**Introduction**

Zinc is an essential element for crop production and optimal size of fruit, also it required in the carbonic enzyme which present in all photosynthetic tissues, and required for chlorophyll biosynthesis (Graham et al., 2000; Ali et al., 2008; Mousavi, 2011; Xi-Wen et al., 2011). In addition, zinc will contribute on the pollination by impact on the pollen tube formation (Marschner, 1995; Outten et al., 2001; Pandey et al., 2006). Nanomaterials are cornerstones of nanoscience and nanotechnology. Nanomaterials are of interest because at this scale unique optical, magnetic, electrical, and other properties emerge. These emergent properties have the potential for great impacts in electronics, medicine, agriculture, and other fields. Nanoparticles (NPs) with small size and large surface area are expected to be the ideal material for use as a Zn fertilizer in plants. It has been stated that application of micronutrient fertilizers in the form of NPs is an important route to release required nutrients gradually and in a controlled way, which is essential to mitigate the problems of fertilizer pollutions (Naderi and Abedi, 2012). In calcareous soils solubility of micronutrients is similar Zn far less due to high pH, and this reduces ability of nutrient uptake by plants and naturally plants requirement increases to these elements (Alloway, 2008 and Mousavi et al., 2007). Foliar spraying of fertilizers has been considered an important strategy to biofortify crops, because it has

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**Effect of zinc nano-chelate foliar and soil application on qualitative and quantitative characteristics of maize (Zea mays L.) at different stages of growth**

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**Abstract**

In order to investigate the effect of zinc nano-chelate foliar and soil application on qualitative and quantitative characteristics of maize (Zea mays L.) at different grown stages, an experiment was conducted in the factorial form based on a completely randomized block design with three replications during growing seasons of 2013-2014. Treatments were nano-chelate zinc application in four levels: a$_1$: soil application, a$_2$: foliar application, a$_3$: soil application + foliar application, a$_4$: control and different growth stage in three levels contain b$_1$: 8-10-leaves stage, b$_2$: taselling and b$_3$: SA grain filling stage. The analysis of variance showed significant effect of Zn nano-chelate application and different growth stage on stem dry weight. Also, effect of Zn-chelate application on husked ear weight, ear length, cob dry weight and grain to cob weight ratio was significant (p<0.01). The detailed results of the study showed that Zn nano-chelate foliar application at 8-10 leaves stage had more stem dry weight (34%). Moreover, Zn nano-chelate foliar application had 54%, 13%, and 39% more husked ear weight, ear length and cob dry weight, respectively.

**Keywords**: Corn, foliar application, growth stage, nano-chelate zinc and soil application
shown to improve absorption and/or translocation of minerals via xylem, it enhances the vegetative growth and yield and it may stimulate the synthesis of nutritional and functional compounds (Gomez-Galera et al., 2010). Soil and/or foliar applications of zinc also brings several agronomic benefits for crop production (Mirvat et al., 2006).

The aim of this study was to investigate the effects of zinc nano-chelate foliar and soil application on qualitative and quantitative characteristics of maize (Zea mays L.) at different growth stages.

Materials and Methods
The field experiment was carried out in factorial form by completely randomized block design with three replicates at the Research Station of the Islamic Azad University, Tabriz Branch, north-western Iran, during 2013 - 2014. The first factor was nano-chelate zinc application in four levels: a1: soil application, a2: foliar application, a3: soil application + foliar application and a4: control. The second factor was different growth stage in three levels [b1:8-10-leaves stage, b2: tasselling, b3: SA grain filling stage. Each plot consists of 4 rows, 75 cm row spacing and 25 cm plant interval. There were 2-5 seeds beside each other and they were thinned at three leaves stage to obtain plant density of 5 plants per m². On the basis of the soil test (Table - 1), 1 in 1000 foliar application and 4 Kg / ha¹ were determined. Taking into account the size of the plots and in order to ease foliar application and to increase the delicacy of the spraying, a hand sprayer was used. In order to have an even and efficient spraying, 50 cm distance from the plants seemed reasonable. The spraying was carried out thoroughly until the foliar was dropping from the plants. Furthermore, Tween 80 was used as surfactant to have the leaves absorb nutrient mineral. The control plots were water sprayed consistently to avoid the effects of foliar application used for experimental plots. Stem dry weight, husked ear weight, ear length, cob dry weight and grain to cob weight ratio were recorded.

