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Physiological, Growth and Yield Responses of Yellow Squash and Snapbean to a Potassium and Zinc Foliar Fertilizer

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Yellow squash (*Cucurbita pepo* L.) and snapbean (*Phaseolus vulgaris* L.) are two of the main vegetable crops grown in south Florida. A field study was conducted to evaluate the effectiveness of a foliar-applied commercial fertilizer formulation (Strong Billow K®) containing potassium (K), zinc (Zn) and organic carbon on physiology, growth and yield of yellow squash and snapbean. Each crop was divided into three treatments: (T1) control (foliar applications of tap water), (T2) foliar applications of Strong Billow K® at the manufacturer's recommended rate (2.5 ml L^{-1}), and (T3) foliar application of K (as K_2O) and soluble Zn, applied at the same concentration as in the Strong Billow K® treatment. Application of Strong Billow K® had a positive effect on the leaf chlorophyll index (SPAD values), variable to maximum chlorophyll fluorescence ratio (Fv/Fm), net CO_2 assimilation (*A*), stomatal conductance (g_s), transpiration (*E*), and total fruit number per plant of squash and snapbean, as well as total fruit weight per plant of snapbean compared to the other two treatments. The effectiveness of Strong Billow K® on improving physiology, growth, and yield of yellow squash and snapbean were not due solely to the addition K and Zn in the Strong Billow K® formulation because applying these elements alone was no more effective than the control treatment.

The application of foliar fertilizers can decrease nitrogen (N), phosphorous (P), and potassium (K) soil fertilizers by up to 25%, thus reducing soil pollution and enhancing soil fertility (Alexander and Schoeder, 1987). Foliar fertilizers have been shown to increase net CO_2 assimilation (*A*), transpiration (*E*), stomatal conductance (g_s) (Haytova, 2015), vegetative and fruit biomass (Dimpka and Bindraban, 2016), and crop yield (Fageria et al., 2009). An advantage of foliar fertilizers over soil-applied formulations is that foliar fertilizers are often absorbed more rapidly than soil-applied fertilizers. Therefore, nutrients become available and accessible to the plant in a relatively short time (Baloch et al., 2008).

In addition to nutrient elements, commercial foliar fertilizer formulations often contain additional substances including vitamins, phytohormones, amino acids, humic acids, and adjuvants. Some of these substances provide additional benefits to the plant. For example, humic acids have been shown to increase soil water holding capacity (Behzad, 2014), plant dry weight, (Khaled and Fawy, 2011) and crop yields (Bakry et al., 2013).

Yellow squash (*Cucurbita pepo* L. cv. Enterprise) and snapbean (*Phaseolus vulgaris* L. cv. Caprice) also called green bean, are two of the main vegetable crops grown in Miami-Dade County, FL (Seal et al., 2016). Florida accounts for about 90% of the United States squash and fresh snapbean production. About 57% (11,050 ha) of Florida's snapbeans are grown in Miami-Dade County with a yield/ha of 321–494 bushels (13.6 kg = 1 bushel) (Zhang et. al., 2017). Miami-Dade grows about 2430 ha of yellow squash i and accounts for about 21% of Florida's yellow squash production (Hochmuth and Hanlon, 2017). The yield/ha is 741–1111 bushels (19.1 kg = 1 bushel) (Seal et. al., 2016). In southern Florida, yellow squash and snapbean are grown in oolitic limestone soils classified as Krome or Chekika very gravelly loam, characterized as loamy-skeletal, carbonatic hyperthermia lithic rendolls (Noble et al., 1996). These soils are alkaline (pH of 7.2–8.0), low in organic matter, very porous and have very low water- and nutrient-holding capacities (Li, 2001). Due to the high pH of these soils, minor elements applied to the soil are often bound or precipitated and not available to the plants unless applied as very expensive chelated formulations (Li, 2001). Application of foliar fertilizers, particularly minor elements, can overcome these soil nutrient limitations. Thus, identifying effective foliar micronutrient formulations is of paramount importance for vegetable crops grown on alkaline soils.

The objective of this study was to evaluate the effectiveness of a commercial foliar fertilizer formulation (Strong Billow K®; Grupo, Kaikun S.A.S., Medellin, Colombia) containing K_2O, zinc (Zn), and organic carbon on the physiology, growth, and yield of yellow squash and snapbean grown in an alkaline soil.

