.* 1996).

Results of studies show that combining the two control methods helps to reduce weed density and increase the grain yield of chickpea. For example, hand weeding plus application of pendimethalin and trifluralin (Yousefi *et al.* 2006; Moradi *et al.* 2010), pendimethalin + trifluralin + double cultivate (Modhej and Alikhani 2017), pyridate + pendimethalin (Yousefi *et al.* 2006), clethodim + pyridate (Maghsudi *et al.* 2017) and simazine + prometryn (Mousavi *et al.* 2010) had the highest chickpea yield due to reduced weed biomass (Table 2). In Lorestan, pre-emergence application of imazethapyr plus post-emergence application of pendimethalin were the best treatments for weed biomass reduction (Mousavi 2009). It has also been observed that combining pyridate with a surfactant increases its efficacy on weeds and reduces the herbicide rate (Molaie *et al.* 2017).

The effect of herbicides also depends on the weed species composition in the chickpea field. For example, trifluralin + pyridate controls 68% of CONAR

Table 2. Herbicides used in chickpea weed research in Iran

Herbicides	Chickpea planting time
Trifluralin, imazathapyr (Abbassian *et al*. 2016)	S
Pyridate, isoxaflutole, metribuzin, linuron (Ahmadi *et al*. 2017)	S
Pyridate, terbutrin, cyanazine, linuron, propyzamid, chlorothal dimethyl, paraquat (Bazzazi *et al*. 2008)	S
Trifluralin, pyridate, imazathapyr, pendimethalin (Gholampour Shamami *et al*. 2014)	S
Furamsulfuron, rimsulfuron, imazathapyr, pyridate (Izadi Darbandi *et al.* 2017)	S
Pyridate, clethodim, sethoxidim, haloxyfop-r-methyl, cycloxydim (Maghsoudi *et al*. 2017)	S
Pyridate, imazathapyr, paraquat (Mahdiyeh *et al*. 2013)	W and S
Trifluralin, pendimethalin (Modhej and Alikhani 2017)	A
Pyridate, imazathapyr (Molaie *et al*. 2017)	S
Trifluralin, imazathapyr, oxyfluorfen, pendimethalin (Moradi *et al*. 2010)	S
Ethalfuralin, trifluralin, pendimethalin, imazathapyr, isoxaflutole, pyridate, bentazon, metribuzin, haloxyfop-r-methyl (Mousavi 2009)	S
Simazine, prometrin, fomsafen, imazathapyr, pendimethalin, pyridate (Mousavi *et al*. 2010)	S
Pyridate (Naghashzadeh and Farrash Beyranvand 2015)	S
Simazine, prometrin, fomsafen, imazathapyr, pendimethalin, pyridate (Mousavi *et al*. 2010)	S
Terbutryn, cyanazine, linuran, propyzamide, paraquat, chlorthal-dimethyl (Sarparast and Sheikh 2010)	S
Pyridate (Seyed Sharifi *et al*. 2008)	S
Propyzamide, cyanazine, terbuterin, trifluralin, fluazifop-p buthyl (Veisi 2016)	A
Isoxaflutole, pendimethalin, imazathapyr, metribuzin, pyridate, metribuzin (Veisi *et al.* 2019)	A
Isoxaflutole, pyridate (Veisi *et al.* 2018)	S
Isoxaflutole, pyridate (Veisi and Shimi 2004)	A and S
Pyridate, linuron, simazine (Veisi *et al.* 2003)	A and S
Trifluralin, oxyfluorfen, pyridate, pendimethalin (Yousefi *et al.* 2006)	A

S – spring; A – autumn; W – winter

while the most effective herbicide on CHEAL was isoxyfluorfen (Yousefi *et al.* 2006). The combination of cyanazine and propizamide reduced the density of GALTR, VACPY, *Anthemis cotula* L. (ANTCO) (Veisi 2016). *Geranium tuberosum* L. (GERTU) is not controlled by isoxaflutole (Veisi *et al.* 2019) and *Portulaca oleracea* L. (POROL) is not controlled by imazethapyr and trifluralin (Abbassian *et al*. 2016). Grassy weeds in chickpea are controlled by haloxyfop-R-methyl (Zand *et al*. 2017)

According to the studies conducted in chickpea fields in Iran, with the exception of pyridate and isoxaflutole, which alone can appropriately control weeds, the majority of other herbicides, if combined with hand weeding, cultivators, surfactants or herbicides, would have a favorable effect on weeds and yield.

