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Interactive effect of ultraviolet-B and mineral nutrients on accumulation and translocation of trace elements in wheat crop

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Abstract

Field study was conducted in two wheat cultivars (*Triticum aestivum* L. cv. HD 2329 and HUW 234) by supplimenting UV-B irradiation with different levels of mineral nutrients in order to evaluate the accumulation and translocation of trace elements. sUV-B significantly affected accumulation and translocation of most of the metals studied. Application of nutrients at higher doses enhanced the accumulation of trace elements in plants and grains of both cultivars. A higher dose of nutrient along with sUV-B resulted in increased accumulation of lead both in plants and grains, cadmium and chromium in grains, and copper in plants and decreased accumulation of cadmium in plants, copper in grains, chromium in plants and iron in plants and grains of both the tested cultivars. Nickel concentration increased in plants of HUW 234 due to simultaneous stress. Trace element concentration did not differ noticeably in the tested cultivars but the stress response differed perceptibly. Cultivar HD 2329 showed more significant interaction than HUW 234.

Key words

Mineral nutrients, *Triticum aestivum,* Ultraviolet-B, Trace elements

Introduction

The increase of nutrients in edible food is a challenge for every researcher. Also, application of radiation has revolutionized current day research in the field of agricultural science and food technology (Maity *et al.,* 2009). Trace elements are essential components of biological structures, but at the same time they can be toxic at concentrations beyond those necessary for their biological functions. In addition, there is a danger of toxicity extended to other non-essential elements of very similar atomic characteristics that can mimic the reactivity of a trace element (Fraga, 2005). The presence of trace elements in food is often determined by availability of metals in the soil.

Plants are exposed to UV-B and other xenobiotics simultaneously in today's industrialized world (Rathore *et al.,* 2003; Agrawal *et al.,* 2004a; Agrawal *et al.,* 2006). Previous studies suggests that the uptake and translocation of trace element within the plant can effect elevated UV-B radiation (Yue *et al.,* 1998; Premkumar and Kulandaivelu, 2001; Misra *et al.,* 2010). Plant response to UV-B can further be modified by nutrient application. Fertilization practices have been recognized as a major factor that determines the bioavailability of metals in the soil (Smolders *et al.,* 1998). Evidence of interaction between UV-B exposure and mineral nutrients in plants has emerged in recent years (Tosserams *et al*., 2001; Agrawal *et al.,* 2006; Agrawal and Rathore, 2007).

Wheat, is one of the 'big three' cereal crops and one of the major source of food with over 600 million tonnes being harvested annually. History of wheat cultivation for human dietary purposes can be traced back to 10,000 years (Shewry, 2009). A wide inter- and intra-specific responses to UV-B have been reported among various plants (Kramer *et al*., 1991; Feng et al., 2000, 2003) including wheat variety (Agrawal *et al.,* 2004a, b).

However, studies on the effect of UV-B on plant trace element accumulation was limited to some specific trace elements and no study was made on the accumulation and translocation of soil-occurring trace elements in combination with mineral nutrients. In view of the above, the present study was aimed to investigate and compare the effect of UV-B independently as well as in combination with mineral nutrients on accumulation of trace element viz. Pb, Cd, Ni, Cu, Cr and Fe on vegetative part of plant and its translocation via reproductory parts to seeds (in this study grains) in two cultivars of *Triticum aestivum* L (cultivar HD 2329 and HUW 234).

Materials and Methods

The study was performed at the agricultural farm of Allahabad Agricultural Institute located in Allahabad city of the state of Uttar Pradesh (India), situated at 24°47' N latitude and 82°21' E longitude, and 96m above mean sea level. Genetically similar seeds of two cultivars of wheat (*Triticum aestivum* L. cv. HD 2329 and HUW 234) were sown separately under field conditions in 24 plots of size 1m × 1m. After germination, plants were thinned in each row (spaced 30 cm apart) for uniformity in growth to one plant at every 15 cm. Four border rows were sown around each plot in order to minimize heterogeneity in microclimate.

The experimental design was a split plot with UV-B treatments as whole plots and fertilizer treatments as the sub plots randomized within the whole plots. Each treatment was replicated three times. The experiment had two factors (i) sUV-B treatment and (ii) fertilizer treatments. Effects of the factors were studied singly and in combination. Four different fertilizer treatments were as follows : F0 without NPK application; recommended dose (i.e. 120, 80 and 60 kg ha^{-1} N, P and K, respectively) of NPK (RD), F1; F1.5 1.5 times of RD; F2 double of RD. N, P and K were applied in the form of urea, single superphosphate and muriate of potash, respectively. Corresponding sUV-B treatment sample were designated as F0T, F1T, F1.5T and F2T. A half dose of N and full dose of P and K were given as basal dose and remaining half dose of N was given as top dressing.

