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Xanthium strumarium L. impact on corn yield and yield components

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Abstract: *Xanthium strumarium* L. is a major weed affecting flour corn in Khyber Pakhtunkhwa Province of Pakistan. Studies conducted in 2006 and 2007 evaluated corn yield and yield component responses to competition from *X. strumarium* over a range of corn populations (5, 7.5, 10, and 12.5 plants m^{-2}) and *X. strumarium* densities (0, 2, 4, 6, 8, 10, and 12 plants m^{-2}). Flour corn yield and yield components (grains ear^{-1}, 1000-grain weight, harvest index, and days to silking) were significantly correlated with and affected by corn population, weed density, and the interaction between them. The percent reduction in grain yield was 5%–40% and fit a quadratic relationship. The number of grains ear^{-1} declined in a linear fashion with increasing *X. strumarium* density, except at the highest corn density, with an average decrease of 5%–6% in grains ear^{-1} for every *X. strumarium* plant m^{-2}. As the *X. strumarium* density increased, 1000-grain weight and harvest index declined, while the number of days to silking increased slightly. Increasing densities of either crop or weed generally delayed silking and decreased yield and yield components due to inter- and intraspecific competition, suggesting that increasing crop density will likely not be effective in suppressing *X. strumarium* and making up for possible yield loss in corn.

Key words: Cocklebur, corn, interference, *Xanthium strumarium*, yield, *Zea mays*

1. Introduction

Yield loss due to weed competition is one of the most important challenges to crop production wherever crops are grown, but especially under limited conditions. In Pakistan, where corn (*Zea mays* L.) is mostly grown for flour, farmers face economic limitations, such as the price of modern hybrids, herbicides, and labor. Increasing crop density is one of the more efficient weed management strategies that allows for more soil surface coverage and more light capture to compete with weeds. Crop density may change the grain number per ear and grain weight (Dastfal et al., 1999; Pagano et al., 2007). Effects of manipulating the corn crop density are likely to vary with weed density, but no such information is available, especially for this part of the world.

The impacts of competition on corn growth and yield are influenced by how particular weed species alter nutrient and water availability and light quality (Rajcan and Swanton, 2001). Resources sequestered by weeds are obviously not available to the corn crop, with the result that corn yield is reduced in relation to weed biomass production. Studies on resource manipulation have shown that water and nutrient limitations reduce number of kernels per ear and, to a lesser extent, kernel weight (NeSmith and Ritchie, 1992; Pandey et al., 2000; Mehmeti et al., 2012). Likewise, seasonal competition from a mixture of weeds, before the R1 stage, has been shown to reduce corn yield by reducing kernel number (Maddonni and Otegui, 2004; Cox et al., 2006). Competition among corn plants because of higher crop population, even in weed-free conditions, began at about the V4 to V6 stages, reducing crop growth rate, grain number per ear, and, ultimately, yield of grain (Pagano et al., 2007). When weeds were not suppressed in corn until later vegetative stages, grain yield was reduced due to a 2-day delay in silking and reductions in leaf area index (LAI) and kernel number (Cox et al., 2006). Conditions during the presilking period, which corresponds to the critical period for weed control, apparently determine the potential number of kernels per ear (Swanton et al., 1999). A comparison of yield components showed that ear number per plant, weight per seed, and kernels per ear declined with the duration of weed interference, but the effects were not always significant (Evans et al., 2003; Iftikhar-ud-Din et al., 2011; Memon et al., 2012). The final number of grains appears to be determined not by the number of florets per ear, but by resource and environmental conditions that regulate apportioning of late pollinated silks (Pagano et al., 2007).

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Currently, farmers in Khyber Pakhtunkhwa (KP), Pakistan, have no information on how crop density interacts with weed populations to impact flour corn yield or the components that determine quality. Weed-tolerant corn varieties' development for stressful environments, such as those in KP, Pakistan, requires better mechanistic understanding about weed-related yield loss in order to identify rate-limiting processes that might be altered in breeding programs. The objective of this study was to evaluate effects of corn and *X. strumarium* L. (common cocklebur) densities on flour corn grain yield and yield components.