Zand *et al*. (2017) indicated that pre-emergence application of imazethapyr, fomsafen and oxyflurofen herbicides had good and excellent effects on seven, five and 6 species of the dominant weeds, respectively (Table 3). Post-emergence application of fomsafen and pyridate had good to excellent control on five dominant weeds (Table 3).

Mechanical management

Hand weeding is the most commonly used weed control method in chickpea fields in Iran. Since implementation of this method is costly for farmers, it can be used primarilyon low-area farms. On the other hand, in order to achieve an acceptable grain yield, double hand weeding is recommended (Akbari *et al.* 2010). Hand weeding can increase grain yield up to 92% (Mousavi *et al.* 2007). Hand weeding once, three weeks after sowing in rain-fed chickpea and five weeks after sowing in irrigated chickpea resulted in the highest yield and the lowest dry weight of weeds (Vesal *et al.* 2004). It has been suggested that the most suitable weeding time in chickpea is during the critical period of weeds. The critical period of weed control in Kermanshah is between 25 and 65 days after chickpea emergence (Abdullahi *et al.* 2005), as well as from the four-leaf stage to the beginning of flowering in chickpea (Mohammadi *et al.* 2005).

Mechanical weed control is limited to aggressive and multiple tillage operations prior to planting with ploughs, culti-vators or disks and post-plant to early post-emergence use of a harrow, culti-packer or rotary

Table 3. Efficiency of herbicides on weed control in pulses fields (Zand *et al.* 2017)

Herbicides	*Solanum nigrum*	*Convolvulus arvense*	*Xanthium strumarium*	*Kochia scoparia*	*Chenopodium album*	*Sinapis arvensis*	*Amaranthus retroflexus*	*Salsola rigida*	*Echinocloa cruss galli*	*Hordeum murinum*	*Portulaca oleracea*	*Avena ludoviciana*
Pre-plant/pre-emergence												
Eradicane	**	–	–	*	**	–	**	*	****	****	–	****
Alachlore	***	–	–	*	*	–	***	**	***	****	–	*
Pendimethalin	–	–	–	**	**	–	***	**	****	****	–	*
Imazathapyr	****	*	***	***	*	****	****	***	**	***	–	*
Ethalfluralin	*	–	–	***	***	–	****	***	****	****	–	**
Trifluralin	–	–	–	**	**	–	****	***	****	****	–	*
Chlorthaldimethyl	*	*	–	–	***	*	**	–	**	*	–	–
Prometryn	–	–	–	–	****	–	–	–	–	–	–	–
Fomsafen	****	–	***	–	****	–	****	–	–	–	****	–
Oxyfluorfen	****	–	–	–	***	–	****	–	****	****	****	–
Linuran	**	–	–	–	****	–	**	–	–	–	–	–
Post-emergence												
Bentazone	**	****	****	*	**	****	*	*	–	–	–	–
Fomsafen	****	–	***	–	****	–	****	–	–	–	****	–
Pyridate	***	–	–	–	***	****	***	–	*	*	****	–

****excellent control, ***good control, **moderate control, *poor control, (–) the weed is not included in the label of herbicide control list

hoe (Yenish 2007). Plowing plays a major role in disturbing the structure of weed populations (Amini *et al.* 2015). In Iran, rich farmers who mechanically cultivate chickpea manage the weeds by increasing the row spacing (45 and 50 cm width), and using a weed cultivator. Inter-row tillage by chisel increases the grain yield of chickpea (up to 505 kg · ha^{-1}) (Seyed Sharifi *et al.* 2008). Barzegar *et al.* (2003) showed that the use of moldboard plows before sowing does not have a significant effect on the yield of chickpea. In their study a lower yield was observed with moldboard plows than with disc harrows. However, deep plowing before sowing plus inter-row (37 cm space) tillage with a chisel are the most favorable methods for controlling weeds and increasing chickpea yield in Maraqeh (Asgharimaydani and Bazzazi 2005).