Materials and Methods

The study was conducted from 19 Dec. 2017 to 15 Feb. 2018 at the Tropical Research and Educational Center (UF-TREC) in Homestead, FL. (Lat. 25º30'40.809" N; Long. 80º30'3.983"). During the experiment, air temperature, humidity, rainfall and evapotranspiration data were collected from a Florida Automated

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Weather Network (FAWN); <http://fawn.ifas.ufl.edu/> weather station located at UF-TREC. Evapotranspiration was calculated using the Blaney-Criddle method and the irrigation rate was calculated based on soil volumetric water content (Allen and Pruitt, 1986).

Yellow squash and snapbean were planted from seed on two raised beds, each 91.4 m long × 0.91 m wide × 0.18 m high with 1.83 m between centers. Prior to planting a 6–12–12 (N–P–K) granular fertilizer that contains 1.83% NO_2, 2.10% $CO(NH_2)_2$ soluble in water, 2.08% of $CO(NH_2)_2$ insoluble in water, 12% K_2O, 12% P_2O_5, and microelements including 0.25% Zn (Nutrient Agricultural Solutions, Homestead, FL) was soil-applied to each bed at 1307 kg·ha^{-1} in two furrows, each 0.20 m from and parallel to either side of the row and was incorporated 0.15 m into the top soil. Prior to covering the beds with plastic mulch, two polyethylene irrigation tubing (Ro-Drip, USA) with drip emitters spaced 0.3 m apart were placed 0.15 m apart on each side parallel to the center of each bed for irrigation. The beds were then covered with black polyethylene mulch (Kennco micro-combo, Kenco Manufacturing Co Inc., Atoka, OK). Holes (0.07 m diameter) were made manually in the plastic with a metallic hole digger 0.30 m apart within the bed. Two yellow squash seeds were planted in each hole in one-half of each bed and two snapbean seeds were planted in each hole on the other half of each bed. About one week after seeds germinated, the number of plants was thinned to one plant per hole. Beds were drip irrigated twice a day at 10:00 am and 4:00 pm, at a rate of 9.1 L per min/91.4 m for 15 min during the first two weeks, then the irrigation time was increased to 30 min until the end of the experiment. The plants were fertilized through the drip irrigation system twice a week for nine weeks with a 3–0–10 liquid fertilizer containing 2.99% NO_2, 0.01 % NH_3-H, and 10 % K_2O (Helena Chemical Company, Homestead, FL) at a rate of 178 L·ha^{-1} the first two weeks, 234 L·ha^{-1} for weeks three and four, and 297 L·ha^{-1} from week five through the end of the experiment.

Each crop received three treatments: (T1) control (foliar applications of tap water) applied to the point of run-off with a hand sprayer (Roundup sprayer, Fountainhead Group, Inc., New York, N.Y.) at the same time as applications of the other treatments, (T2) foliar applications of Strong Billow K® applied to the point of run off with a hand sprayer at the manufacturer's recommended rate (2.5 mL·L^{-1}) every 10 d beginning 7 d after germination, and (T3) foliar application of 35 g·L^{-1} of K_2O and 15 g·L^{-1} of Zn (the same concentration of K_2O and Zn as is in Strong Billow K® treatment) applied to the point of run off with a hand sprayer every 10 days beginning seven days after germination. The third treatment was included to determine if the effects of Strong Billow K® were due solely to the K_2O and Zn in the Strong Billow K® or to the complete Strong Billow K® formulation. For the first two applications, 5 mL of Strong Billow K® (T2) or K_2O and Zn solution (T3) were mixed with 2 L of water. For the remaining applications, 10 ml of Strong Billow K® (T2) or K_2O and Zn solution (T3) were mixed with 4 L of water. The pH of tap water, K_2O and Zn, and Strong Billow K® solutions were all between 7.3 and 7.5. Treatments for each crop were arranged in a randomized complete block design with five replications (15 blocks, each 3.05 m long with 10 plants) for yellow squash and four blocks (replications) (12 blocks, each 3.05 m long with 10 plants) for snapbean; the space between blocks was 0.61 m.