2. Materials and methods

Field experiments were conducted in 2006 and 2007 at the Research Farm of the University of Agriculture in Peshawar, Pakistan. The study site (33°40′N, 71°27′E and 34°31′N, 72°47′E) is dominated by a silty clay loam (40% clay, 51.3% silt, and 8.7% sand) with a mean soil pH of 8.02 (Bhatti, 2002). The climate is semiarid subtropical and is characterized by environmental extremes, with summer temperatures up to 40 °C and winter minima of 6 °C. Rainfall during the growing season (July to September) ranges from 75 to 110 mm (http://www.pakissan.com/english/allabout/crop/maize), and agricultural land is irrigated from a canal system using water pumped from the Indus and Kabul rivers.

A yield loss study was conducted to determine flour corn yield loss related to *X. strumarium* interference. *Xanthium strumarium* was introduced to KP Province from Afghanistan during the Afghan War in the early 1980s by the mass migration of Afghan people and their livestock (Hashim and Marwat, 2002). This weed has been a serious problem for several crops for many years, causing yield losses in corn (Saayman et al., 1996; Baldoni et al., 2000) in most parts of the world. Bussler et al. (1995) reported substantial yield losses in corn after an increase in cocklebur density.

A factorial experiment was conducted with 4 corn densities in main plots and 7 weed densities in subplots (a total of 28 treatments). The main plots were arranged in randomized complete blocks with 3 replications. The study was conducted on the same site both years, with assignment of treatments rerandomized among plots in 2007. In the main plots, corn was planted at densities of 5, 7.5, 10, and 12.5 plants m^{-2}. In each main plot were 7 subplots containing *X. strumarium* at densities of 0, 2, 4, 6, 8, 10, and 12 plants m^{-2}. Each subplot was 12 m^2 in size, with 4 rows of corn, each 4 m long and separated by 75 cm.

An open-pollinated flour corn variety, Azam, was used in the experiments; it was developed by the Cereal Crops Research Institute, Pirsabak (Nowshera), KP, Pakistan. Seeds of *X. strumarium* were collected by hand from an infested field at the Pakistan Forest Institute at the University of Peshawar. The study site had no history of *X. strumarium*. Flour corn seeds were planted by hand in plots after the soil was plowed and harrowed twice in June 2006 and 2007. *Xanthium strumarium* seeds were sown on the same day as the crop, in a 10-cm band over the crop row. At each target site, 2–3 *X. strumarium* seeds were sown, and seedlings were thinned to desired densities 15 days after planting. Occasionally, *X. strumarium* seedlings were transplanted to attain the required density (<1% of plants). Other agronomic practices were kept uniform for all the treatments from sowing to harvest. Nitrogen and P fertilizers were surface-applied at planting at rates of 60 and 100 kg ha^{-1}, respectively, in the form of urea and single super phosphate. An additional application of N was side-dressed at a rate of 60 kg ha^{-1} at 1 month after sowing. All weeds besides *X. strumarium* were removed manually on a weekly basis throughout the corn growing season. Irrigation water was applied 3 times in 2006 and 6 times in 2007. Data on rainfall, temperature, relative humidity, and other meteorological variables were recorded daily at a weather station within the farm area.

Data were collected at corn physiological maturity (black layer development). All crop and weed plants were harvested separately from the central 2 rows of each subplot. Data on grain yield were recorded by cutting 2 central rows, 4 m in length, from each subplot. The ears were husked, dried, and shelled and the grain weight was converted into kg ha^{-1}. Grains per ear was determined from 10 ears randomly selected from the corn plants, and the number of grains was counted after threshing each plant separately. Thousand-grain weight (TGW) was determined from triplicate samples taken at random from the grain lot of each subplot, and samples were weighed using a digital scale.

Data were subjected to ANOVA in SAS to evaluate main effects and interactions. Data from each year were analyzed separately due to variation in weather. There was a significant interaction between main effects of corn density and *X. strumarium* density. Data were plotted and least-squares regression analyses were conducted. Linear and quadratic models were evaluated to describe the relationship between the measured dependent variables and corn or weed density as the independent variable, as appropriate. Interaction plots are shown for all variables, along with the regression equation that best described the data, based on significance of regression.

