Research Article

Intercultural Tillage Reduced Efficacy of the Pre-Emergence Herbicides in Cotton for Integrated Weed Management

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Abstract | Weeds are a major threat to seed cotton production. Though herbicide offers efficient weed control but it also introduces issues such as the development of herbicide-resistant weeds and environmental pollution which forces experts and farmers to look for better integrated weed management options. Intercultural tillage after pre-emergence herbicides may be used in integration for weed management in cotton crop; however, tillage may reduce the efficacy of pre-emergence herbicides. The present study was conducted to evaluate the impact of tillage (hoeing) on the efficacy of two pre-emergence herbicides (Pendimethalin 330 EC at 825 a i g ha^{-1} + Acetochlor 50 EC at 1125 ai g ha^{-1}) for weed control in cotton under field condition. The results revealed that hoeing 23 days after sowing (DAS) significantly reduced the impact of pre-emergence herbicides, while hoeing 37 DAS resulted in better weed control and higher seed cotton yield. From this study, it can be concluded that intercultural tillage might reduce the impact of pre-emergence herbicides in field cotton crop. However, the timing of the intercultural operations has to be carefully decided for a better integrated weed management.

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Introduction

Cotton (*Gossypium hirsutum* L.) is a multipurpose crop mainly grown for fiber. It has been cultivated worldwide in more than seventy countries. The first three major cotton producing countries are China, India and USA (Khan *et al.*, 2020). Textile industry is based on raw material provided by the cotton crop. There is a significant gap in average yield and attainable yield potential. It is due to many climatic and agronomic factors (Gwimbi and Mundoga, 2010). Among all other agronomic factors, weeds caused major yield losses to cotton in Pakistan. Weeds are relatively the most competitive, hardy, unwanted, and self-growing plants, which limit the yield of many crops. Weeds have strong potential to produce more seeds, resist to pests and pathogens, persist as dormant plants under unfavorable circumstances and also germinate necessarily under favorable conditions (Jha *et al*., 2017). Weed competition induces more crop losses in yield than losses expected from combined influence of all pests and diseases (Gala *et al*., 2020). Besides losses in crop yield, weeds also affect the quality of the cotton.

Precise management of weed density per unit area based on classification of pre-and post-emergent weedicides provide a reliable and practical foundation for selection of weed management via herbicides at proper timings (Tariq *et al*., 2020). Different weeds decline the seed cotton yield by affecting plants directly or indirectly. Cotton being a widely spaced, heavily fertilized and irrigated crop. It invites enormous weed germination, which creates competition with crop plants during early sowing days. Cotton plant is more susceptible to weeds at its initial stages of growth when the crop has a thin canopy (Venugopalan *et al*., 2009). Pre-emergence herbicides have been an efficient method to control weeds in cotton. Despite the indiscriminate post-emergence use of glyphosate in glyphosate-tolerant transgenic cotton crop due to development of glyphosate resistant weeds, it requires up to 60 days weed-free period after germination (Owen *et al*., 2015; Tariq *et al*., 2020). However, excessive use of herbicides has resulted in a herbicide-resistant weed and environmental pollution. Therefore, integrated weed management has been suggested to reduce use of synthetic herbicides for eco-friendly and sustainable cotton production (Owen *et al*., 2015).

Different weed management options are being practiced in different regions of the world where cotton is sown as one of the major crops (Doğan *et al*., 2014). For example, use of pre- and post-emergence herbicides, tillage, allelopathy, cultural practices, stale seedbed etc. (Doğan *et al*., 2014). However, these techniques are rarely used in an integrated way. Integrated weed management would be the most cost-effective approach to control weeds in cotton for production of quality-lint with a clean environment (Doğan *et al*., 2014). Pre-emergence herbicides provide efficient weed control in cotton during its early seedling stage up to 30 days after sowing (DAS) (Tariq *et al*., 2018). Thereafter, the impact of pre-emergence herbicides is lost and weeds start to germinate especially due to rainfall and higher supply of fertilizers to the field. At this stage, many smallholder farmers opt for intercultural tillage in the form of hoeing in addition to pre-emergence herbicides keeping the cotton weed-free during the critical period of weed-crop competition (i.e., 60 DAS; (Nadanassababady *et al*., 2001; Owen *et al*., 2015). However, timing of intercultural tillage may carefully be decided because it may have significant effects on the efficacy of pre-emergence herbicides (Mushtaq *et al*., 2020).