Net CO_2 assimilation, g_s, E, leaf chlorophyll fluorescence [the ratio of variable to maximum chlorophyll fluorescence (Fv/Fm)], and leaf chlorophyll index (SPAD values) were measured on the adaxial surface of one recently fully expanded mature leaf of 40 plants (8 plants within each of 5 blocks per treatment). There were eight plants in each block with the plants at the ends of each block considered buffer plants which were not measured). For yellow squash, A, g_s, and E were measured on three dates (11, 19, and 27 days after germination) with a CIRAS-3 portable gas exchange system (PP System Inc., Amesbury, MA). For A, g_s and E measurements, the photosynthetic photon flux density (PPFD) in the leaf cuvette, from a halogen light source, was set at 1000 μmol·m^{-2}·s^{-1} quanta, the reference CO_2 concentration in the cuvette was 410 μmol·mol^{-1} CO_2 and the air flow rate into the cuvette was 400 mL/min. The Fv/Fm, an indicator of damage to the photosynthetic apparatus (Krause and Weis, 1991), was measured with an OS-30 hand-held chlorophyll fluorimeter (Opti-Sciences Inc., Hudson, NH) on four dates (11, 29, 27, and 35 d after germination). The leaf chlorophyll index was measured with a SPAD-502 meter (Minolta, Inc., Osaka, Japan) on the same four dates that Fv/Fm was measured. For snapbeans, A, g_s and E were measured on three dates (12, 20, and 28 d after germination). The Fv/Fm and leaf chlorophyll index of snapbean were measured on four dates (12, 20, 28, and 36 d after germination).

Yellow squash fruits were harvested as they matured over a period of four weeks. Snapbeans were harvested 52 d after germination. Fruit number and fruit fresh weight were determined for eight plants in each block of each treatment and expressed as total fruit number and total fruit weight per plant.

Statistical differences among treatment means for fruit yields were determined by one-way analysis of variance (ANOVA) and a Waller-Duncan K-ratio test. Differences among treatments means for physiological variables were determined by repeated measures ANOVA. The SAS 9.4 statistical software package (SAS Institute, Cary, NC) was used for all statistical analyses.

Results

Throughout the experiment, the minimum and maximum temperatures were 4.2 °C and 28.5 °C, respectively, with minimum and maximum mean daily temperatures of 8.1 °C and 24.7 °C, respectively and an average daily temperature of 20.6 °C. During that period, mean daily relative humidity was 79.7%, mean daily rainfall was 0.58 mm, and mean daily evapotranspiration was 2.9 mm. Due to the soil properties, when the soil matrix potential reached between –10 to –30 kPa, the available soil water was 12.74 L/block. The irrigation rate was 9.08 L/block/day for the first two weeks and 18.2 L/block/day until the end of the experiment. For both crops, the mean difference between actual evapotranspiration and the irrigation rate per block was 0.005% in December, 0.007 % in January, and 0.02 % in February.

Yellow squash

The leaf chlorophyll index and Fv/Fm were significantly higher for plants in the Strong Billow K® treatment than for plants in the other two treatments (Fig. 1). There were no significant differences in A, E or g_s among any treatments on the first measurement date (Fig. 2). However, on the second measurement date, plants in the Strong Billow K® treatment had higher A and g_s than plants in the other two treatments and higher E than plants in the control treatment (Fig. 2). On the third measurement date, there were no differences in A among treatments. However, on that date, E was higher for plants in the Strong Billow K® treatment than in the other treatments, and g_s was higher for plants in the Strong Billow K® treatment compared to the control treatment (Fig. 2).

