RESEARCH

ALLELOPATHIC EFFECTS OF SUNFLOWER RESIDUE ON GROWTH OF RICE AND SUBSEQUENT WHEAT CROP

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Sunflower (*Helianthus annuus* L.) is a well known allelopathic plant species. However, Pakistani farmers generally incorporate the sunflower residue in the soil with the aim to enhance soil fertility and organic matter. Field experiments were, therefore, carried out to evaluate the effect of sunflower residue incorporation on growth and yield of rice (*Oryza sativa* L.) and subsequent wheat (*Triticum aestivum* L.) crop. For rice crop, there were four treatments viz. control, sunflower residue incorporation (RI), NPK fertilizers, and NPK+RI. Two rice varieties (Basmati Pak and Basmati Super) were cultivated. Incorporation of sunflower residue markedly reduced plant growth and yield in 'Basmati Pak'. There was 34% reduction in yield of this variety due to RI. 'Basmati Super' was tolerant to sunflower allelopathy, where the effect of RI was generally insignificant on plant growth and grain yield. Two commonly cultivated varieties of wheat (Inqalab 91 and Punjab 96) were sown in the same plots after harvesting the rice, without any addition of either RI or NPK. In 'Punjab 96', the effect of RI or RI+NPK was insignificant on grain yield. In contrast, in 'Inqalab 91', RI in combination with NPK fertilizers significantly reduced the grain yield by 41% as compared to NPK alone. The present study concluded that rice 'Basmati Super' and wheat 'Punjab 96' are suitable for cultivation under sunflower allelopathic stress.

Key words: Allelopathy, genotypic tolerance, *Oryza sativa*, *Helianthus annuus*, *Triticum aestivum*.

The potential impacts of allelopathy on agriculture have been described during last 40 years. Many crops have been reported to be allelopathic towards other crops grown either simultaneously or subsequently (Chattopadhyay, 1995; Kawata *et al*., 1996; Khanh *et al*., 2005). Consequently, it has been suggested that crops with allelopathic effect on the other crops should not be followed by susceptible ones (Kausar, 1999). Roth *et al*. (2000) observed that *Sorghum bicolor* (L.) Moench frequently reduced grain yield of wheat (*Triticum aestivum* L.) when the crops are grown in rotation. Oleszek and Jurzysta (1987) reported wheat seed germination and seedling growth were suppressed by water and alcohol extracts of alfalfa (*Medicago sativa* L.) roots. This phenomenon has also been reported in other crops like corn (*Zea mays* L.) and oat (*Avena sativa* L.) (Nielsen *et al*., 1960; Al-Tawaha and Odat, 2010), rice (*Oryza sativa* L.) (Hisashi, 2004; Javaid *et al*., 2008) and cotton (*Gossypium hirsutum* L.) (Ioannis *et al*., 2005). The allelopathic effects are selective, depending upon the concentrations and residue type, either inhibitory or stimulatory to the growth of companion or subsequent crops or weeds (Mushtaq *et al*., 2003; Cheema *et al*., 2004; Javaid *et al*., 2007).

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Sunflower (*Helianthus annuus* L.) is recognized as an important crop in several areas of Pakistan due to suitability of the crop to local agroclimatic conditions, its importance as source of edible oil and protein, resistance to drought and its short duration (Kamal and Bano, 2009). However, yields of some crops following sunflower are lower than normal, possibly because of inadequate nutrition and chemical inhibition (Kamal and Bano, 2008). More than 200 natural allelopathic compounds have been isolated from different cultivars of sunflower (Kamal and Bano, 2009). Sunflower leaf extracts caused reduction in radical and hypocotyl length of mustard seedling (Wardle *et al*., 1991; Bogatek *et al*., 2006). Sedigheh *et al*. (2010) observed that sunflower parts significantly inhibit the germination of *Solanum nigrum* L. Being a short duration and economically important crop, sunflower is cultivated twice a year (spring and autumn) in Pakistan. However, generally sunflower is cultivated on larger scale in spring than in autumn season. Spring sown sunflower is cultivated during March-April and is harvested in June in Pakistan. Generally, it is followed by rice cultivation. In past farmers used to burn sunflower residue after harvest. Nowadays, sunflower residue is generally incorporated in the soil with the idea that it will add to the organic matter and fertility of the soil. The allelochemicals released from crop residues in the soil are likely to cause adverse effects on the proceeding crops, and such detrimental interactions cannot be over looked in rice-wheat cropping system in the country. The present study was, therefore, designed to investigate the effect of incorporation of sunflower residue on growth and yield of two rice varieties and two wheat varieties grown thereafter.