The present study was, therefore, conducted to evaluate the effect of intercultural tillage (hoeing) on efficacy of two widely used pre-emergence herbicides (Acetochlor + Pendimethalin) for weed management in cotton crop under the field condition. The weed flora in the field consisted of narrow leaf weeds purple nutsedge (*Cyperus rotundus*) and bermuda grass (*Cynodon dactylon*) including other broad leaf weed common horse purslane (*Trianthema portulacastrum*), etc.

Materials and Methods

Experimental site, design and treatments

The experiment was conducted at the Research Farm of the University of Agriculture Faisalabad, Sub Campus Burewala at Vehari, Pakistan during the crop season 2018-19 using a randomized complete block design (RCBD) with two factors, replicated three times on a gross plot size 9m x 3m. Four different doses of herbicides namely full (Pendimethalin 330 EC@ 825 ai g ha^{-1}+Acetochlor 450 EC@ 1125 ai g ha^{-1}), half (Pendimethalin 330 EC @ 412.5 ai g ha^{-1} + Acetochlor 450 EC at 562.5 ai g ha^{-1}), one quarter (Pendimethalin 330 EC at 206.3 ai g ha^{-1} + Acetochlor 450 EC at 281.3 ai g ha^{-1}, and zero (control) were used. Whereas, the hoeing was performed at 23 and 37 DAS, including no hoeing as a control treatment. Both herbicides were sprayed as a pre-emergence within 24 h after sowing the cotton crop at a volume of 300 L ha^{-1} using a knapsack manual sprayer with a flat fan nozzle and pressure of 270 k Pa.

Crop husbandry

Cotton (cv. BS-15) was planted in the field after ploughing twice with a bed mechanical planter at seed rates of 25 kg ha^{-1}. First irrigation was supplied just after plantation, 0 days after sowing (DAS), while second irrigation 5 DAS. Doses of recommended

N-P-K fertilizers were applied @ 120-60-30 kg ha^{-1}. All potassium and phosphorus were applied at sowing time along with 1/3rd dose of the total N. While remaining N was applied at the time of 3rd and 4th irrigation in two splits. All standard plant protection practices for insect pest and disease management were used.

Data collection and analyses

The individual and total weed densities data were collected 45 DAS at random from an area of 1 m^2 in each plot. All weeds were dried at 70°C for 48 hours for dry biomass. Five plants of cotton were selected at random from each plot to count the number of sympodial branches. Cotton was picked manually twice to get total seed cotton yield. The data were analyzed statistically with ANOVA using Statistix 8.1. Least significant difference (LSD) test at 0.05 probability was used to compare treatments means of all parameters.

Results

Effect of intercultural tillage and pre-emergence herbicides on individual weeds

Regarding the individual effect of treatments, hoeing and pre-emergence application of herbicides (Pendimethalin + acetochlor) significantly inhibited the density of purple nutsedge, bermuda grass and horse purslane, recorded 45 DAS (Table 1) Individually, hoeing at 37 DAS and full dose of herbicides resulted in maximum reduction in weeds density and dry weight (Table 1). Interactive effect of hoeing and herbicides was also analyzed, which showed that maximum inhibition of weeds density was observed where full dose of pendimethalin was applied as pre-emergence spray, but no hoeing was performed. The inhibition of individual weeds varies from 55-60% (Figures 1-3). However, in interactive effect, when hoeing was done at 23 DAS, the population of purple nutsedge, bermuda grass and horse purslane was increased as compared with no hoeing treatment and the inhibitory effect was only 15-20% (Figures 1-3).