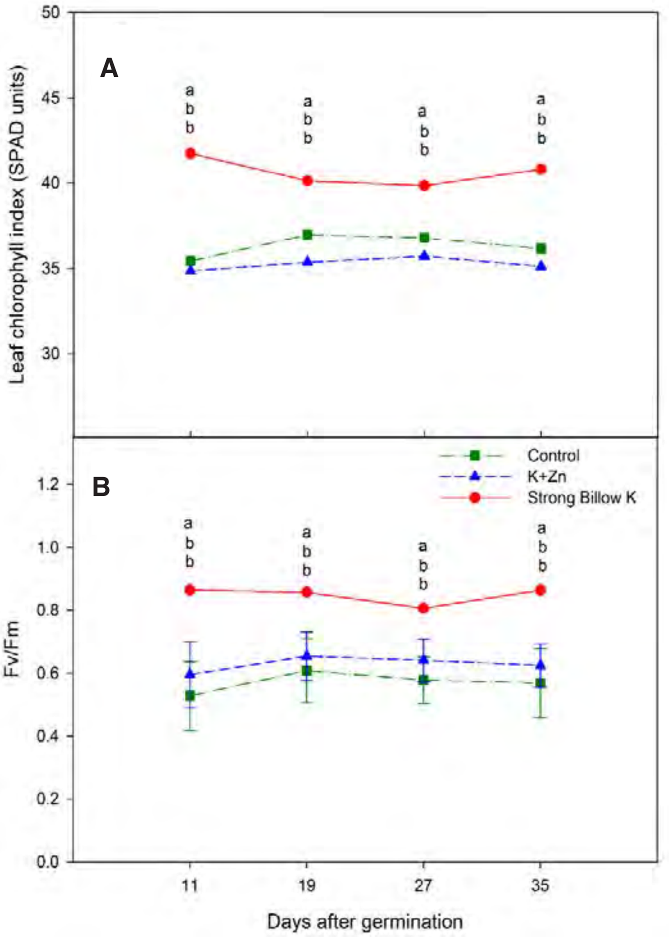

Fig. 1. Effects of foliar fertilizer treatments on **A**) leaf chlorophyll index and **B**) ratio of variable to maximum chlorophyll fluorescence (Fv/Fm) of yellow squash. Different letters indicate significant difference among treatment means ($P < 0.05$). Symbols represent means of 8 plants per 5 blocks (replicates) and bars indicate + 1 standard error.

Table 1. Effect of foliar fertilizer treatment on total leaf dry weight, total fruit number, and total fruit weight per yellow squash plant.

Treatment	Fruit number/plant	Total fresh fruit wt/plant (kg)
Strong Billow	13.4 a	4.4a
Control	8.4 b	2.5a
K and Zn	7.6 b	2.4a

[z]Different letters within columns indicate a significant difference among treatment means according to the Waller-Duncan K ratio test ($P < 0.05$).

Total fruit number per plant was significantly higher in the Strong Billow K® treatment than in the other two treatments. The yield per hectare was higher than commercials yields, it was 29.15 kg/0.0014 ha or 0.20 kg/plant. Although not statistically significant ($P > 0.05$), the total fresh fruit weight per plant was more than 30% higher in the Strong Billow K® treatment than in the K_2O and Zn or control treatments (Table 1).

Snapbean

On all three measurement dates, the leaf chlorophyll index was significantly higher for plants in the Strong Billow K® treatment than plants in the other two treatments (Fig. 3). The Fv/Fm was significantly higher for plants in the Strong Billow K® treatment than plants in the other two treatments on the second and last measurement dates (Fig. 3). On the first and third measurement dates, Fv/Fm was significantly higher for plants in the Strong billow K® treatment than those in the control treatment, but there