MATERIALS AND METHODS

Incorporation of sunflower residue

Certified seeds of sunflower var. Hysun 33 (Monsanto Pakistan (Pvt) Ltd.), commonly cultivated in Pakistan, were sown on ridges in 2 × 2 m plots at a depth of 1 cm in March 2007. Seeds were planted with inter-row and inter-plant spacing of 75 and 30 cm, respectively. A basal dose of 120 kg N ha^{-1} as urea, 90 kg P_2O_5 ha^{-1} as triple super phosphate and 60 kg K_2O ha^{-1} as potassium sulfate was applied in each plot. Plots were irrigated as recommended for sunflower. After 90 d of sowing, mature sunflower plants were decapitated. Remaining vegetative parts were uprooted, cut into small pieces of 3-5 cm, mixed into the field soil up to the depth of 15-18 cm and left till the cultivation of rice crop in July.

Cultivation of rice

Two commonly grown rice varieties ('Basmati Pak' and 'Basmati Super') were selected for field study. Rice nursery was raised during June in field plots of 4 × 6 m. Plots were supplied with recommended fertilizer doses and regular irrigation and hand weeding was carried out as and when required. Forty days old seedlings of the two selected rice varieties were transferred to field plots with inter and intra row spacing of 22 cm. There were four treatments: Control, sunflower residue incorporation (RI), NPK fertilizers, and RI+NPK. The recommended dose of chemical fertilizers was: 120 kg N ha^{-1} as urea, 60 kg P_2O_5 ha^{-1} as triple super phosphate, and 60 kg K_2O ha^{-1} as sulfate of potash. Plants were harvested at vegetative, flowering, and ripening stages. Data regarding number of tillers per plant, shoot length and dry weight, and root dry weight were recorded at all the three harvest stages. Similarly, data regarding panicle length, grain yield and 100 grains weight were recorded at ripening stage.

Cultivation of subsequent wheat crop

After the harvesting of rice crop, two wheat varieties ('Inqalab 91' and 'Punjab 96') were sown in same plots without any addition of NPK fertilizers or sunflower residue. Data regarding various plant growth and yield parameters were recorded at three growth stages similar to that of rice crop.

Statistical analysis

All the data were analyzed by ANOVA followed by Tukey's test to separate the treatment means using computer software SPSS 11.

RESULTS

Effect of sunflower residue incorporation on growth and yield of rice

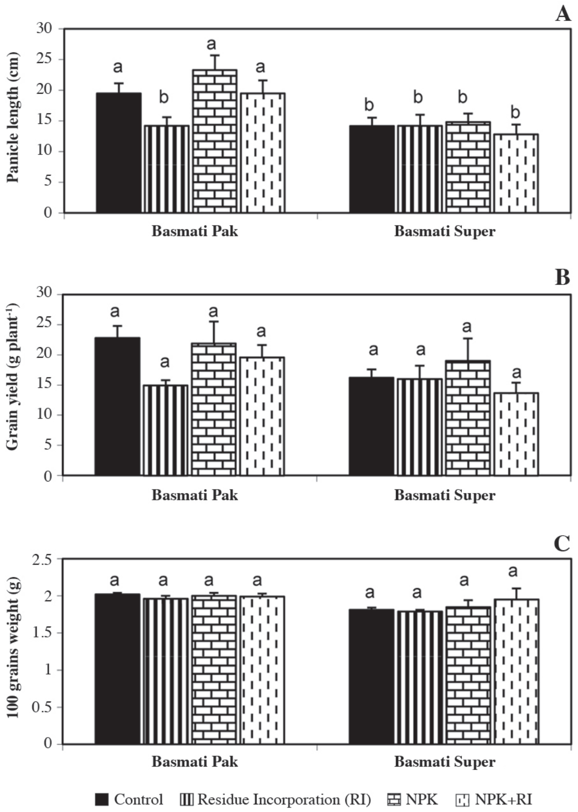
The effect of incorporation of sunflower residue and NPK fertilizers on vegetative growth of rice is presented in Table 1. In rice 'Basmati Pak', sunflower RI insignificantly reduced the number of tillers and shoot length at all three growth stages. In contrast, RI significantly suppressed shoot biomass at vegetative stage. The effect of RI was insignificant on root biomass at all three growth stages. Rice 'Basmati Super' was comparatively tolerant to sunflower residue amendment. The effect was insignificant on all studied plant growth parameters in this variety. NPK fertilizers significantly enhanced shoot dry biomass at vegetative growth stage in 'Basmati Pak'. In general, various plant growth parameters were markedly suppressed when sunflower residue was incorporated in combination with NPK fertilizers as compared to NPK fertilizers alone. The effect was more pronounced in 'Basmati Pak' than in 'Basmati Super'.