UV-B treatment was started just after emergence of seedlings and provided till maturity of crop (140 Days after sowing for HD 2329 and 125 days for HUW 234). Supplemental level of UV-B was provided by Q-Panel UV-B 313 fluorescent lamp (Q-Panel, Cleveland, USA) 6 hrs per day during photoperiod with 6.8 mW cm^{-2} intensity till the maturity of crop. For UV-B treatment, four lamps per bed were suspended above and perpendicular to the planted rows on adjustable steel frame at all experimental plots. The lamps were covered with either 0.13 mm cellulose diacetate filters (Cadillac Plastics, Baltimore, USA) which absorbed radiation emitted by lamps below 280 nm (to exclude UV-C radiation) for sUV-B (Supplemental UV-B) radiation or with 0.13 mm polyester filters (absorbed radiation below 320 nm) for control. Intensity of lamps on the top of plant canopy was measured by ultraviolet intensity meter (UP Inc., San Gabriel, USA) and maintained by adjustable steel frames. The readings were converted to $UV\text{-}B_{BE}$ values by comparing with Spectro Power Meter (Scientech, Boulder, USA). Plants under polyester filter lamps received only ambient UV-B (8.6 KJ m^{-2} $UV\text{-}B_{BE}$) on the summer solstice weighted against generalized plant response action spectrum. The plant beneath cellulose diacetate film received $UV\text{-}B_{BE}$ (ambient +7.1 KJ m^{-2}) that mimicked 20 % reduction in stratospheric ozone in Allahabad (20̂ 47'N) during clear sky conditions on the summer solstice (Green *et al.,* 1980) normalized at 300 m. The ozone column thickness was assumed at 3.0 mm, the albedo 0 and the scatter 1.0. After full maturity, the plants were harvested. Plant and grain samples were used for analysis.

Plants and grains were sampled randomly in triplicates from respective treatments after maturity of crop. Quantitative analysis of vegetative parts showed accumulation of trace element in plant body while quantitative analysis of grains provided information on concentration of trace element translocated from plants to grain. For trace element analysis, samples (1 g) were digested by adding tri-acid mixture (HNO_3, H_2SO_4, and $HClO_4$ in 5:1:1 ratio) at 80° C until a transparent solution was obtained (Allen *et al.,* 1986). After cooling, the digested sample was filtered using Whatman no. 42 filter paper, and maintained at a volume of 50 ml with deionised water. The concentration of soil available elements in plants were determined by Atomic Absorption Spectrophotometer (Model 2380, Perkin-Elmer, Inc., Norwalk, CT, USA) fitted with specific lamp of particular metal using appropriate drift blank

Effects of factors, sUV-B treatment, fertilizer dose and their interactions were determined by using SPSS software (SPSS Inc., version 10.0). Multivariate Analysis of Variance (ANOVA) test was conducted to test the significant effects of UV-B treatment, fertilizer dose and their interactions on data recorded and presented in Table 1.

Results and Discussion

UV-B radiation has not only been an ecological regulated factors since it varies with the time of day and year, latitude and cloud cover (Rozema *et al.*, 1997), but also stressed one (Rozema *et al.*, 1997; Jansen *et al.*, 1998). The effects of enhanced UV-B radiation on earth's ecosystems might increase in future (Madronich *et al.,* 1998). A wide range of biochemical, physiological, morphological, anatomical and growth responses of plants have been reported to elevate UV-B radiation (Caldwell *et al.,* 1998; Feng *et al.,* 2000, 2003; Zhang *et al.,* 2003; Agrawal *et al.,* 2005). Research on the effect of UV-B on plant trace element accumulation is scarce; however few studies (Yue *et al.,* 1998; Premkumar and Kulandaivelu, 2001) have described the possibility of direct effect of increased solar UV-B radiation on nutrient uptake. In the present study, it was observed that mineral nutrients increased the accumulation and translocation of trace elements in both wheat cultivars which was further influenced by UV-B treatment.

