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Research Article

Unraveling the Impact of Salinity on Maize Cultivars Growth under Hydroponic Conditions: A Study to Identify Resistant Cultivars

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ABSTRACT

Breeding crops for yield and other quantitative characteristics requires precise genotype evaluation in the field. While numerous screening measures have been proposed to distinguish salt tolerant genotypes in controlled environmental conditions, their filed validation remains crucial. Selecting salt- tolerant genotypes is vital to sustain crop production on salt-affected lands to meet the rising global food demand. Crop growth and development, or even individual species' cultivars are significantly influenced by soil salinity, beginning from germination. To screen maize hybrids for salt tolerance under hydroponic conditions, a two factorial Complete Randomized Design (CRD) experiment were performed at the Department of Agronomy, MNS-University of Agricultural Multan, Pakistan. The experiment involved two salinity levels S0 (0 dS m-1) and S1 (10 dS m-1) and 6 maize cultivars including namely YH-1898, YH-1148, YUH-5394, FH-793, FH-949, and P-1543 respectively. Maize seedlings at the two leaf stage were transplanted into hydroponic solutions. Results revealed significant ($P < 0.05$) variations in length of roots and shoots, quantity of leaves on a plant, and mass production of fresh and dried across salinity levels. Some maize cultivars exhibited high sensitivity to salinity. Among the tested cultivars, The best results were obtained by YH-1148 in terms of seedling growth and other metrics. On the other hand, FH-793 and FH-949 demonstrated the greatest susceptibility to salt stress.

Keywords: Hydroponic, Salinity stress, Maize seedling, Cultivars selection.

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INTRODUCTION

Globally, salt affects about 1128 million hectares (Mha) (Wicke et al., 2011). A crucial food grain, maize (*Zea mays* L.) is grown around the world in a variety of temperatures, from tropical to ward areas. World-wide maize production in the year 2023-24 was approximately 1.23 billion metric tons (USDA, 2024). The crop's nutritional quality satisfies human food requirements, however production performance is negatively impacted by adverse abiotic factors as low temperatures, water stress, and salt stress (Fita et al., 2015). Research on maize cultivars' tolerance to salinity is crucial for establishing an effective approach to this goal through assessment and selection (Hoque et al., 2015). Depending on stage of growth, a crop's response to salt varies (Banziger et al., 2007). At the seedling stage, there is a great deal of genotypic variation in maize cultivars' resilience to drought and salt. Additionally, several crop genotypes have been chosen for their ability to withstand saline and drought stressors.

Recent research has shown significant variances in the biomass, length of root and shoot of several hybrids under varying salinity levels (Maiti et al., 2012). Higher saline concentrations have more detrimental effects on maize during the germination and seedling stages than they do later in the development process (Maiti et al., 2012). Numerous crops have been shown to undergo a number of biochemical alterations as a result of salinity, according to published research. During the germination stage, the maize crop transferred a significant quantity of Na^+ and Cl^- to the developing portion of the shoot, and with time, the concentrations of K^+ and Ca^{2+} in the tissues situated in the embryonic region reduced (Ashraf and Wahid, 2000). Seed lipids degradation gradually throughout germination to provide sugars in soluble forms for the developing embryo's metabolism (Kochak-Zadeh et al., 2013). Osmotic ion and oxidative stress are linked to the salinity effect on plant development. The increase in collected solutes in both inorganic and organic forms caused halophytes and glycophytes to adapt osmotically (Shrivastava and Kumar, 2015), which ultimately results in a larger drop in potential of cell solute than the concentration of exterior salt. This might be explained by a balance between the potential of solute of the ions-dominated vacuoles and the collected organic solutes in the cytoplasm (Slam et al., 2015). It is commonly known that osmolyte accumulation and stress adaption are positively correlated. Several writers have acknowledged the molecular basis of salt tolerance (Gupta and Huang, 2014).

From germination to maturity, plants under saline stress undergo distinctive changes that might include wilting, doughtiness, and loss of productivity, even in moist and humid soils (Munns, 2002). In order to cultivate soils impacted by salinity, researchers are working to create crops that can withstand salty conditions due to the expanding number of lands damaged by salinity and population growth (Yamaguchi and Blumwald, 2005; Munns et al., 2006). Due to its many uses, maize is growing in area under cultivation and production every year. It is extremely sensitive to salt and exhibits clear symptoms of stress, such as wilting even in the presence of sufficient soil moisture (Farooq et al., 2015). Elevated soil salinity damages roots, resulting in nutritional deficits that significantly impair plant yield potential (Wahomeet al., 2000; Penella et al., 2016).