3. Results

Environmental conditions were quite different during the 2 years of the study, with monthly temperatures between 23 and 34 °C in 2006 and 26 and 37 °C in 2007 (Table 1). Rainfall was nearly 4 times higher in 2006 (184

Table 1. Average monthly temperature and total monthly precipitation during 2 growing seasons at the weather station at the experimental site, The University of Agriculture Peshawar, Pakistan.

Month		Avg. maximum		Avg. minimum			Precipitation	
		2006	2007	2006	2007		2006	2007
		°C					mm	
June		37.6	39.6	23.2	25.8		18.6	00.0
July		34.8	37.7	25.6	25.9		80.0	00.0
August		33.8	37.2	24.4	26.6		46.6	21.5
September		35.3	36.6	21.7	25.6		6.8	17.3
October		31.8	35.7	18.2	24.4		32.2	9.0
	Average	33.7	37.1	22.6	25.7	Total	184.2	47.8

mm) than 2007 (48 mm), with no precipitation recorded during the first 2 months of the study in 2007. Crops were irrigated both years to reduce water stress; therefore, weed interference in these plots most likely operated through competition for light and nutrients.

3.1. Crop yield and yield loss

There were significant outcomes from corn plant density, weed density, and their interaction on the flour corn grain yield both years (Table 2). The interaction plots show that grain yield declined in a linear fashion with increasing *X. strumarium* density in both years (Figures 1a and 1b). The slopes from the equations of these lines show a decline in grain yield of 193 to 270 kg ha^{-1} for each additional weed m^{-2}. The corn density of 7.5 plants m^{-2} generally produced the highest grain yield both years. Analyses at individual densities showed that this density did not differ from 10 corn plants m^{-2}, but grain yield declined with densities below 7.5 plants m^{-2} and above 10 plants m^{-2} (data not shown). The range of *X. strumarium* density in this study caused yield reductions averaging from about 5% to 40% (Figures 1c and 1d). The relationship between yield loss and *X. strumarium* density fit third-order nonlinear equations for every corn population both years. The more commonly used negative hyperbolic function explained a lower percent of the variation due to lack of fit at the lowest weed density. The equation used here is less mechanistic and cannot be extrapolated beyond the data, but it provided R^2 values from 0.95 to 0.99.

Table 2. F values and significance levels for ANOVA of corn yield components in 2006 and 2007 in irrigated plots in northwest Pakistan.

Source	df	Grain yield		Weed biomass		Grains per ear		Harvest index		TGW		Days to silking	
		F	P > F	F	P > F	F	P > F	F	P > F	F	P > F	F	P > F
2006													
Model	35	124.7	<0.001	232.7	<0.001	37.9	<0.001	37.7	<0.001	20.6	<0.001	9.4	<0.001
Corn density (C)[a]	3	94.6	<0.001	208.9	<0.001	31.9	<0.004	37.5	<0.003	36.8	<0.003	62.9	<0.001
Weed density (W)	6	623.3	<0.001	1187.2	<0.001	172.0	<0.001	106.3	<0.001	73.6	<0.001	22.9	<0.001
C × W	18	5.8	<0.001	10.6	<0.001	3.6	<0.002	6.3	<0.001	2.2	<0.017	2.0	<0.025
2007													
Model	35	108.0	<0.001	168.3	<0.001	32.6	<0.001	18.6	<0.001	19.8	<0.001	7.3	<0.001
Corn density (C)[a]	3	47.7	<0.001	4.5	<0.001	77.3	<0.001	62.0	<0.001	35.1	<0.003	7.8	<0.017
Weed density (W)	6	565.1	<0.001	922.8	<0.001	136.8	<0.001	62.3	<0.001	70.7	<0.001	17.5	<0.001
C × W	18	2.7	<0.003	4.5	<0.001	1.9	<0.042	1.9	<0.037	2.0	<0.031	1.9	<0.034

[a]: The error term for testing main effect of corn density using type III mean squares was rep × C; other tests used the residual error term of the split-plot analysis.