No such function of lead was reported in plant's metabolism, in fact it was considered toxic for plants. In this study, nil concentration of lead was found in plant and very low in grains with F0 treatment. Accumulation of lead increased with application of mineral nutrients which was further enhanced by sUV-B irradiation in both the varieties of wheat (Fig. 1, 2). Enhancement in lead after UV-B exposure was higher in HUW 234 than HD 2329. Accumulation of lead to wheat grain was higher than vegetative portion which further increased by nutrient application and UV-B treatment. Statistically, difference in accumulation of lead was significant at treatment and fertilizer dose in plant and grains of HD 2329 and at fertilizer dose in grains of HUW 234 (Table 1). Uptake of Pb in plants is regulated by pH, particle size and exchange capacity of the soils as well as by root exudation and other physico-chemical parameters (Sharma and Dubey, 2005). A similar study by Premkumar and Kulandaivelu (2001) also reported increased Pb concentration in cowpea seedlings after UV-B exposure.

Cadmium may be easily absorbed by plants and it may also be accumulated in agricultural products, in concentrations that can even be considered toxic for some plant species (Izadiyar and Yargholi, 2010). Addition of Cd contaminated plants in human diet can cause several disorders including prostate cancer (Miller *et al.,* 1995). Experiments conducted in the present study showed increased Cd concentration in plant and grains due to application of mineral nutrient in both the varieties. UV-B supplementation reduced Cd accumulation in plants while translocation to grain was increased in both the cultivars (Fig. 1, 2). HUW 234 accumulated less Cd as compared to HD 2329. Analysis of variance showed non-significant difference in accumulation of cadmium in plants and significant accumulation in grains of HD 2329 and HUW 234, significant for treatment in plants and treatment and fertilizer dose in grains (Table 1). The accelerated uptake of Cd not only suggests an increase in cell permeability but also supports the earlier reports on the damage of biomembranes due to UV-B and heavy metals. Agrawal and Mishra (2009) observed increased uptake of Cd after UV-B exposure in pea plants. Izadiyar and Yargholi (2010) reported variable Cd level in different plant parts of sorghum, sainfoin and clover while in alfalfa Cd accumulation was higher in roots than aerial parts.

Copper and nickel increased in UV-B exposed plants in both the cultivars. The increase was minimum in F1 for copper (2.98% in HD 2329 and 7.81% in HUW 234). A reverse trend of copper translocation was observed in grains of tested cultivars after sUV-B exposure. Nickel increased further in grains with

Table 1 : Variance ratio of *Triticum aestivum* L. cultivars HD 2329 & HUW 234 grown with and without sUV-B at varying fertility levels

Wheat cultivar		Trace element	Treatment (T)	Fertilizer Dose (F)	T×F
HD 2329	Plant	Lead	**	***	NS
		Cadmium	NS	NS	NS
		Copper	***	***	***
		Nickel	***	***	**
		Chromium	***	***	***
		Iron	***	**	NS
	Grain	Lead	NS	***	NS
		Cadmium	***	***	***
		Copper	**	**	NS
		Nickel	**	***	***
		Chromium	***	***	***
		Iron	***	***	***
HUW 234	Plant	Lead	NS	NS	NS
		Cadmium	*	NS	NS
		Copper	NS	NS	NS
		Nickel	NS	NS	NS
		Chromium	***	***	***
		Iron	***	***	***
	Grain	Lead	NS	***	NS
		Cadmium	***	**	NS
		Copper	**	**	NS
		Nickel	***	***	*
		Chromium	***	***	***
		Iron	***	***	***

Level of significance: *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$, NS= Not Significant