When maize was grown under salinity stress, Ouda et al. (2008) observed delay in growth characteristics and potential of yield. Once more, they noted conflicting findings on the crop's moderate sensitivity to soil salt based on C4 metabolic characteristics. Maiti et al. (1996) also documented genetic differences for salt tolerance in maize crops. According to several researchers, maize and all crops initial seedling stage is most vulnerable to effects of salinity stress, and crop growth declines as salinity rises (Shalhevet, 1995). When researching maize for salt tolerance and resistance, chosen characteristics include growth rate, seedling weight and root and shoot parameters in the stress conditions. Therefore, the current study is to assess the following goals: 1) determine how salinity affects the maize seedlings growth and development in hydroponic culture; and 2) investigate the variations in salt tolerance across the cultivars of maize.

MATERIAL AND METHODS

Planting Materials

Six maize varieties seeds namely YH-1898 (V1), YH-1148 (V2), YH-5394 (V3), FH-793 (V4), FH-949 (V5), P1543 (V6) were obtained from different agricultural research institutes and used as experimental materials.

Experimental Design

With three replications and two treatments, including the administration of NaCl, the research was carried out using a completely randomized design (CRD). The size of each tub was 100L. Equal amounts of macro and micronutrients were given to each treatment. Two water tubs were utilized in total for this investigation. Each tub received a different set of treatments at random. The experiment was carried out at 25°C in a growing environment with a 12-hour light/dark cycle, 70% relative humidity, and a pH adjustment of 6.5.

NaCl and Nutrients application

The seeds on the tub for S1 were sprayed with a 10 dS m^{-1} concentration of NaCl solution during the germination stage, whereas the seeds on the tub for the control treatments were treated with distilled water to guarantee 0 dS m^{-1} (S0). With the exception of NaCl, all other nutrients were added to the tub at the required dosage (Table 1). At intervals of eight days, ten dS m^{-1} NaCl solutions were supplied to the tub's water.

Hydroponic Experimental

Seedlings that were one week old were moved to a 100L water tub filled with a continually aerated nutritional solution. Fresh nutrient solutions were added to the solution every eight days. The nutrition solution's composition is listed below:

Table 1. Sources of nutrients and the recommended dosage utilized in the experiment

Macronutrients			
Sr No.	Chemicals	Stock solution g/L	Stock/mL for half strength Hoagland solution
1	$Ca(NO_3)_2.4H_2O$	236	2.5 mL
2	KNO_3	101	2.5 mL
3	KH_2PO_4	136	0.5 mL
4	$MgSO_4.7H_2O$	246	1.0 mL
Micronutrients			
1	$ZnSO_4.7H_20$	0.22	1.0 mL
2	$H_2MoO_4.H_2O$	0.02	1.0 mL
3	H_3BO_3	2.86	1.0 mL
4	Fe-EDTA	37.33	1.0 mL
5	$MnCl_2.4H_2O$	1.81	1.0 mL
6	$CuSO_4.5H_2O$	0.08	1.0 mL

Data Collection

Data were gathered both 0 days (0 DAS) and 14 days (14 DAS) following the seedling transplant. At specific stages of seedling development, the following morphological traits were measured: (a) root length; (b) shoot length; (c) leaves number per plant; and (d) Root and shoot fresh weight (e) Root and shoot dry weight. In order to examine the fresh and dry weight, the seedlings were gathered and processed. After weighing four new seedlings, they were put in an oven set at 80±2°C for 24 hours. An electronic balance was used to measure the fresh and dry weights.