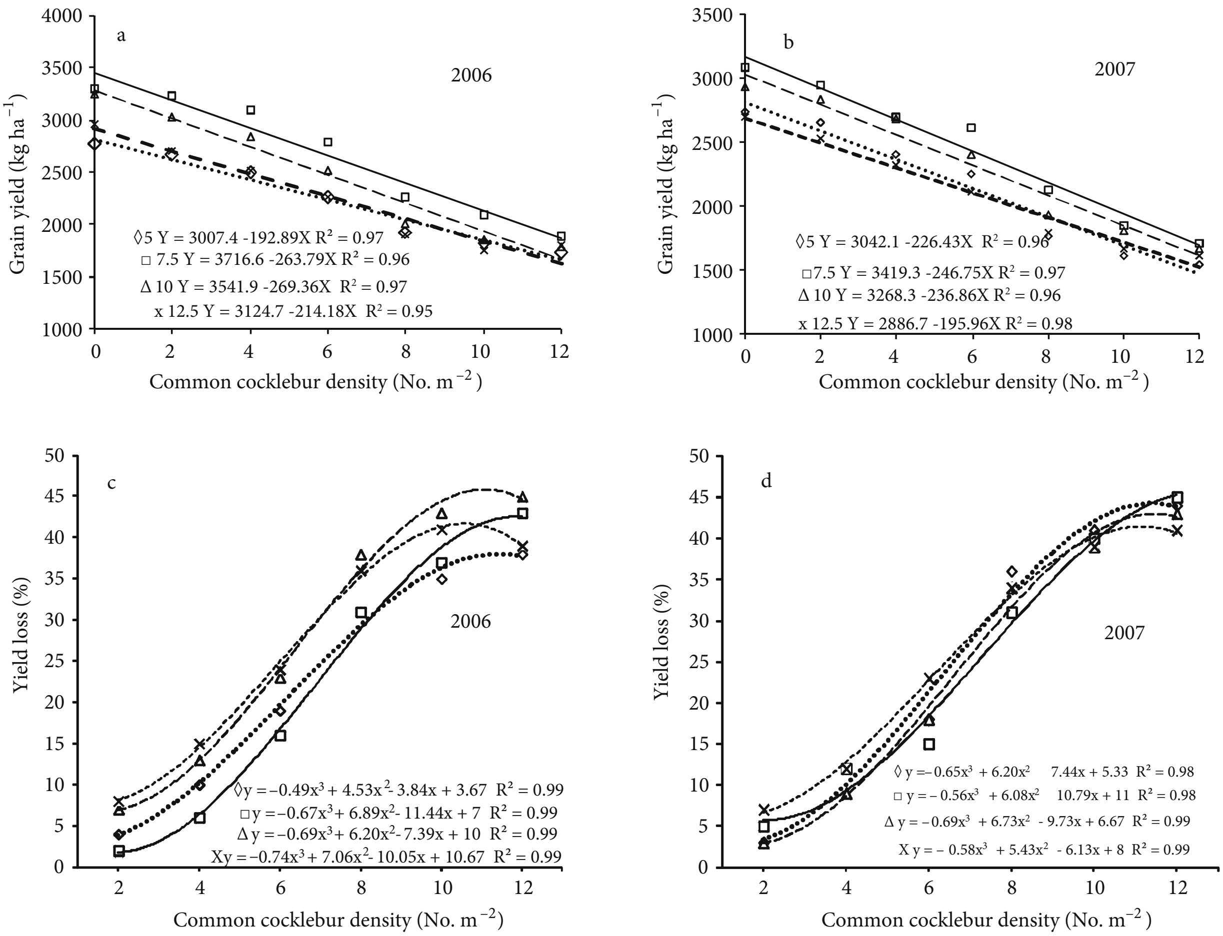

Figure 1. Effect of corn density (◊ = 5, □ = 7.5, Δ = 10, x = 12.5 plants m^{-2}) and *X. strumarium* density on grain yield and percent yield loss (relative to weed-free plots) of flour corn during 2006 and 2007 in irrigated fields in Peshawar, Pakistan.