Many regions of Iran, including provinces where rain-fed chickpea is cultivated, have relatively dry climates, which have been exacerbated by climate changes and reduced rainfall during recent years (Veisi *et al.* 2016). Therefore, the potential use of conservation tillage in these areas is seen as being necessary. In practical terms, reduced tillage (after 6 years) in combination with good crop rotation may reduce weed density and expenditures in weed management (Murphy *et al.* 2006). Conservation tillage systems increase yield and improve soil properties in the long run (Hemmat and Eskandari 2004). Chickpea yield in the no-tillage system is significantly (24 to 57%) higher than the minimal, traditional tillage system (Hemmat and Eskandari 2004). By using this system, the leakage of those herbicides which are prone to leach into the surface water, will be reduced (Holland 2004). The conservation tillage system requires the application of selective herbicides in chickpea. In Iran, farmers use pyridate as a selective herbicide, while paraquat and ammonium glufosinate are used as a directed inter-row spray. An effective way to reduce weeds before emergence of spring chickpea is the application of paraquat after chickpea sowing (Mahdiyeh *et al.* 2013).

Crop management

Cultivar

Early growth of weeds reduces chickpea yield due to close competition for light, moisture and nutrients. The competitive balance index was positively correlated with the chickpea aboveground biomass and ground coverage especially in the early stage (25 DAE), and with the chickpea plant height (Radicetti *et al.* 2012). Therefore, there is a need for the cultivars of chickpea to have the greatest ability to compete with weeds. Local cultivars of Bivanij, Zanjan and Philip in Zanjan province (Karimi Torki *et al.* 2012) and spring cultivar ILC482 in Lorestan province (Mousavi *et al.* 2007) have been reported as weed tolerant cultivars. The growth of *Sonchus oleraceus* L. (SONOL) in glasshouse experiments was reduced the most by '99071-1001', a chickpea cultivar with a short phyllochron (Cici *et al.* 2008). Furthermore Singh *et al.* (2003) stated that Avarodhi chickpea cultivar had the maximum plant height and canopy cover as well as less weed dry weight than Radhey and Pant G 114.

Planting density

High density planting would provide earlier canopy closure and reduce the impact of weeds on yield by increasing the competitiveness of the crop (Mohammadi *et al.* 2005). Even low densities of <10 plants · m^{-2} caused large (approx. 50%) reductions in yield (Whish *et al.* 2002).

Increasing inter-row spacing reduces the biological yield, grain yield and yield components of chickpea because of the increased weed biomass (Akbari *et al.* 2010). However, Singh *et al.* (2003) demonstrated thatmore grain yield of chickpea was recorded with 45 cm row spacing in comparison to 30 cm row spacing (weed control was carried out with pendimethalin). Whish *et al.* (2002) stated that the use of wide rows has minimal impact on weed competition in northern chickpea crops. Under weed free and infested conditions, the highest grain and biological yields were observed with 30 cm spacing, and significantly differed from 20 and 40 cm row spacing (Pooniya *et al.* 2009). The maximum grain yield was recorded with hand weeding and paddy straw + chickpea treatments with 30 cm row spacing (Pooniya *et al.* 2009). Mousavi *et al.* (2007) found that increasing the plant density of chickpea does not cost more than 50 plants per square meter in autumn sown chickpea. According to the report by Jettner *et al.* (1999) the most suitable plant density for chickpea is 50 plants per square meter under rain-fed conditions.