The effect of sunflower RI and NPK fertilizers on various reproductive growth parameters of the two tested rice varieties is illustrated in Figure 1. In rice 'Basmati Pak', the highest panicle length was recorded in NPK fertilizers treatment. Incorporation of sunflower residue significantly reduced the panicle length as compared to

Table 1. Effect of sunflower residue incorporation (RI) on plant vegetative growth of two rice varieties at different growth stages.

	Vegetative stage				Flowering stage				Ripening stage			
Treatments	Tillers $plant^{-1}$	Shoot length	Shoot dry weight	Root dry weight	Tillers $plant^{-1}$	Shoot length	Shoot dry weight	Root dry weight	Tillers $plant^{-1}$	Shoot length	Shoot dry weight	Root dry weight
		cm	g	g		cm	g	g		cm	g	g
					Rice var. Basmati Pak							
Control	20ab	79b	33.2b	6.6b	17abc	92ab	36.7ab	6.9abc	21ab	88a	35.0ab	9.6ab
RI	15bc	73bc	21.8c	4.8bc	15abc	85abc	25.0bc	8.7ab	15b	89a	25.3bc	7.3ab
NPK	22a	92a	48.1a	9.1a	22a	96a	47.1a	11.9a	27a	91a	46.8a	18.2a
RI+NPK	17ab	84ab	28.5bc	6.6b	19ab	90ab	36.4ab	10.4ab	20ab	88a	33.5ab	10.3ab
					Rice var. Basmati Super							
Control	10cd	52d	10.2de	1.6e	11bc	65c	17.3c	5.3bc	15b	70b	16.5c	5.3b
RI	7d	56d	7.4e	1.4e	11bc	72bc	13.7c	4.5bc	14b	67b	14.9c	3.5b
NPK	14bc	63cd	20.4cd	4.1cd	14abc	73bc	20.5bc	5.4bc	15b	68b	19.1c	5.5ab
RI+NPK	10cd	57d	10.6cd	1.9de	10c	65c	11.1c	1.9c	14b	65b	14.5c	3.2b

In a column, values with different letters show significant difference as determined by Tukey's Test at $P \leq 0.05$.



Vertical bars show standard errors of means of three replicates. Values with different letters show significant difference according to Tukey's test at $P \leq 0.05$.

Figure 1. Effect of sunflower residue incorporation (RI) on yield of two rice varieties.

control and other treatments. Addition of NPK fertilizers in combination with sunflower residues increased the panicle length significantly in this rice variety. In rice 'Basmati Super', the effect of various treatments on panicle length was insignificant as compared to control (Figure 1A). Grain yield in rice 'Basmati Pak' was reduced by 34% due to the application of sunflower residue. Application of NPK fertilizers markedly alleviated the allelopathic stress of sunflower residue. The effect of residue on grain yield of rice 'Basmati Super' was insignificant (Figure 1B). The effect of different treatments of sunflower residue and NPK fertilizers on 100 grain weight of the two rice varieties was insignificant (Figure 1C).