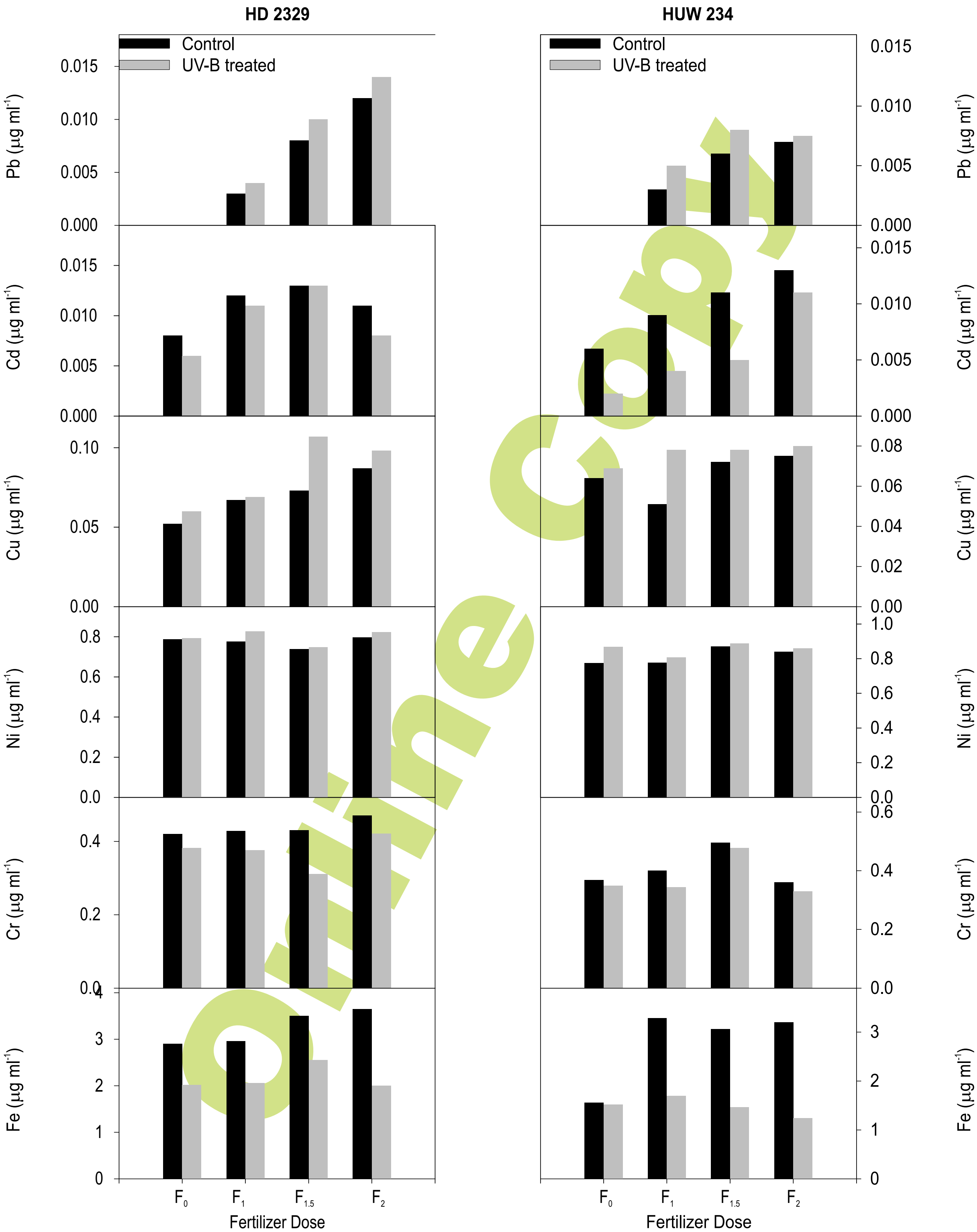

Fig. 1 : Effect of sUV-B radiation on trace element concentration in plants of *Triticum aestivum* L. var. HD 2329 and HUW 234 under varying levels of fertilizers