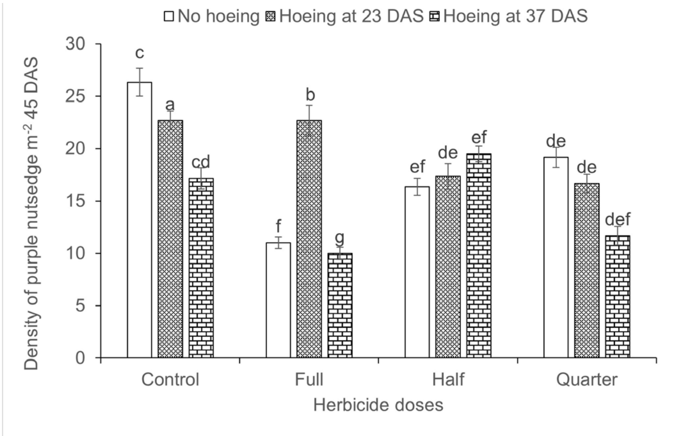


Figure 1: *Interactive effect of hoeing timing and pre-emergence herbicides on density of purple nutsedge 45 days after sowing (DAS). Different letters show significantly different treatment means at P<0.05. Data are presented as means of three replications. Control= No Herbicide; Full= Pendimethalin 330 EC at 825 ai g ha^{-1} + Acetochlor 50 EC at 1125 ai g ha^{-1}; Half= Pendimethalin 330 EC @ 412.5 ai g ha^{-1} + Acetochlor 450 EC at 562.5 ai g ha^{-1} Quarter= Pendimethalin 330 EC at 206.3 ai g ha^{-1} + Acetochlor 450 EC at 281.3 ai g ha^{-1}*

Table 1: *Individual effect of hoeing and herbicide on density and dry matter production of weeds 45 DAS.*

Treatments	Purple nutsedge density m^{-2}	Bermudagrass density m^{-2}	Horse purslane density m^{-2}	Total weed density m^{-2}	Total weed dry weight g m^{-2}
Hoeing					
No hoeing	18.20^A	9.38^B	29.63^A	82.88^A	174.83^A
Hoeing 23 DAS	19.83^A	12.46^A	27.03^B	78.11^B	156.08^B
Hoeing 37 DAS	14.58^B	5.46^C	21.83^C	68.11^C	148.83^B
Herbicide					
Control (No herbicide)	22.05^A	10.55^A	27.25^A	100.08^A	212.22^A
Full (Pendimethalin 330 EC at 825 ai g ha^{-1} + Acetochlor 50 EC at 1125 ai g ha^{-1})	14.55^C	7.90^B	23.83^B	65.51^B	137.22^C
Half (Pendimethalin 330 EC @ 412.5 ai g ha^{-1} + Acetochlor 450 EC at 562.5 ai g ha^{-1})	17.72^B	6.45^C	26.17^A	65.56^B	137.89^C
Quarter (Pendimethalin 330 EC at 206.3 ai g ha^{-1} + Acetochlor 450 EC at 281.3 ai g ha^{-1})	15.83^C	11.51^A	27.4^A	72.73^B	152.33^B

Data are presented as mean of three replications; DAS= Days after sowing; values in columns sharing different letters are significantly different at P<0.05 based on least significant difference test.

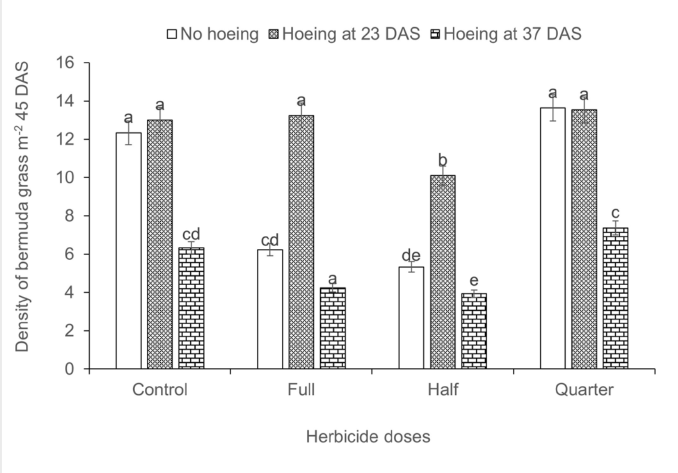


Figure 2: *Interactive effect of hoeing timing and pre-emergence herbicides on density of bermuda grass 45 days after sowing (DAS). Different letters show significantly different treatment means at P<0.05. Data are presented as means of three replications. Control= No Herbicide; Full= Pendimethalin 330 EC at 825 ai g ha^{-1} + Acetochlor 50 EC at 1125 ai g ha^{-1}; Half= Pendimethalin 330 EC @ 412.5 ai g ha^{-1} + Acetochlor 450 EC at 562.5 ai g ha^{-1} Quarter= Pendimethalin 330 EC at 206.3 ai g ha^{-1} + Acetochlor 450 EC at 281.3 ai g ha^{-1}*