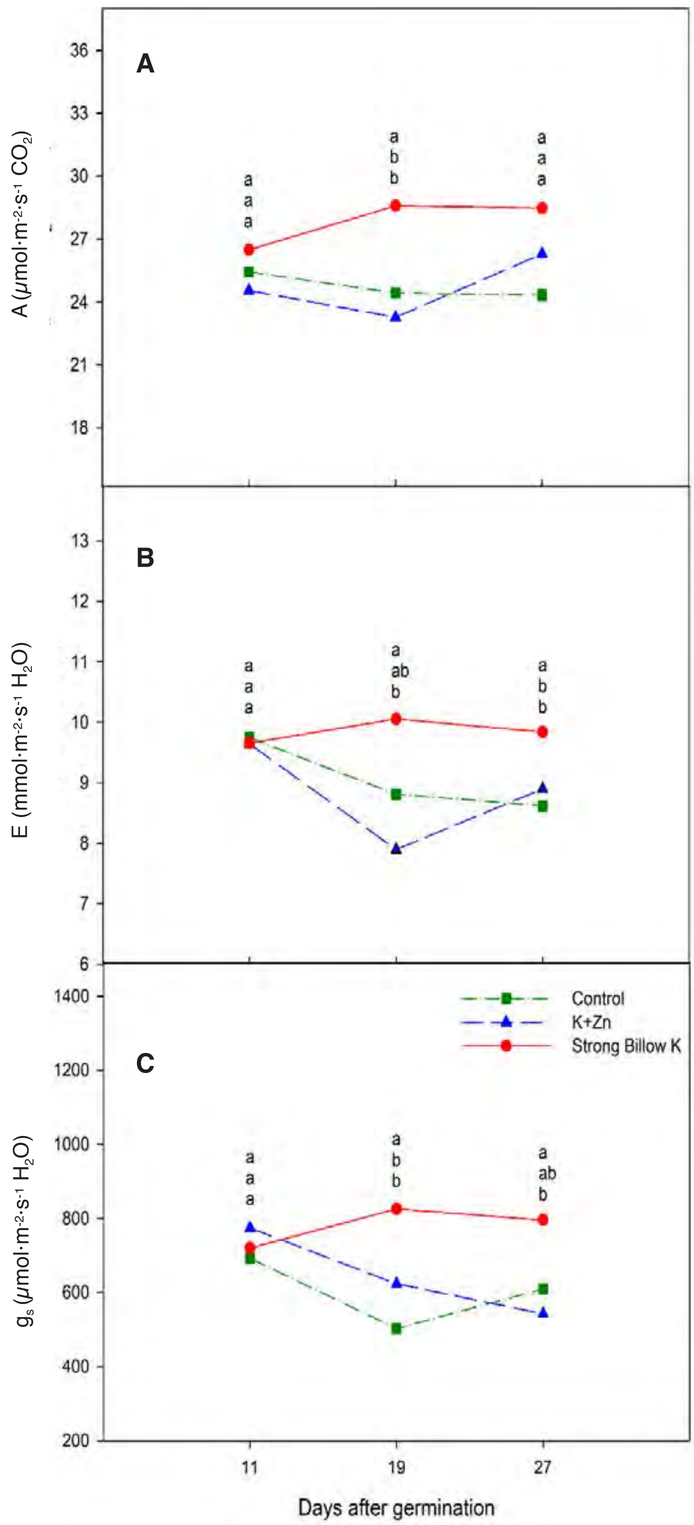

Fig. 2. Effect of foliar fertilizer treatments on **A**) net CO_2 assimilation (A), **B**) stomatal conductance (g_s), and **C**) transpiration (E) of yellow squash. Different letters indicate significant difference among treatment means ($P < 0.05$). Symbols represent means of 8 plants per each of 5 blocks (replicates) and bars indicated + 1 standard error.

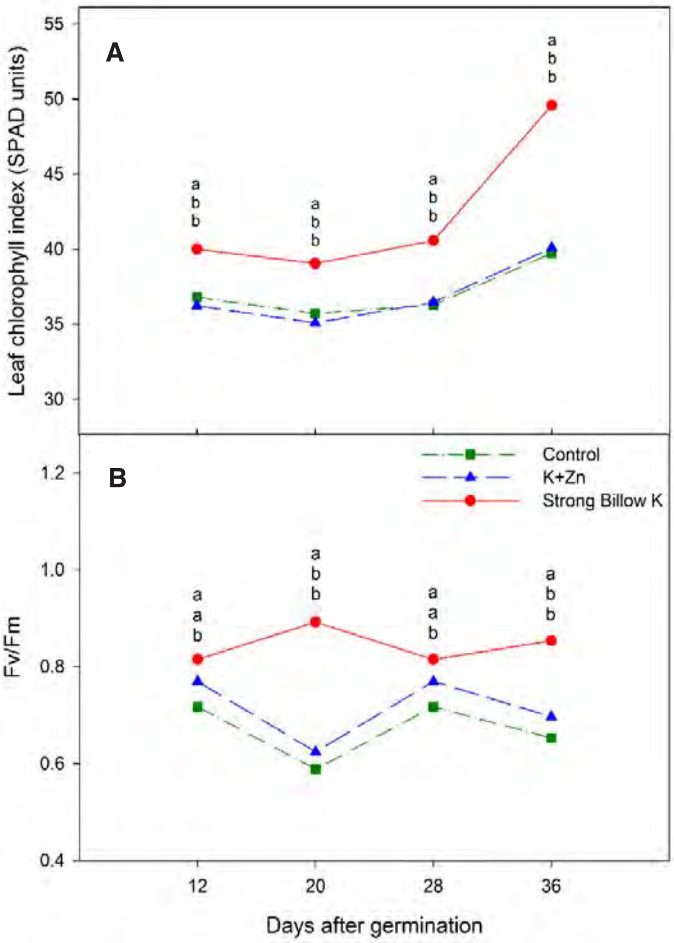

Fig. 3. Effects of foliar fertilizer treatments on **A**) leaf chlorophyll index and **B**) ratio of variable to maximum chlorophyll fluorescence (Fv/Fm) of snapbeans. Different letters indicate significant difference among treatment means ($P < 0.05$). Symbols represent means of 8 plants per each of 4 blocks (replicates) and bars indicate + 1 standard error.

was no significant difference in Fv/Fm between the Strong Billow K® treatment and the K_2O and Zn treatment on those measurement dates (Fig. 3).