Effect of sunflower residue incorporation on growth and yield of wheat

Data regarding the effect of sunflower RI and NPK fertilizers on vegetative growth of wheat is summarized in Table 2. Incorporation of sunflower residue insignificantly reduced number of tillers at vegetative growth stages in 'Inqalab 91'. RI exhibited insignificant effect on shoot length in 'Inqalab 91' at all growth stages. However, residue application significantly reduced shoot length at flowering and ripening stages in 'Punjab 96'. Residue incorporation significantly declined shoot dry weight at vegetative stage in 'Inqalab 91'. In contrast, the effect of RI on this plant growth parameter of 'Punjab 96' was insignificant at all three growth stages. Although RI adversely affected root growth, this effect was statistically insignificant on root dry biomass in both wheat varieties. Application of NPK fertilizers generally enhanced root and shoot growth. The effect was more pronounced and significant at flowering and ripening stages than at vegetative growth stage. Wheat 'Punjab 96' showed more susceptibility to sunflower RI in the presence of NPK fertilizers as compared to 'Inqalab 91'. There was insignificant effect of RI and NPK on number of tillers at all three growth stages in 'Inqalab 91' as compared to NPK fertilizers alone. In contrast, in 'Punjab 96', a significant reduction in tillering was recorded at flowering and ripening stages. Shoot dry weight was significantly reduced at flowering stage only in 'Inqalab 91' while residue incorporation showed insignificantly effect on this plant growth parameter in 'Punjab 96'. Root dry weight was significantly reduced at flowering stage in 'Punjab 96', due to combined application of sunflower residue and NPK as compared to NPK fertilizers alone.

Table 2. Effect of sunflower residue incorporation (RI) on plant vegetative growth of two wheat varieties cultivated in the same field after harvesting the rice crop.

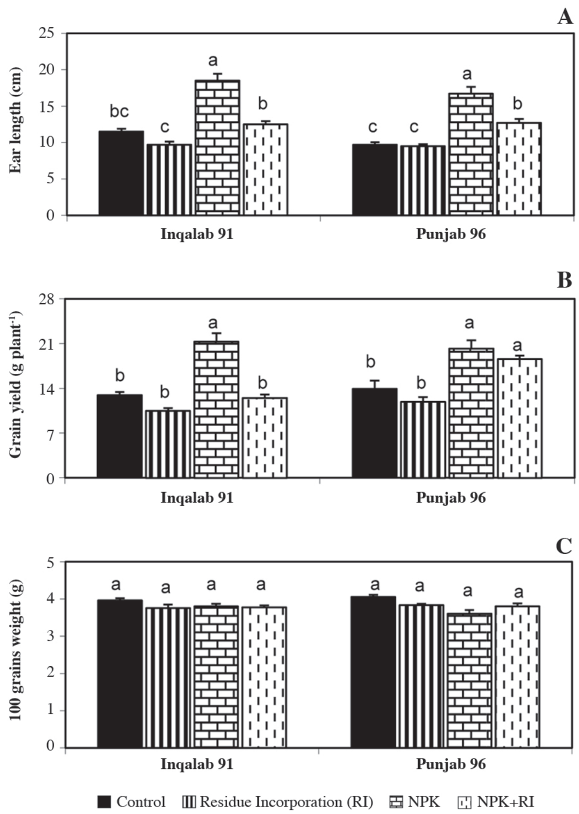
	Vegetative stage				Flowering stage				Ripening stage			
Treatments	Tillers plant^{-1}	Shoot length	Shoot dry weight	Root dry weight	Tillers plant^{-1}	Shoot length	Shoot dry weight	Root dry weight	Tillers plant^{-1}	Shoot length	Shoot dry weight	Root dry weight
		cm	g	g		cm	g	g		cm	g	g
Wheat var. Inqalab 91												
Control	7ab	57b	6.5ab	1.8b	7bcd	72a	13cd	3.1c	12bc	73b	27d	2.2bc
RI	4c	56b	3.4c	0.74b	6d	68a	9d	2.8c	10c	71bc	24d	2.1bc
NPK	8a	57b	8.0a	3.97a	12b	69a	29b	7.1bc	18a	75ab	46ab	4.3a
RI+NPK	8a	57b	7.7a	2.3ab	10bcd	81a	23bc	6.4bc	13b	73b	28d	2.1bc
Wheat var. Punjab 96												
Control	5abc	54b	5.3abc	1.60b	8bcd	75a	16cd	4.3bc	10c	73b	31cd	3.9ab
RI	5abc	49c	3.7bc	0.72b	6d	74a	12cd	4.2bc	10c	67c	26d	2.0c
NPK	7ab	62a	7.9a	1.70b	18a	84a	51a	12.8a	16a	78a	50a	3.2abc
RI+NPK	6abc	55b	5.6abc	1.15b	11bc	77a	27b	8.1b	12bc	75ab	38bc	3.1abc