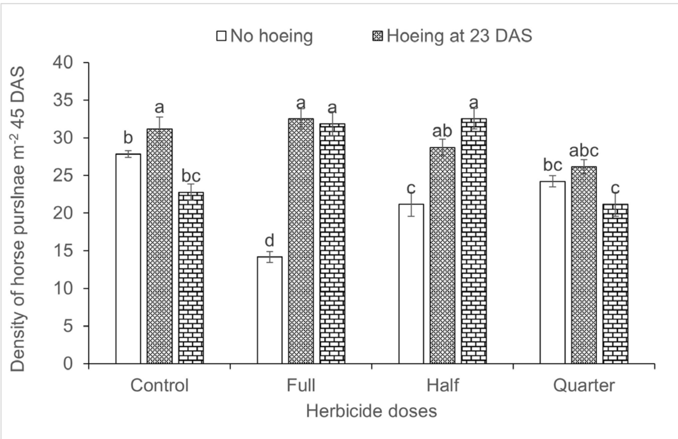


Figure 3: *Interactive effect of hoeing timing and pre-emergence herbicides on density of common horse purslane 45 days after sowing (DAS). Different letters show significantly different treatment means at P<0.05. Data are presented as means of three replications. Control= No Herbicide; Full= Pendimethalin 330 EC at 825 ai g ha^{-1} + Acetochlor 50 EC at 1125 ai g ha^{-1}; Half= Pendimethalin 330 EC @ 412.5 ai g ha^{-1} + Acetochlor 450 EC at 562.5 ai g ha^{-1} Quarter= Pendimethalin 330 EC at 206.3 ai g ha^{-1} + Acetochlor 450 EC at 281.3 ai g ha^{-1}*

Effect of intercultural tillage and pre-emergence herbicides on total weeds

The full dose of pendimethalin + acetochlor and hoeing independently inhibited the total weeds density and dry weight (Table 1). Maximum weeds inhibition was observed in individual application of hoeing at 37 DAS and full dose of herbicides (Table 1). Interaction of hoeing and herbicides revealed that full dose of herbicides + no hoeing significantly reduced the total weeds density and dry matter production (Figure 4). The dry matter production was decreased by up to 60% by this interactive treatment as compared with control. Nonetheless, application of hoeing at 23 DAS significantly reduced the impact of herbicides and the weed control in terms of weed dry weight was decreased to about 15% (Figure 4).

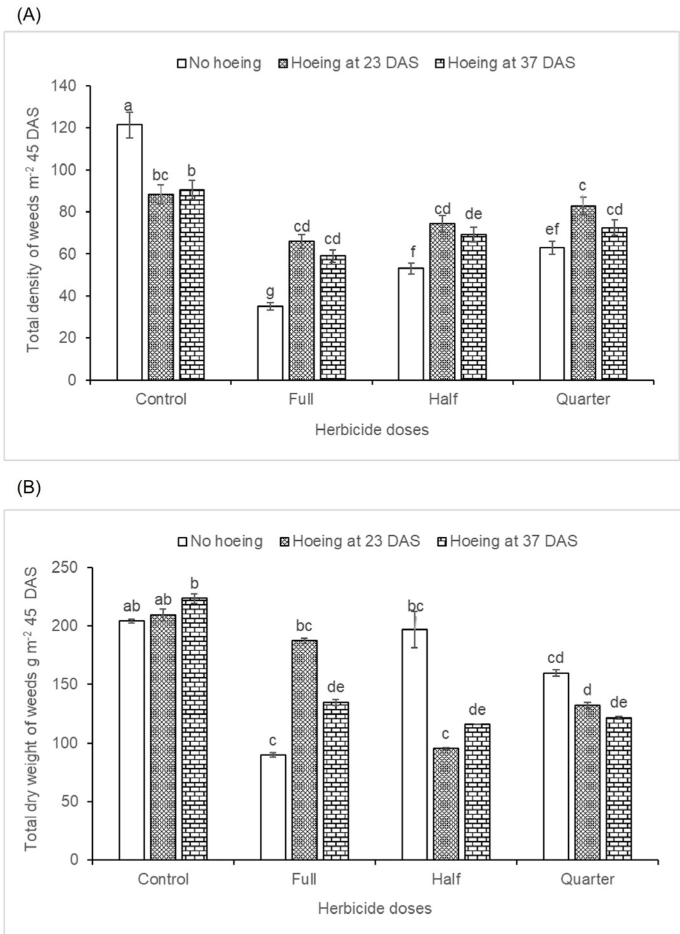
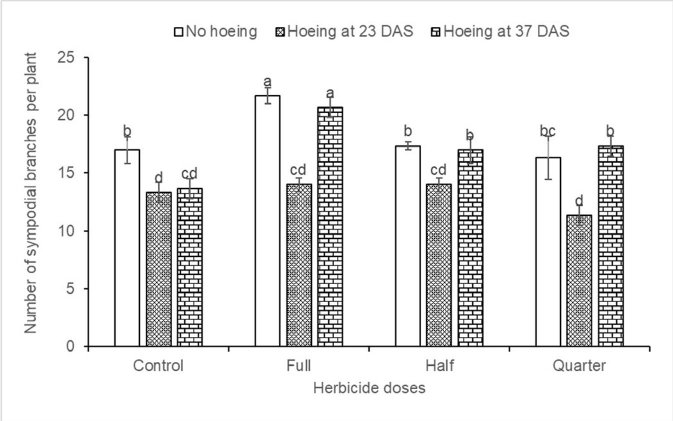