Fertilizer

The use of new and high-yielding cultivars instead of domestic cultivars in recent years has resulted in increased inputs (Asghari and Armin 2015). In most studies, weeds have been shown to be luxury consumers of the fertilizer. Application of chemical fertilizer in chickpea increases the weed population. In terms of chickpea interference with weeds, the onset of yield loss by using chemical fertilizers occurs sooner than the use of organic fertilizers. High levels of nitrogen enhance the absorption of nutrients by weeds and increase their dry weight (Abbasi *et al.* 2006). Fertilization did not favor chickpea because weed competition limited legume crop growth. The grain yield of chickpea was not increased by fertilization (Bladivieso-Freitas *et al.* 2018). In general, legumes do not need supplemental N fertilization (Clayton *et al.* 2004) because they can obtain a significant proportion of N by symbiotic nitrogen fixation (Walley *et al.* 2005)

Abdullahi *et al.* (2013) stated that a wheat-chickpea intercropping system would result in lower consumption of urea (46% N) fertilizer, and would be a step towards organic production of chickpea. Different levels of nitrogen had no significant effect on grain yield (intercropping wheat-chickpea), however bio-fertilizer with no N had higher grain yield than with other N levels (Abdullahi *et al.* 2013).

Different fertilizer treatments were found to be insignificant with regards to density and dry weight of weeds at harvest. In general, maximum density and dry weight of weeds were observed with 5 t · ha^{-1} FYM (farmyard manure) in comparison to other treatments. Furthermore, the number of pods · plant^{-1} and 100 seed weight of chickpea was also found to be insignificant due to fertilizer treatment (Patel *et al.* 2006).

The combination of manure + nitroxin led to the highest weed dry weight and density compared to manure, chemical fertilizer, nitroxin and organic fertilizers alone (Koocheki *et al.* 2011). Furthermore, the use of organic fertilizers reduces the half-life of certain herbicides such as metribuzin in the soil (Koocheki *et al.* 2011).

Allelopathy

In recent years, the use of allelopathy has been recognized as an appropriate method for controlling weeds due to environmental pollution hazards posed by herbicide residues in the environment. The use of allelopathic plants can reduce the emphasis on herbicide application (Hensley and Counselman 1979). Combinations of plant and herbicide residues involve a step towards integrated weed management (IWM) and ecological agriculture (Hamzei and Seyedi 2013). Putnam and Defrank (1983) reported that the density and biomass of many weed species reduced the use of sorghum, barley, oat, wheat and rye residues. In Iran, incorporating barley (Bazzazi *et al.* 2008; Seyed Sharifi *et al.* 2008) or safflower (Bazzazi *et al.* 2008) residues with the soil in late autumn reduced weed density in spring chickpea. Other studies have shown that barley straw residues decrease annual weeds in the chickpea, but it does not affect perennial weeds (Jafarzadeh 2005). Rye, sorghum, rice, sunflower, rape seed, and wheat have been documented as important allelopathic crops. These crops express their allelopathic potential by releasing allelochemicals which not only suppress weeds, but also promote underground microbial activities (Jabran *et al.* 2014).

Intercropping system

Intercropping is considered to be an effective way of establishing agricultural systems by providing a set of sustainable agriculture goals. Weed control is usually considered to be one of the benefits of intercropping systems (Hiltbrunner *et al.* 2007). Increasing soil surface cover and plant diversity are two principles of the intercropping system that result in weed control more effectively than the pure crop. Wheat and chickpea intercropping increases yield per unit area, land use efficiency and weed control efficacy (Hamzei *et al.* 2014). Several studies have been carried out on the superiority of the intercropping system in terms of yield and weed control. Intercropping wheat and chickpea increases total productivity per unit area, improves land use efficiency and supresses weeds (Banik *et al.* 2006).

Solymanpour *et al.* (2016) reported that the grain biomass of chickpea (weed infested) using the intercropping system (despite the less cultivated area) was not significantly different than pure cropping, thus indicating the superior performance of intercropping compared to pure cropping. Abdullahi *et al.* (2013) reported that intercropping (wheat-chickpea) was superior to sole cropping under conditions of no or less use of urea fertilizer and no control of weeds. Hamzei and Seyedi (2013) reported that in all intercropping treatments (barley-chickpea) the land equivalent ratio (LER) was more than one. In general, under both weed control and weed interference conditions, barley and chickpea intercropping systems were better than sole cropping for both of them. According to a study performed by Tabarraei *et al.* (2018) the treatment of 50% cumin – 50% chickpea had the lowest weed density and showed superiority to monoculture and other intercropping treatments. In general, intercropping treatments reduced the density and dry weight of weeds by increasing the competitive pressure caused by the presence of cumin and chickpea plants (Tabarraei *et al.* 2018).