Statistical analysis
In order to check the normality of data, analysis of variance, and mean comparison MSTAT-C software were used. The means of the treatments were compared using the DMRT (Duncan’s Multiple Range Test) at p<0.05.

Results and Discussion
The analysis of variance showed significant interaction effects of Zn nano-chelate application and different growth stage on the stem dry weight and number of row/ear. Also, effect of Zn-chelate application on husk ear weight, ear length and cob dry weight was found to be significant (Table - 2).

Stem dry weight
Results showed that Zn nano-chelate foliar application at 8-10 leaves stage had the highest (222 g) (Table - 3). While control had the lowest (165/45 g) stem dry weight. Average comparison related to Zn nano-chelate using showed the stem dry weight increased 34% compared with the control. Significant relationships between grain yield and biomass at anthesis or biomass during grain filling have been reported in bread wheat (Turner, 1997), barley (Ramos

### Table - 1. Physical and chemical analysis of Soil

<table>
<thead>
<tr>
<th>pH</th>
<th>Ec* 10³</th>
<th>N %</th>
<th>Available Mn (PPM)</th>
<th>Available Zn (PPM)</th>
<th>Available P (PPM)</th>
<th>Available K (PPM)</th>
<th>Sand %</th>
<th>Silt %</th>
<th>Clay %</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/25</td>
<td>1/76</td>
<td>0/056</td>
<td>0/84</td>
<td>1/08</td>
<td>0/8</td>
<td>168</td>
<td>76</td>
<td>14</td>
<td>10</td>
</tr>
</tbody>
</table>
Future gains in yield potential must largely be achieved by developing cultivars with greater biomass whilst maintaining a high harvest index (Slafer et al., 1999).

**Husked ear weight**

Based on the results, the highest (206 g) husked ear weight was related to Zn nano-chalate foliar application (Table - 3). This treatment had more husked ear weight (54%) than control (without Zn application treatment). There was no significant effect observed between Zn foliar application and soil application, and Zn and Zn demonstrated that micronutrients in the form of NPs can be used in crop production to increase yield.

**Ear length**

Zn nano-chalate foliar application and control had the highest (23/56 cm) and lowest (20/78 cm) ear length respectively (Table - 4). Zarei et al. (2012) reported that ear length was effective for yield improvement since it revealed positive and significant relationship with grain yield. Gautam et al. (1999) reported the highest relation between grain yield and number of grains per row, plant height and length of cob.

**Table 2. The analysis of variance of measured traits**

<table>
<thead>
<tr>
<th>S.O.V</th>
<th>df</th>
<th>Stem dry weight</th>
<th>Husked ear weight</th>
<th>Ear length</th>
<th>Cob dry weight</th>
<th>Grain to cob weight ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rep</td>
<td>2</td>
<td>1017 *</td>
<td>4771 **</td>
<td>3/66 ns</td>
<td>15/54 ns</td>
<td>37/74 ns</td>
</tr>
<tr>
<td>NZn</td>
<td>3</td>
<td>2071**</td>
<td>10296*</td>
<td>15/05**</td>
<td>78/92*</td>
<td>343/56**</td>
</tr>
<tr>
<td>GS</td>
<td>2</td>
<td>146 ns</td>
<td>1102 ns</td>
<td>9/80 ns</td>
<td>2/36 ns</td>
<td>186/26**</td>
</tr>
<tr>
<td>Zn × GS</td>
<td>6</td>
<td>1027**</td>
<td>739 ns</td>
<td>3/71 ns</td>
<td>20/97 ns</td>
<td>106/88**</td>
</tr>
<tr>
<td>Error</td>
<td>22</td>
<td>223</td>
<td>1133</td>
<td>4/39</td>
<td>21/18</td>
<td>137/29</td>
</tr>
<tr>
<td>CV</td>
<td></td>
<td>7/74</td>
<td>18/38</td>
<td>9/23</td>
<td>14/86</td>
<td>45/99</td>
</tr>
</tbody>
</table>

* and ** significant at 5% and 1% respectively, NZn: nano-chalate Zn, GS: Growth Stage