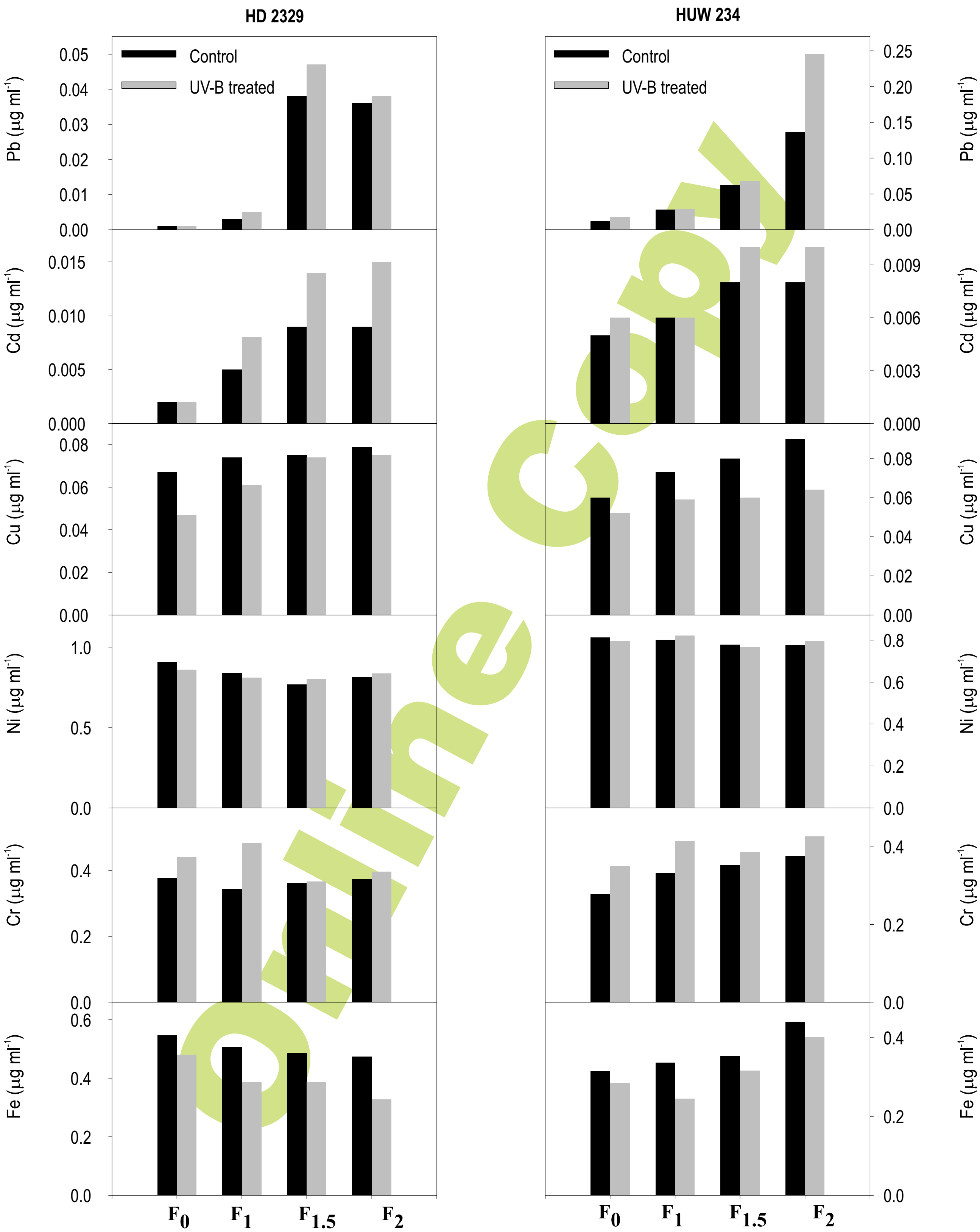

Fig. 2 : Effect of sUV-B radiation on trace element concentration in grains of *Triticum aestivum* L. var. HD 2329 and HUW 234 under varying levels of fertilizers

higher nutrients amendment (Fig. 1, 2). Significant difference in copper accumulation in grains of HD 2329 was observed in UV-B treatment, fertilizer dose and their combined treatment (Table 1). Copper content was less in grains than plants. In the present investigation, nickel content was not affected by simultaneous stress of UV-B and mineral amendment in $F_{1.5}T$ of HD 2329 plants. UV-B exposure decreased nickel content of grains in F_0T and F_1T in HD 2329 cultivar and F_0T and $F_{1.5}T$ in HUW 234 cultivar, respectively. Premkumar and Kulandaivelu (2001) reported increased nickel content in primary and trifoliate leaves of cowpea seedlings.

Chromium decreased in the plants of both wheat cultivars after sUV-B exposure with minimum decrease at F2 in HD 2329 (10.42%) and F1.5 in HUW 234 (3.43%) cultivars. Contrary to plants, accumulation of chromium in grain increased in sUV-B exposed plants. Concentration of Cr was similar in vegetative part and seeds suggesting low mobility of element in wheat. Minimum increase of chromium in grains was found in mineral nutrients amended plants (Fig. 1, 2). Statistically, decrease and increase of chromium in plants and grains was significant (Table 1). Decreased chromium level in leaves and increased chromium level in grains showed higher translocation of chromium from leaves to grains due to high energetic ultraviolet radiation.

Iron concentration decreased in grains and plants of both cultivars after exposure to UV-B radiation. A low iron content was allocated from plants to grain. Decrease in iron was higher in plants than grains (Fig. 1, 2). Analysis of variance showed significant difference in iron accumulation in plants and grains of both cultivars for UV-B treatment and nutrient levels (Table 1). Decreased iron in the present study is contrary to the results of Yue *et al.* (1998) who reported high ferrous level in leaves and grains of UV-B exposed *Triticum aestivum*. Rosa *et al.* (2001) observed high ferrous content at low UV-B intensity with high and low nutrients concentration in silver birch seedlings, which decreased with increased UV-B intensity in both fertility regimes.

Zeppa *et al.* (2007) reported that solar UV radiation has significant effect on the chemical speciation of trace metals. Change in trace element accumulation in plant body and their translocation to grains of tested plants due to independent and simultaneous effect in this study could be explained as transformation of available form of trace elements due to UV-B stress or mineral interactions.

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