Integrated Weed Management (IWM)

IWM consists of a combination of agronomic, mechanical, biological, genetic and chemical crop methods for effective and economical weed control. IWM rules should provide a basis for the optimal development of weed control systems and efficient use of herbicides (Knezevic *et al.* 2002). The best approach for chickpea weed management is the integrated management system (Buhler 2002). In order to increase the competitive power of the chickpea against weeds, herbicides can be used alone or in combination with agronomic methods (Miller *et al.* 2002). The combination of agronomic (change of planting date), chemical (pyridate 1.2 kg $\cdot$ ha^{-1}) and mechanical (inter-row tillage) control methods can effectively suppress weeds in chickpeas (Mousavi *et al.* 2007). Crop rotation and application of herbicides can lead to changes in the seed bank of weeds in farm soil (Amini *et al.* 2015). Mahdiyeh *et al.* (2013) noted that the combination of inter-row mechanical control plus intra-row hand weeding were cost effective to increase chickpea yield. Study results of IWM show that the use of pendimethalin and a seeding rate of 45 plants $\cdot$ m^{-2} (Gholampor Shamami *et al.* 2014), weeding and a density of 40 plants $\cdot$ m^{-2} (Fallah and Pezeskpour 2009), and the application of 75% of the recommended dose of pyridatetogether with inter-row tillage or hand weeding (Nosrati *et al.* 2017a) increased yield and yield components of chickpea (Akbari *et al.* 2010).

Challenges and strategies

- 64 weeds species (57 broad-leaved species and 7 species of grasses) were identified in the chickpea fields that belonged to 21 families.
- 29 herbicides have been tested in research studies, of which only two herbicides are used for broadleaved weeds (pyridate and isoxaflutole) and one herbicide for grassy weeds (haloxyfop-R-methyl).
- The combination of agronomic (change of planting date), chemical and mechanical (inter-row cultivator) control methods can effectively suppress weeds in chickpeas.
- Hand weeding, surface or deep plowing before sowing and using chisels between chickpea rows (50 cm) are the most common methods of mechanical weed control in Iran.
- Nitrogen fertilization may not only increase the population and weed biomass, but also reduce chickpea yield.
- Cultivation of allelopathic products such as wheat and barley in rotation with chickpea may reduce weed density.
- Crop rotation, including fallow, is an important strategy for controlling permanent weeds, such as CONAR and GLTGL by integrated weed management

Perspectives

- Due to the high yield of autumn and winter sown chickpea, and the great damage of weeds to these crops, future research should consider this aspect of cultivation system more.
- Rain-fed VICVI is a crop with a large canopy that is a good competitor for weeds and should be considered in future research on chickpea rotation.

- More research is needed on the addition of surfactants to herbicides to reduce herbicide use and, consequently, reduce costs.
- Intercropping systems are one of the strategies to reduce weeds. But the most important problem is the mechanized harvesting of this crop. In future, it is expected that more studies on harvest methods in intercropping systems will be conducted.
- Chickpea cultivar breeding should be done with an emphasis on their competitiveness with weeds.
- Timing of planting can significantly influence a crop's competitive ability over various weeds (Mukharjee 2007).
- Given the fact that rain-fed chickpea is rotated with rain-fed wheat, effects of herbicide residues (such as sulfonylureas) on the next rotation should also be considered.
- Appropriate control of broad-leaved weeds in wheat will reduce the seed bank in the soil and cut these weeds in the chickpea crop the following year. Therefore, weed management in wheat is essential to weed reduction in chickpea.
- In future research, further studies are needed on different rotations in rain-fed fields.

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