Statistical Analysis

The MSTAT-C software was used to statistically analyze the data for analyses of variance (ANOVA) in compliance with the CRD principles. Variations between the treatments were compared using Duncan's Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

Shoot length

Salinity and variety together had a substantial ($p < 0.05$) impact on shoot length (Figure 1). The treatment V4S0 combination had the longest shoot length at 14 DAS, measuring 29.63 inches. With 10 dS m-1 NaCl, V1S1 had the shortest shoot length (16 inches). The shot lengths of FH-949 and FH-793 were statistically comparable under stress. With the salinity level, FH-793 showed a 33% reduction in shoot length, whereas FH-949 showed a 20% drop. When the concentration of NaCl rose, the shoot growth of all the maize varieties reduced (Pessarakli and Kopec, 2009). Gill and Singh (1989) in rice, Hoque et al. (2015) in maize, and Mohammad et al. (1998) in tomato all reported similar outcomes. Excessive salt buildup in the cell wall elasticity is the cause of the decrease in shoot length (Hoque et al., 2015).

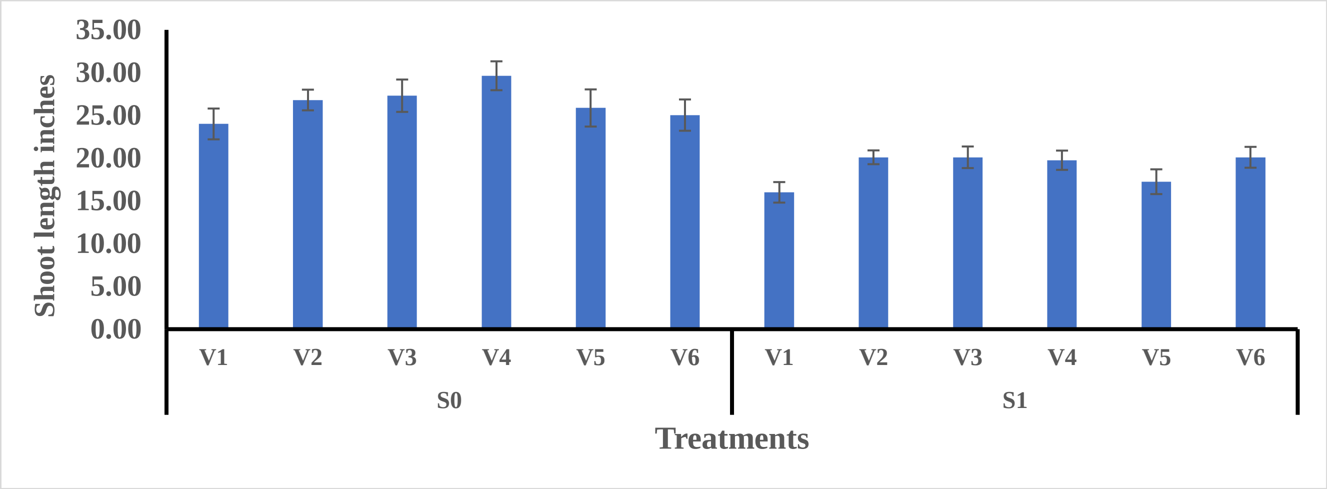

Figure 1. Salinity and variety impact on shoot length

Root length

Root length was significantly impacted by variety and salinity ($p < 0.05$). Figure 2. The treatment V4S0 combination had the longest root length (19.30 inches). In V1S1 with 10 dS m^{-1} NaCl, the shortest root length (9.70 inches) was measured. The root lengths of FH-793, YH-1898, and FH-949 were statistically comparable under stress conditions. With the salinity level, YH-1898 showed a 40% reduction in root length, whereas FH-793 showed a 33% drop. The notable variations in root length across cultivars and salinity (NaCl levels) are comparable to those found in studies by Hoque et al. (2015) and Ashraf et al. (2005). Root length was greatly increased when there was no salt (0 dSm^{-1}) in the culture media. Because excessive salt concentrations in the media have a significant impact on root development. For this reason, salinity quickly diminishes or stops roots (Ashraf et al. 2005).