In a column, values with different letters show significant difference as determined by Tukey's Test at $P \leq 0.05$.

Data about the effect of sunflower RI and NPK fertilizers on various reproductive growth parameters of the two tested wheat varieties is shown in Figure 2. In both wheat varieties, the effect of sunflower RI was insignificant on ear length and grain yield and 100 grains weight (Figures 2A-C). NPK fertilizers alone significantly enhanced ear length in both wheat varieties as compared to control. Ear length was significantly reduced in both wheat varieties in combined application RI+NPK as compared to NPK fertilizers alone (Figure 2A). Grain yield was significantly enhanced by 39% and 31% in 'Inqalab 91' and 'Punjab 96', respectively, due to NPK fertilizers as compared to control. However, there was significant decrease of 41% in grain yield in 'Inqalab 91' when RI+NPK was applied as compared to NPK fertilizers alone. By contrast, in 'Punjab 96', there was insignificant difference in grain yield between NPK fertilizers alone and RI+NPK treatments (Figure 2B).

DISCUSSION

In the present study, two varieties of rice were cultivated in field soil amended with sunflower residue with or without application of recommended dose of NPK fertilizers. In rice 'Basmati Pak', sunflower RI significantly reduced shoot biomass and grain yield. Earlier, Morris and Parrish (1992) observed declined yield of winter wheat when sunflower residues were tilled into the soil. Similarly, Batish *et al.* (2002) reported decreased germination, growth, and yield of four summer season crops namely millet, sorghum, corn, and clusterbean, when grown in fields containing sunflower residues. Recently, Ashrafi *et al.* (2008) found that soil incorporation of fresh sunflower roots and both roots and shoots reduced wild barley (*Hordeum spontaneum* K. Koch.) germination, plant height and weight when compared with a no-residue control. The reduced plant growth in soil amended with sunflower RI could be attributed to the presence of allelochemicals in different parts of sunflower. Many terpenes and phenols have been reported in different sunflower cultivars (Ghafar *et al.*, 2001; Macias *et al.*, 2004). These allelochemicals are often water-soluble substances which are released into the surrounding environment through root exudation, leaching and decomposition of plant residues (Ashrafi *et al.*, 2008), and adversely affect germination and growth of other plants (Batish *et al.*, 2002).



Vertical bars show standard errors of means of three replicates. Values with different letters show significant difference according to Tukey's test at P ≤ 0.05.

Figure 2. Effect of sunflower residue incorporation (RI) on yield of two wheat varieties cultivated in the same field after harvesting rice crop.

After harvesting rice crop, two varieties of wheat ('Inqalab 91' and 'Punjab 96') were cultivated in same plots without any further addition of sunflower residue or NPK fertilizers. The negative effect of the RI on root and shoot growth as well as grain yield of the two wheat varieties was not as much pronounced as was in case of the two rice varieties. It could be due to degradation of allelochemicals in the soil by physical, chemical, and microbial processes (Katase, 1981; Hess *et al.*, 1992; Vidal and Bauman, 1992). However, in treatments where RI+NPK was applied in previous rice crop, the response of the two wheat varieties was different. In case of 'Inqalab 91', a significant reduction in grain yield was recorded in RI+NPK application as compared to NPK fertilizers alone. In contrast, in 'Punjab 96', the effect was insignificant on grain yield. Since, generally NPK fertilizers are applied in rice crop, thus wheat 'Punjab 96' is more suitable for cultivation under sunflower allelopathic stress than 'Inqalab 91'.