**Table 3: Mean comparison of Zn nano-chalate application and different growth stage on traits**

<table>
<thead>
<tr>
<th>Growth Stage</th>
<th>NZn</th>
<th>Stem dry weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-10 leaves</td>
<td>SA</td>
<td>221/03 ab</td>
</tr>
<tr>
<td></td>
<td>FA</td>
<td>222/67 a</td>
</tr>
<tr>
<td></td>
<td>SA + FA</td>
<td>192/17 abcd</td>
</tr>
<tr>
<td></td>
<td>control</td>
<td>195/28 abcd</td>
</tr>
<tr>
<td>Tasseling</td>
<td>SA</td>
<td>182/87 bcd</td>
</tr>
<tr>
<td></td>
<td>FA</td>
<td>208/48 abc</td>
</tr>
<tr>
<td></td>
<td>SA + FA</td>
<td>170/58 cd</td>
</tr>
<tr>
<td></td>
<td>control</td>
<td>209/41 abc</td>
</tr>
<tr>
<td>Seed-filling</td>
<td>SA</td>
<td>187/99 abcd</td>
</tr>
<tr>
<td></td>
<td>FA</td>
<td>193/21 abcd</td>
</tr>
<tr>
<td></td>
<td>SA + FA</td>
<td>165/45 d</td>
</tr>
<tr>
<td></td>
<td>control</td>
<td>167/43 d</td>
</tr>
</tbody>
</table>

NZn: nano-chalate Zn, GS: Growth Stage, SA: Soil application, FA: Foliar application, SA+FA: Soil application + foliar application

**et al., 1985** and durum wheat (Ramadani, 2004). Future gains in yield potential must largely be achieved by developing cultivars with greater biomass whilst maintaining a high harvest index (Slafer et al., 1999).
Cob dry weight

Our results also showed that the highest cob dry weight was related to nano-chalate Zn foliar application (32/92 g). Whereas, control (without application) had the lowest cob dry weight (23/66 g), (Table - 4). This treatment had more cob dry weight (39%) than without Zn application treatment. Cobs, central part of maize are important residues of corn processing and consumption. For every 1 kg of dry corn grains produced, about 0.15 kg of cobs (USDA, 2011). Corn cobs have several advantages compared with using all of the stover for both thermochemical and fermentation conversion platforms. Crofcheck and Montross (2004) found that cobs had the highest glucose concentration during enzyme hydrolysis compared with other stover fractions with and without pretreatment. This means the cob fraction had the highest quality as a cellulosic fermentation feedstock.

Grain to cob weight ratio

Based on the results, the highest (26/41) grain to cob weight ratio was related to Zn nano-chalate foliar application (Table - 4). Mohammadi (2003) reported that percent of cob had high significant negative relation with grain yield.

Conclusion

It could be concluded that, use of nano-chalate zinc foliar application had a positive effect on indirect yield components (stem and cob dry weight, husked ear weight and ear length) of maize. Based on the results, Zn nano-chalate foliar application had the highest husked ear weight, ear length, cob dry weight and grain to cob weight ratio. Zinc foliar application of Zn-nano chalate treatment at 8-10 leaves stage also had The chalate treatment at 8-10 leaves stage also had the highest stem dry weight, suggesting that the soil application and foliar application could be considered to enhance qualitative and quantitative characters in maize.

References


Table – 4. Mean comparison of Zn nano-chalate application on traits

<table>
<thead>
<tr>
<th>Zn nano-chalate application</th>
<th>Husk ear weight with (g)</th>
<th>Ear length (cm)</th>
<th>Cob dry weight (g)</th>
<th>Grain to cob weight ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil application</td>
<td>194/7 a</td>
<td>23/25 a</td>
<td>31/73 a</td>
<td>24/14 a</td>
</tr>
<tr>
<td>Foliar application</td>
<td>206/76 a</td>
<td>23/56 a</td>
<td>32/92 a</td>
<td>22/99 ab</td>
</tr>
<tr>
<td>Soil application + foliar application</td>
<td>198/12 a</td>
<td>23/24 a</td>
<td>26/60 b</td>
<td>26/41 a</td>
</tr>
<tr>
<td>Control</td>
<td>132/97 b</td>
<td>20/78 b</td>
<td>23/66 a</td>
<td>20/28 b</td>
</tr>
</tbody>
</table>


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