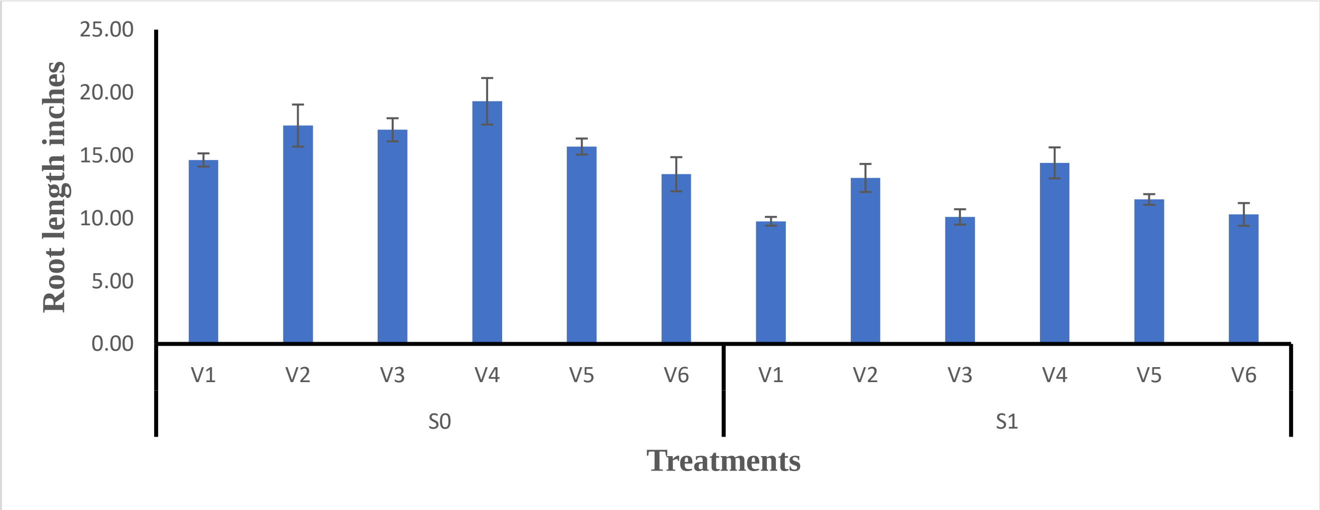

Figure 2. Salinity and variety impact on root length

Number of leaves per plant

The leaves number per plant were noticed to be unaffected by variety and salinity ($p < 0.05$). Figure 3. Following V6S0, V2S0, and V3S0, the treatment V4S0 combination had the most leaves per plant (8). In V1S1, V2S1, V3S1, and V4S1, the lowest number of leaves per $plant^{-1}$ was seen (5) with 10 dS m^{-1} NaCl. The number of leaves per plant was statistically identical for FH-793, P-1543, YH-1898, and YH-5394 under stress conditions. With the salinity level, P-1543 showed a 33% reduction in leaves per plant, whereas FH-949 showed a 31% loss. YH-1148, among other cultivars, produced more leaves under 10 ds m-1 than under salt conditions. With the exception of YH-1148, this behavior suggests a decrease in the emergence of new leaves, which may be related to the osmotic stress mentioned by Munns et al. (2002) and Munns and Tester (2008).