The results of the present study clearly demonstrate the genotypic variation in growth and yield response of different varieties of rice and wheat to allelopathic stress caused by decomposing sunflower residue. Between the two rice varieties, 'Basmati Super' was comparatively more tolerant to allelopathic stress of sunflower residue than 'Basmati Pak'. Similarly, the adverse effect of RI on grain yield was more pronounced on wheat 'Inqalab 91' than on yield in 'Punjab 96'. Earlier, Javaid *et al.* (2007) reported genotypic variation in rice cultivars against allelopathic stress of *Cyperus rotundus* L. They reported that rice 'IRRI-8' and 'IRRI-Fine' were more tolerant to phytotoxicity of *C. rotundus* than various Basmati varieties viz. 'Pak Basmati', 'Basmati Super', and 'Basmati 385'. Genotypic variation in tolerance to allelopathy has also been reported in other crop-allelopathic plants interactions (Table 3). This unequal susceptibility of various rice

Table 3: Genotypic variation in tolerance to allelopathic stress.

Allelopathic plants	Allelochemicals/extracts	Target Crop	Effect	References
Sunflower (*Helianthus annuus* L.)	Aqueous extracts of root, stem and leaves.	4 wheat varieties.	The aqueous extract of three sunflower varieties tested against wheat varieties significantly decreased biomass of wheat seedlings, especially at concentrations of 40% and 50%.	Anjum and Bajwa (2010)
		4 rice varieties.	Showed variable effect on growth and yield of rice varieties.	Bashir *et al*. (2011)
Eucalyptus camaldulensis Dehnh.	Aqueous extracts of different parts of the plant.	12 wheat varieties.	Aqueous extracts showed variable adverse affect on the germination, growth and yield of different wheat varieties.	Khan *et al*. (2008)
Albizia saman (Jacq.) Merr.	Aqueous extract of different parts.	3 varieties of *Zea mays*, and 4 varieties. of *Triticum aestivum*.	Leaf, stem, root and seeds extracts delayed germination and variably inhibited seedling growth of the test spp.	Mehar and Khan (1994)
Polypogon monspeliensis (L.) Desf.	Aqueous extracts from various parts, including shoots, inflorescences.	2 wheat varieties.	Aqueous extracts from various parts, including shoots, inflorescences, variably affected the germination, plumule and radical growth, number of seminal roots, and biomass of two wheat varieties	Sarah *et al*. (2011)
Cyperus rotundus L.	Aqueous leaf and tuber extract.	6 rice varieties.	Three Basmati varieties and KS-282 were exhibited significantly losses in root and shoot growth while other two are tolerant	Javaid *et al*. (2007)

varieties to the sunflower extracts could be due to inherent differences in physiological and morphological characteristics of various genotypes involved (Macias *et al*., 1992).

CONCLUSIONS

The present study concludes that the adverse effects of sunflower residue incorporation on rice and subsequent wheat crop can be reduced by cultivation of allelopathic tolerant varieties. Rice 'Basmati Super' is more suitable than 'Basmati Pak' for cultivation under allelopathic stress of sunflower followed by cultivation of wheat 'Punjab 96' as grain yield in these varieties is not significantly affected due to sunflower residue incorporation in combination with NPK fertilizers.