3.2. Corn yield components

Main effects of corn density and *X. strumarium* density, and their interaction, were significant for grains per ear, harvest index, TGW, and days to silking in both years ($P < 0.001$ to $P = 0.042$) (Table 2). The interaction effect indicates that the effect of *X. strumarium* on corn yield components was dependent on the level of corn plant population. Due to the significant interactions, all data were graphed in order to depict the combined effect of weed and corn density. Corn yield, weed biomass, and all corn yield components were significantly intercorrelated ($P < 0.001$ to $P < 0.050$) (Table 3).

There was a linear reduction in grains ear^{-1} with increasing *X. strumarium* density except at the highest corn density, where the relationship was curvilinear (Figures 2a and 2b). The number of grains ear^{-1} ranged from about 250 to over 350 (to 325 in 2007) in plots where there was no *X. strumarium*, whereas at the highest weed density the number of grains ear^{-1} averaged 175 to 225. The number of grains ear^{-1} generally decreased with increasing corn density. The values of number of grains ear^{-1} during 2007 were comparatively lower than in 2006, most probably because of more favorable weather conditions in 2006 (Table 1). For the interaction effect of corn and cocklebur densities, a linear decrease in number of grains ear^{-1} was observed for all corn densities during both the years except at 12.5 plants m^{-2}, where the decrease was quadratic.

TGW generally declined with increasing *X. strumarium* density, and the response was dependent on the corn population and year (Figures 2c and 2d). In 2006, the data fit a linear equation for the 7.5 and 12.5 corn densities and quadratic functions for 5 and 10 corn plants m^{-2}; in 2007, the decline was linear except for plots with 10 corn plants m^{-2}. In the weed-free plots, TGW ranged from 182 to 210 g in 2006 and from 177 to 218 g in 2007. For the linear responses, there was a decrease of 5–7 g, or about 3%, for each *X. strumarium* plant m^{-2}. *Xanthium strumarium* had a significant effect on harvest index (HI), which varied with corn density and year (Figures 2e and 2f). The decline in HI with weed density was linear except for the 7.5 and 12.5 corn densities in 2006. In general, there was a 3.5% decline in HI for each additional *X. strumarium* plant m^{-2}.

Table 3. Pearson correlations among corn yield components in 2006 and 2007 (bold) for irrigated plots in northwest Pakistan with different corn densities and *X. strumarium* densities.

	Weed biomass	Grains per ear	Grain yield	Harvest index	Grain weight	Days to silking
Weed biomass		−0.44 <0.001	−0.67 <0.001	−0.40 <0.002	−0.30 <0.050	0.25 <0.0191
Grains per ear	−0.60 <0.001		0.80 <0.001	0.73 <0.001	0.86 <0.001	−0.73 <0.001
Grain yield	−0.79 <0.001	0.82 <0.001		0.88 <0.001	0.67 <0.001	−0.53 <0.001
Harvest index	−0.54 <0.001	0.73 <0.001	0.84 <0.001		0.66 <0.001	−0.53 <0.001
Grain weight	−0.46 <0.001	0.88 <0.001	0.72 <0.001	0.67 <0.001		−0.71 <0.001
Days to silking	0.39 <0.002	−0.59 <0.001	−0.48 <0.001	−0.53 <0.001	−0.59 <0.001	

As *X. strumarium* density increased, there was an increase in the number of days to silking in a manner that varied with corn population and year (Figures 2g and 2h). In 2006 days to silking ranged from 60 to 63 days in the weed-free plots, but with 12 *X. strumarium* plants m^{-2}, there were about 63 days to silking for all corn densities. In 2007 days to silking ranged from 56.7 to 59 days in weed-free plots but was 58.7 to 61 days at the high weed density. This small range of impact, though statistically significant, likely was not a biologically significant driver of the impact of weed and crop density on corn yield.