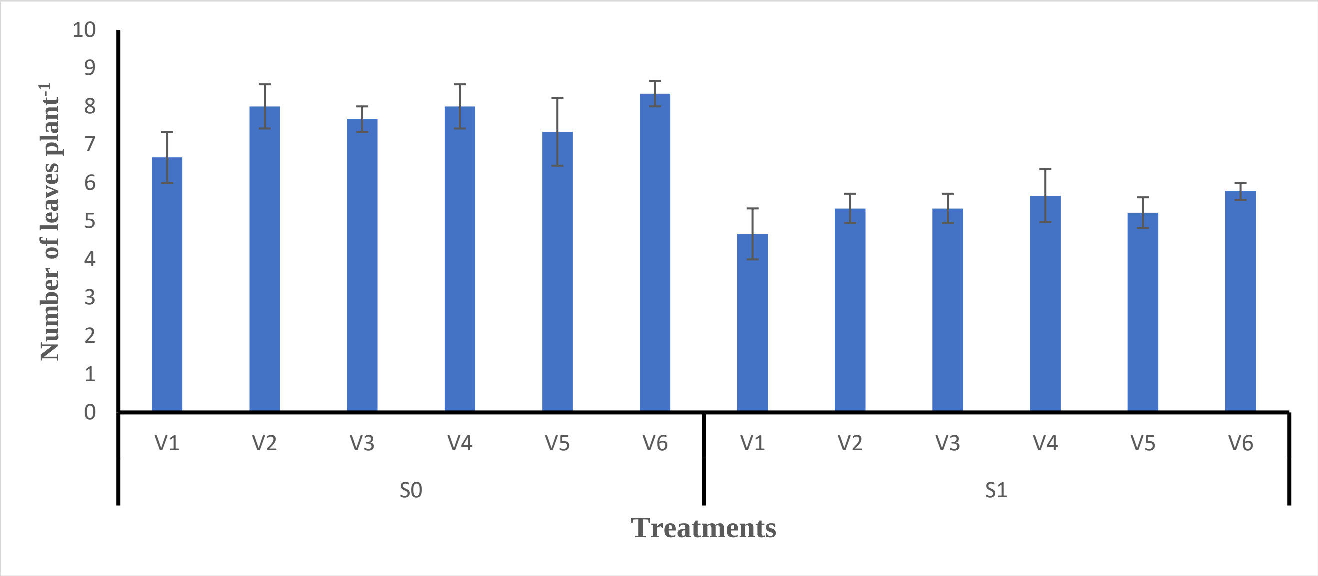

Figure 3. Salinity and variety impact on number of leaves per plant

Root and shoot fresh weight

Salinity level affected roots and shoots fresh weight at 0 and 10 dS m^{-1} ($p < 0.01$) (Figure 4) The maximum fresh weight of roots and shoots (19.30 g and 23.50 g plant-1, respectively) was obtained after treatment with 0 dS m^{-1} NaCl. The fresh weight of the roots and shoots was lowest in FH-793 with 10 dS m^{-1} NaCl (7.49 and 9.70 g plant-1, respectively). As salt concentration rose, shoot and root fresh weight significantly decreased because higher NaCl content may shut down early seedling development owing to osmotic stressors (Giaveno et al. 2007). According to Hoque et al. (2015) and Hameed et al. (2008), the elevated salt content mostly had a negative impact on the fresh weight of the root. Overall biomass output declines when salt levels rise (Hussain et al. 2009).