Efectos alelopáticos de residuos de girasol sobre el crecimiento de arroz y cultivo de trigo subsecuente. El girasol (*Helianthus annuus* L.) es una planta alelopática bien conocida. Sin embargo, los agricultores de Paquistán generalmente incorporan el residuo de girasol en el suelo con el objetivo de mejorar la fertilidad y la materia orgánica del suelo. Los experimentos de campo se realizaron para evaluar el efecto de la incorporación de residuos de girasol en el crecimiento y producción de arroz (*Oryza sativa* L.) y trigo (*Triticum aestivum* L.) subsecuente. Para el cultivo de arroz hubo cuatro tratamientos viz. Control, incorporación de residuo de girasol (RI), fertilizantes NPK, y NPK+RI. Se cultivaron dos variedades de arroz (Basmati Pak y Basmati Super). La incorporación de residuo de girasol redujo marcadamente crecimiento de planta y producción en 'Basmati Pak'. Hubo una reducción de 34% en producción de esta variedad debida a RI. 'Basmati Super' fue tolerante a alelopatía del girasol, siendo el efecto de RI generalmente insignificante en crecimiento de planta y producción de grano. Dos variedades comúnmente cultivadas de trigo (Inqalab 91 y Punjab 96) se sembraron en las mismas parcelas después de cosechar el arroz, sin adición de RI o NPK. En 'Punjab 96', el efecto de RI o RI+NPK fue insignificante en rendimiento de grano. En contraste, en 'Inqalab 91', RI+NPK redujo significativamente la producción de grano, 41% comparado con NPK solo. El presente estudio concluyó que el arroz 'Basmati Super' y trigo 'Punjab 96' son apropiados para cultivo bajo estrés alelopático de girasol.

Palabras clave: Alelopatía, tolerancia genotípica, *Oryza sativa*, *Helianthus annuus*, *Triticum aestivum*.

LITERATURE CITED

Al-Tawaha, A.R.M., and N. Odat. 2010. Use of sorghum and maize allelopathic properties to inhibit germination and growth of wild barley (*Hordeum spontaneum*). Notulae Botanicae Horti Agrobotanici Cluj-Napoca 38:124-127.

Anjum, T., and R. Bajwa. 2010. Sunflower phytochemicals adversely affect wheat yield. Natural Product Research 24:825-837.

Ashrafi, Z.Y., S. Sadeghi, H.R. Mashhadi, and M.A. Hassan. 2008. Allelopathic effects of sunflower (*Helianthus annuus*) on germination and growth of wild barley (*Hordeum spontaneum*). Journal of Agricultural Technology 4:219-229.

Bashir, U., A. Javaid, and R. Bajwa. 2011. Comparative tolerance of different rice varieties to sunflower phytotoxicity. Journal of Medicinal Plants Research 5:6243-6248.

Batish, D., P. Tung, H. Singh, and R. Kohli. 2002. Phytotoxicity of sunflower residues against some summer season crops. Journal of Agronomy and Crop Sciences 188:19-24.

Bogatek, R., A. Gniazdowska, W. Zakrzewska, K. Oracz, and S.W. Gawroński. 2006. Allelopathic effects of sunflower extracts on mustard seed germination and seedling growth. Biologia Plantarum 50:156-158.

Chattopadhyay, S.P. 1995. Allelopathic potential of *Solanum myriacanthum* Dunal (Solanaceae) in relation to seed germination and seedling growth of mustard (*Brassica*). Acta Botanica Indica 23:29-31.

Cheema, Z.A., A. Khaliq, and S. Saeed. 2004. Weed control in maize (*Zea mays* L.) through sorghum allelopathy. Journal of Sustainable Agriculture 23:73-86.

Ghafar A., B. Saleem, Anwar-ul-Haq, and M.J. Qureshi. 2001. Isolation and identification of allelochemicals of sunflower (*Helianthus annuus* L.) International Journal of Agriculture & Biology 3:20-22.

Hess, D.E., G. Ejeta, and L.G. Buttler. 1992. Selecting sorghum genotypes expressing a quantitative biosynthetic trait that confers resistance to *Striga*. Phytochemistry 31:493-497.

Hisashi, K.N. 2004. Allelopathic substance in rice root exudates: Rediscovery of momilactone B as an allelochemical. Journal of Plant Physiology 161:271-276.

Ioannis, V., D. Kico, and E. Ilias. 2005. Allelopathic potential of Bermudagrass and Johnsongrass and their interference with cotton and corn. Agronomy Journal 97:303-313.

Javaid, A., R. Bajwa, N. Rabbani, and T. Anjum. 2007. Comparative tolerance of rice (*Oryza sativa* L.) genotypes to purple nutsedge (*Cyperus rotundus* L.) allelopathy. Allelopathy Journal 20:157-166.

Javaid, A., S. Shafique, S. Shafique, and T. Riaz. 2008. Effect of rice extracts and residue incorporation on *Parthenium hysterophorus* management. Allelopathy Journal 22:353-362.