4. Discussion

The results provide evidence that *X. strumarium* interfered with flour corn growth and development, resulting in lower grain yield. The regression equations suggest that there was a low density of *X. strumarium* at which corn yield loss was around 5%, followed by a linear phase in which there was a constant increase in yield loss with each additional *X. strumarium* plant m^{-2}. At between 8 and 10 *X. strumarium* plants m^{-2} the curves began to flatten out, suggesting that intraspecific competition among the *X. strumarium* plants caused a declining impact on corn yield for each incremental increase in *X. strumarium* density. At around 12 *X. strumarium* plants m^{-2}, the corn yield loss leveled out between 35% and 45%. These results are similar to those reported by David and Kovacs (2007), who found a 28% reduction in corn seed yield at *X. strumarium* densities between 6 and 8 m^{-2}. Whereas our yield losses appeared to level off below 50%, Sarpe and Mihalcea (1999) reported 90%–95% yield losses where *X. strumarium* was not controlled in corn (density not reported). However, grain yield in our study continued to decrease as *X. strumarium* density increased and yield losses became constant after 10 *X. strumarium* per m^{-2} density (Figures 1a–1d), which might be due to the advent of competition among the *X. strumarium* plants themselves.

The intercorrelation among corn yield, weed biomass, and corn yield components suggests that yield determinants were operating together; we could not identify one component of corn yield that was functionally more important than others. Due to the high level of intercorrelation, it was not possible to perform the type of stepwise regression analysis that might have helped to clarify mechanisms underlying crop yield loss where both crop and weed density vary.

The number of grains ear^{-1} is the yield component that some researchers have suggested is most important in determining grain yield of corn (NeSmith and Ritchie, 1992; Cox et al., 2006; Memon et al., 2012). For the linear responses we observed, the slopes of the lines indicated that each additional *X. strumarium* plant m^{-2} resulted in a decrease of 20–25 grains ear^{-1} in 2006 and 16–17 in 2007. This corresponds to a 5%–6% decrease in grains ear^{-1} for every *X. strumarium* plant m^{-2}. The decrease in number of grains ear^{-1} with increasing corn density suggests an effect of intraspecific competition on this yield component. In previous research, the increase in cocklebur density caused a curvilinear decrease in number of grains ear^{-1} and yield of corn (Tessema and Tanner, 1997).

TGW is influenced by both genetic and environmental factors, especially water and nutrient stress (Pandey et al., 2000). Other authors have reported similar reductions in TGW with increasing weed density (Sobkowicz and Tendziagolska, 2005), but Beckett et al. (1988) found only a small decrease in corn seed weight over *X. strumarium*