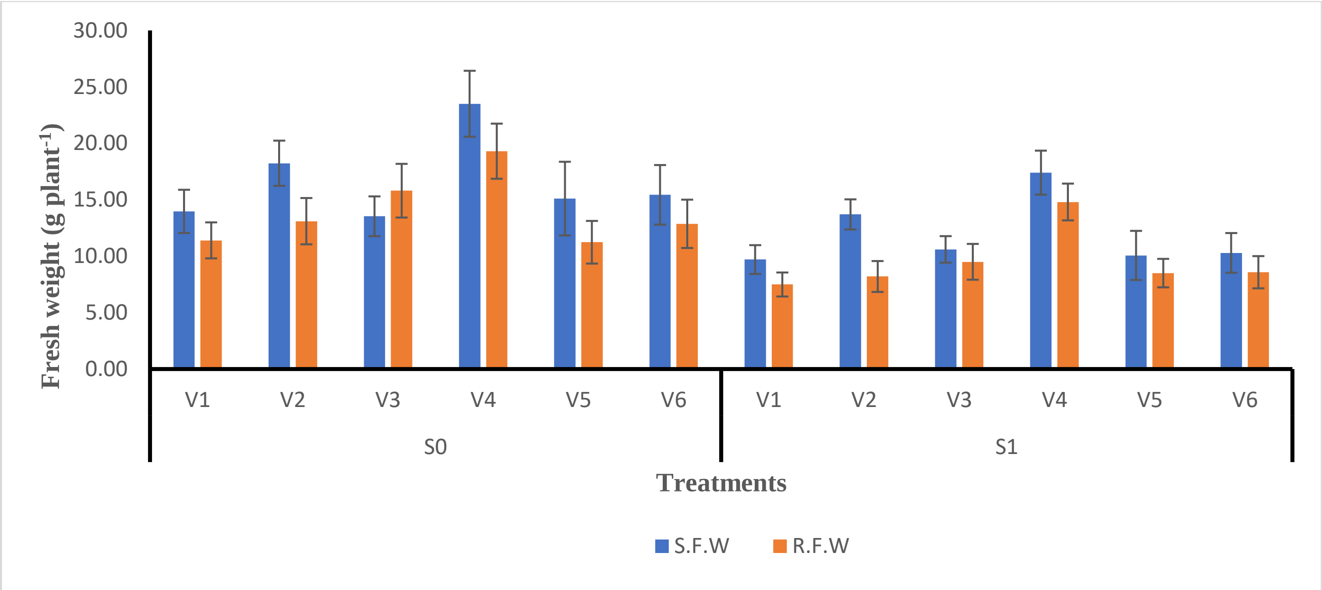

Figure 4. Salinity and variety impact on root and shoot fresh weight

Root and shoot dry weight

The roots and shoots dry weight at 0 dS m^{-1} and 10 dS m^{-1} was significantly affected by NaCl (Figure 5). The treatments V2S0 and V4S0 in 0 dSm^{-1} NaCl had the largest dry weights of roots and shoots (6.07 g plant^{-1} and 4.6 g plant^{-1}). Nevertheless, V4S1 and V2S1 with 10 dS m^{-1} NaCl had the lowermost dry weights (2.82 g plant^{-1} and 2.06 g plant^{-1}, respectively). The dry biomass decreased as a result of the notable decrease in root and shoot biomass seen below elevated salinity (Hussain et al. 2009).

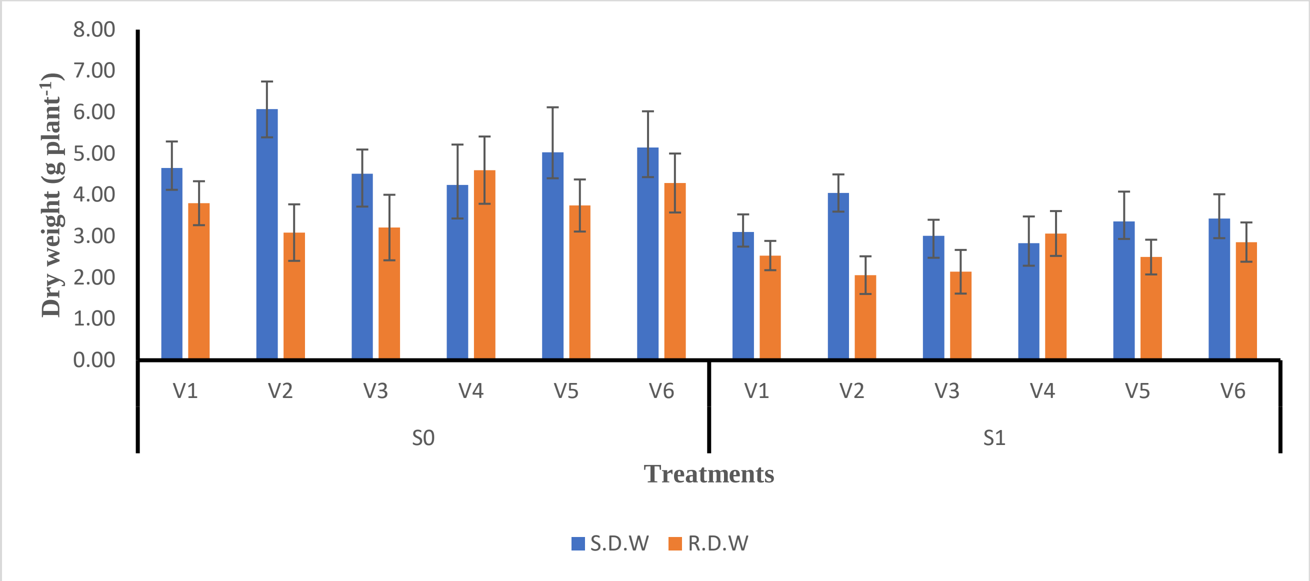

Figure 5. Salinity and variety impact on root and shoot dry weight

CONCLUSIONS

Salinity significantly impacted the development of several varieties of maize. The highest growth was recorded in the cultivar namely YH-1148. On the contrary, maize cultivars i.e. FH-793 and FH-949 showed the highest sensitivity to salinity stress and significantly low growth. Therefore, we strongly recommend the cultivation of maize cultivar YH-1148 on the salt effected soils. Findings of this study will pave the pathway and enable the farmers and policymakers to live with salinity and formulate the policies accordingly.

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AUTHOR CONTRIBUTIONS

Conceived and designed the study: M Ali and W Hassan, Executed the study: A Ullah: Analyzed the data: A Ullah and K Mubeen: Wrote the draft of manuscript: A Ullah, M Ali and W Hassan, Revised the draft: M Ali and W Hassan.

COMPETING OF INTEREST

No conflicts of interest have been disclosed by the authors.

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