Figure 4: *Interactive effect of hoeing timing and pre-emergence herbicides on total weed density (A) and dry weight (B) 45 days after sowing (DAS). Different letters show significantly different treatment means at P<0.05. Data are presented as means of three replications. Control= No Herbicide; Full= Pendimethalin 330 EC at 825 ai g ha^{-1} + Acetochlor 50 EC at 1125 ai g ha^{-1}; Half= Pendimethalin 330 EC @ 412.5 ai g ha^{-1} + Acetochlor 450 EC at 562.5 ai g ha^{-1} Quarter= Pendimethalin 330 EC at 206.3 ai g ha^{-1} + Acetochlor 450 EC at 281.3 ai g ha^{-1}.*

Effect of intercultural tillage and pre-emergence herbicides on cotton crop

Maximum fruit bearing (sympodial) branches were counted with the application of pendimethalin (330 EC at 825 ai g ha^{-1}) + acetochlor (50 EC at 1125 ai g ha^{-1}) + no hoeing, while full dose of pendimethalin (330 EC at 825 ai g ha^{-1}) + acetochlor (50 EC at 1125 ai g ha^{-1}) + hoeing at 37 DAS produced the highest seed cotton yield followed by full dose of herbicides + no hoeing treatment as compared with control (Figure 5).

(A)



(B)

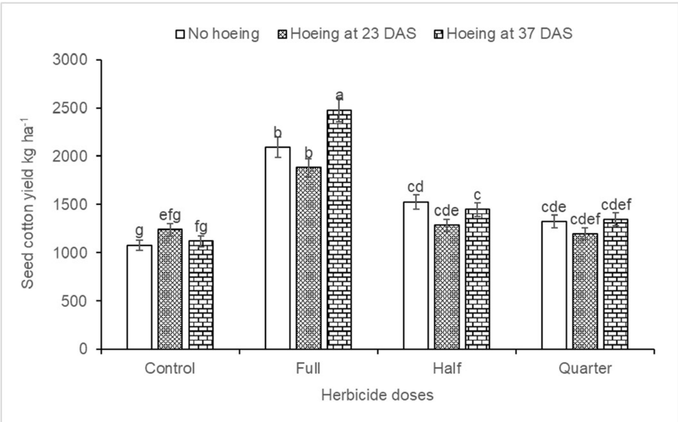


Figure 5: *Interactive effect of hoeing timing and pre-emergence herbicides on number of sympodial branches (A) and seed cotton yield (B). Different letters show significantly different treatment means at P<0.05. Data are presented as means of three replications. Control= No Herbicide; Full= Pendimethalin 330 EC at 825 ai g ha^{-1} + Acetochlor 50 EC at 1125 ai g ha^{-1}; Half= Pendimethalin 330 EC @ 412.5 ai g ha^{-1} + Acetochlor 450 EC at 562.5 ai g ha^{-1} Quarter= Pendimethalin 330 EC at 206.3 ai g ha^{-1} + Acetochlor 450 EC at 281.3 ai g ha^{-1}.*