Kamal, J., and A. Bano. 2008. Allelopathic potential of sunflower (*Helianthus annuus* L.) on soil metals and its leaves extracts on physiology of wheat (*Triticum aestivum* L.) seedlings. African Journal of Biotechnology 7:3261-3265.

Kamal, J., and A. Bano. 2009. Efficiency of allelopathy of sunflower (*Helianthus annuus* L.) on physiology of wheat (*Triticum aestivum* L.) African Journal of Biotechnology 8:3555-3559.

Katase, T. 1981. Stereoisomerization of p-coumaric and ferulic acids during their incubation in peat soil extract solution by exposure to fluorescent light. Soil Science and Plant Nutrition 27:421-427.

Kausar, S. 1999. Identification of allelochemicals in root/shoot of sunflower and their effect on mungbean germination. M.Sc. Thesis. University of Agriculture, Faisalabad, Pakistan.

Kawata, Y., I. Harada, and T. Matsunaka. 1996. Allelopathic interaction of alfalfa (*Medicago sativa* L.) root exudates. Journal of Rakuno Gakuen University. Natural Science 21:79-86.

Khan, M.A., I. Hussain, and E.A. Khan. 2008. Allelopathic effects of Eucalyptus (*Eucalyptus camaldulensis* L.) on germination and seedling growth of wheat (*Triticum aestivum* L.) Pakistan Journal of Weed Science Research 14:9-18.

Khanh, T.D., I.M. Chung, T.D. Xuan, and S. Tawata. 2005. The exploitation of crop allelopathy in sustainable agricultural production. Journal of Agronomy and Crop Science 191:172-184.

Macias, F.A., J.C.G. Galindo, and G.M. Massanet. 1992. Potential allelopathic activity of several sesquiterpene lactone models. Phytochemistry 31:1969-1977.

Macias, F.A., A. Lopez, R.M. Varela, A. Torres, and J.M.G. Molinillo. 2004. Bioactive apocarotenoids annuionones F and G: structural revision of annuionones A, B and E. Phytochemistry 65:3057-3063.

Mehar, N., and M.A. Khan. 1994. Allelopathic potential of *Albizia saman* Merr. Pakistan Journal of Botany 26:139-147.

Morris, P., and D. Parrish. 1992. Effects of sunflower residues and tillage on winter wheat. Field Crops Research 29:317-327.

Mushtaq, M.N., Z.A. Cheema, and S.A. Bazmi. 2003. Allelopathic effects of sunflower aqueous extracts on germination of wheat and some important wheat weeds. Pakistan Journal of Scientific Research 55:71-75.

Nielsen, K.F., T. Cuddy, and W. Woods. 1960. The influence of the extract of some crops and soil residues on germination and growth. Canadian Journal of Plant Science 40:188-197.

Oleszek, W., and M. Jurzysta. 1987. An allelopathic potential of alfalfa root medicagenic acid glycosides and their fate in soil environments. Plant and Soil 98:67-80.

Roth, C.M., J.P. Shroyer, and G.M. Paulsen. 2000. Allelopathy of sorghum on wheat under several tillage systems. Agronomy Journal 92:855-860.

Sarah, S., F. Hussain, M. Ehsan, and T. Burni. 2011. Allelopathic potential of *Polypogon monspeliensis* L. against two cultivars of wheat. African Journal of Biotechnology 10:19723-19728.

Sedigheh, S.R., A. Rahnavard, and Z.Y. Ashrafi. 2010. Allelopathic effect of *Helianthus annuus* (sunflower) on *Solanum nigrum* (black nightshade) seed germination and growth in laboratory condition. Journal of Horticultural Science and Ornamental Plants 2:32-37.

Vidal, R.A., and T.T. Bauman. 1992. Fate of allelochemicals in the soil. Ciencia Rural 27:351-357.

Wardle, D.A., M. Ahmad, and K.S. Nicholson. 1991. Allelopathic influence of nodding thistle (*Cardus nutans* L.) seed on germination and radicle growth of pasture plants. New Zealand Journal of Agriculture Research 34:185-191.