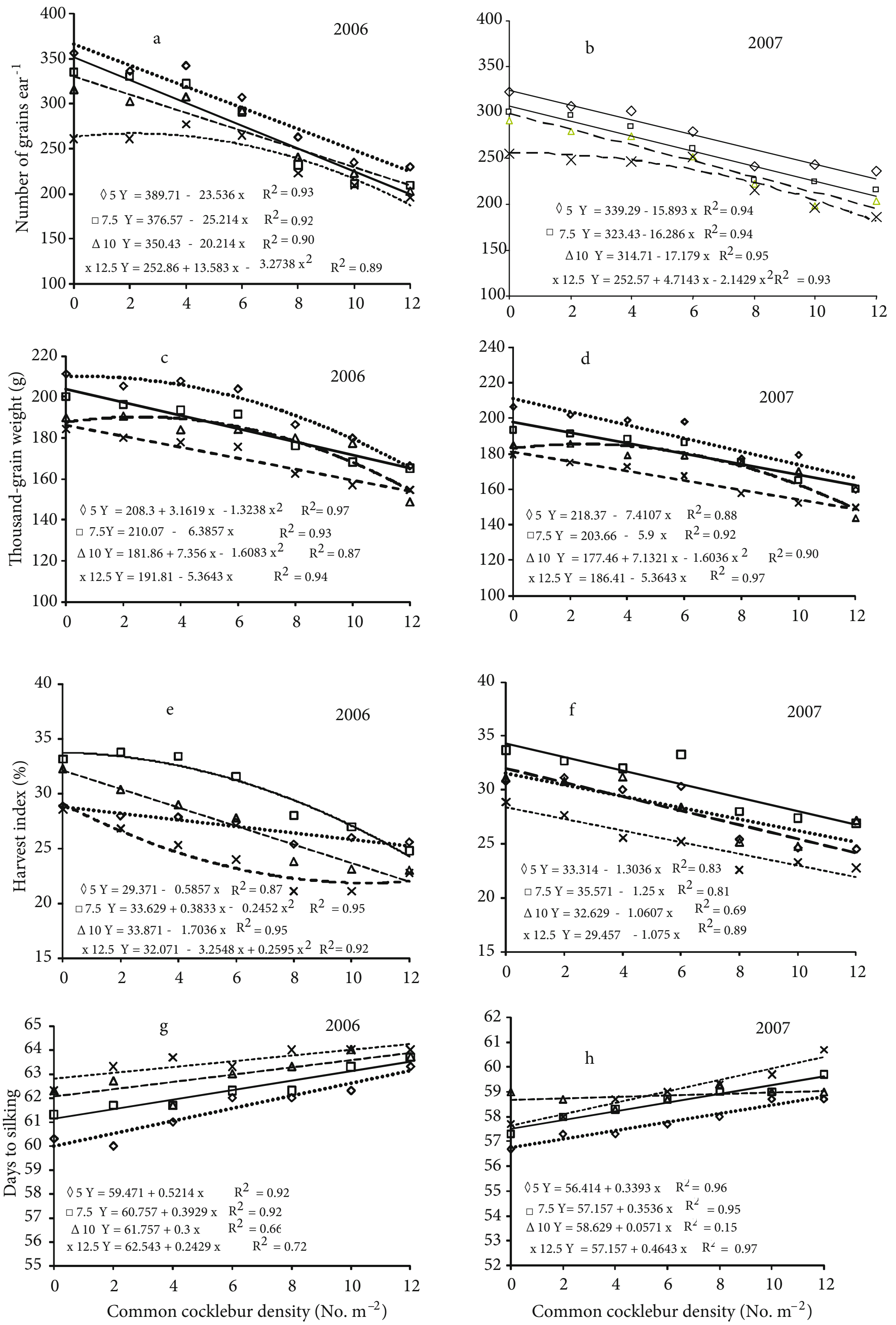

Figure 2. Effect of corn density (◊ = 5, □ = 7.5, Δ = 10, x = 12.5 plants m^{-2}) and cocklebur density on grain yield components of flour corn during 2006 and 2007 in irrigated fields in Peshawar, Pakistan.

densities from 0.4 to 3.6 per meter of row. We do not know why the functional responses for TGW varied at different corn densities, but the biological implications of decreasing TGW with increasing *X. strumarium* density were generally consistent. The effect of weed competition on TGW was likely indirect and due to kernels that remain undeveloped when stress imposed during the period surrounding pollination limits partitioning of dry matter to reproductive tissues (NeSmith and Ritchie, 1992; Pandey et al., 2000).

The harvest index is an indication of relative biomass allocation to grain production rather than to other above-ground structures. The general decline in harvest index with increasing weed density suggests that corn plants moved an increasing amount of photosynthate to stems and possibly leaves, at the expense of grain yield, as the *X. strumarium* density increased. This reallocation of resources away from grain production was exhibited mostly in a decrease in number of grains ear^{-1} but also in a lower weight of individual grains. A possible mechanism for this response, involving the reception of higher FR/R light ratios and development of shade avoidance strategies at higher plant densities, has been proposed by Rajcan and Swanton (2001).

In general, increasing densities of *X. strumarium* caused corn to delay silking and instead put a greater proportion of energy and resources into stem and leaf growth rather than reproductive tissue. This limited the potential for grain production and was manifested in the initiation and filling of fewer grains per ear or possibly also in the incomplete filling of initiated grains. Although yield and yield parameters were affected more by changes in *X. strumarium* densities than corn populations over the ranges studied here, the data showed strong interactions between them. Increasing corn plant density did not have a consistent effect on the corn yield component response to *X. strumarium*, and increasing densities of either crop or weed generally delayed silking and decreased yield and yield components due to inter- and intraspecific competition. The results suggest that increasing planting rates alone would not be effective in suppressing the effects of *X. strumarium* and making up for possible yield loss in corn.

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