Discussion

Pre-emergence herbicides are an excellent choice to control weeds in cotton crop, especially at early seedling stage up to 30 days. After that, their impact may be reduced, and weeds start to emerge. To cope with newly emerging weeds, intercultural tillage (hoeing) is a good option. However, an early hoeing may decrease the effectiveness of herbicides and may have the adverse effect on weed populations (Doğan *et al*., 2014; Tariq *et al*., 2020). In the present study, individual impact of hoeing and pre-emergence herbicides fairly reduced the narrow and broad leaf weeds. Individually, hoeing 37 DAS resulted in better weed control as compared with hoeing 23 DAS. This may be attributed to timing of data collection (45 DAS). The weeds got enough time (22 days) to re-establish themselves from 23 DAS to 45 DAS, while they had only 8 days for the same purpose in case of hoeing 37 DAS. The interactive effect of hoeing and pre-emergence herbicides (pendimethalin+ acetochlor) provided good weed control in cotton. However, hoeing 23 DAS reduced the impact of herbicides as compared with hoeing at 37 DAS. Hoeing treatment both at 23 and 37 DAS resulted in decreased effect of pre-emergence herbicides as compared with control (no hoeing).

The persistence and efficacy of herbicides after hoeing might be decreased due to enhanced microbial activity, photodegradation and volatilization as a result of soil disturbance/tillage (Curran, 2016). Furthermore, germination of weeds may be enhanced because of tillage in the form of hoeing (Chauhan *et al*., 2006). It was reported in a field study that the efficacy of soil applied herbicides in soybean was higher if no tillage was applied subsequently; however, weed control efficiency of the same herbicides was significantly decreased when tillage was used (Hooker *et al*., 1997). Likewise, in the field when *Cynodon dactylon* was subjected initially to tillage, efficacy of herbicides was significantly reduced as compared with no/ less tillage system (Campbell, 2008). Furthermore, the effectiveness of herbicides is also judged based on its ability to suppress types of weeds i.e., narrow leaf, broad leaf or both. In the present study, hoeing decreased the efficiency of pre-emergence herbicides (Acetochlor+ pendimethalin) for both narrow leaf (purple nutsedge and bermuda grass) as well as broad leaf weeds (common horse purslane) (Hooker *et al*., 1997; Walia *et al*., 2005). Additionally, there was a little increase in weed density, especially of narrow leaf weeds, as compared with control at lower (quarter) doses of herbicides when independent effect of herbicides was analyzed. This may be due to the hormetic effect of herbicides at low doses (Abbas *et al*., 2017). Nonetheless, this aspect may be explored further in future studies.

Furthermore, the impact of tillage after pre-emergence herbicides on crop growth and economic yield was also investigated. The sympodial branches are fruit bearing branches of the cotton crop as there is no bearing on monopodial branches. The number of sympodial branches were highest in the treatment where delayed hoeing 37 DAS was performed after application of pre-emergence herbicides (Acetochlor+ Pendimethalin). The same treatment produced maximum seed cotton yield. This may be achieved due to better weed control through pre-emergence herbicides and hoeing (tillage) and enhanced porosity, moisture conversion and microbial activity in the soil; consequently, it contributed to better root growth and development of the crop and uptake of nutrients from the soil, which resulted in better above-ground biomass production and boll formation of the cotton crop (Munkholm *et al*., 2008).

Conclusions and Recommendations

It is concluded that tillage may reduce the efficacy of pre-emergence herbicides and increase weed density. Therefore, tillage may be performed under necessary circumstances and timing for tillage may carefully be planned to avoid excess weed germination and growth. The delayed hoeing after application of pre-emergence herbicides as per need of the crop might result in maximum seed cotton yield.

Novelty Statement

The present study reports that the timing of intercultural tillage is very critical for efficient weed control through pre-emergence herbicides in cotton to obtain higher economic return.

Author's Contribution

Muhammad Naeem Mushtaq: Planned the experiment and wrote manuscript.
Ashfaq Ahmad: Conducted the experiment and collected data.
Aeysha Wishal, Rabia Nadeem, Raihan Ismil and Safdar Hussain: Improved the manuscript and assisted in data interpretation.

Conflict of interest
The authors have declared no conflict of interest.

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