Net CO_2 assimilation was significantly higher for plants in the Strong billow K® treatment than plant in the other treatments on the second and third measurement dates (Fig. 4). Transpiration was significantly higher for plants in the Strong Billow K® treatment than for plants in the other treatments only on the second measurement date, whereas there were no significant differences in E among treatments on the other measurement dates (Fig. 4). There were no significant differences in g_s among treatments (Fig. 4).

Total fruit number per plant and total fresh fruit weight per plant were significantly higher in the Strong Billow K® treatment than in the other two treatments (Table 2).

Discussion

The positive effects of Strong Billow K® foliar fertilizer on the physiology and yield of squash and snapbean in this study were probably not just a result of the addition of K_2O and Zn in the fertilizer formulation because foliar application of K_2O and Zn alone did not have the same positive effects. Thus, another component of Strong Billow K®, perhaps organic carbon, may

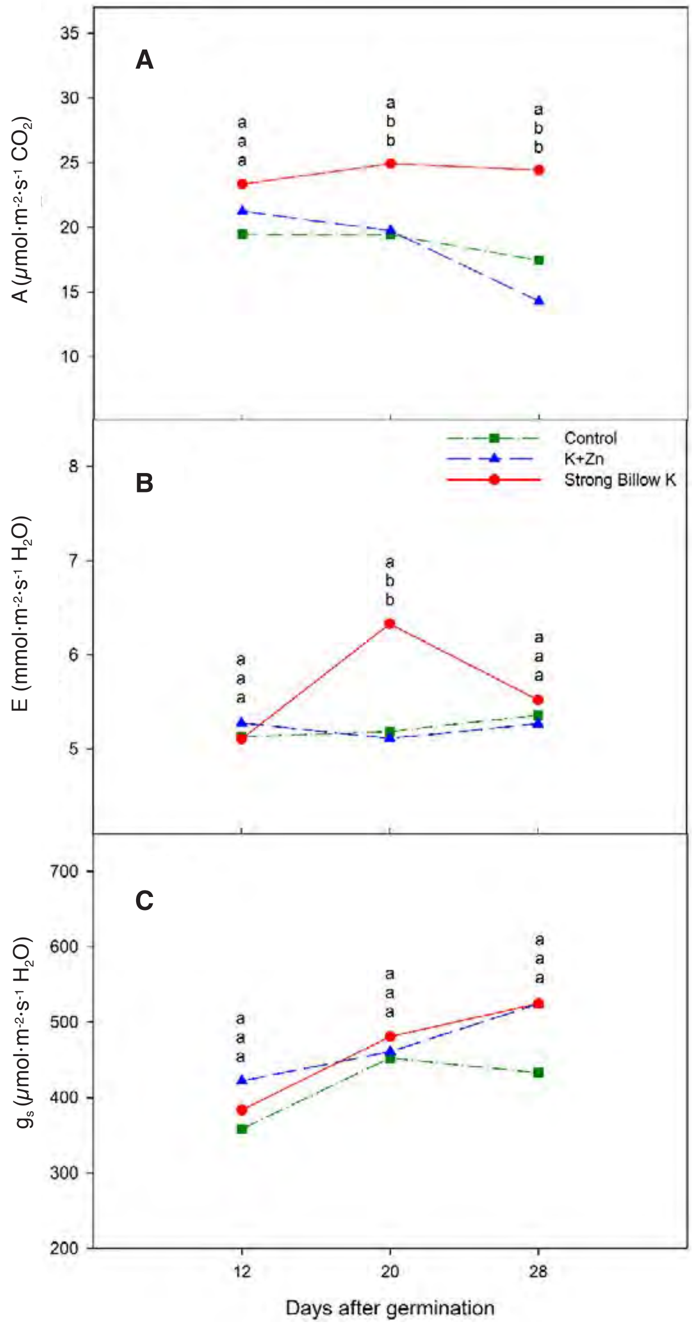

Fig. 4. Effect of foliar fertilizer treatments on **A**) net CO_2 assimilation (A), **B**) stomatal conductance (g_s), and **C**) transpiration (E) of snapbeans. Different letters indicate significant differences among treatment means ($P < 0.05$). Symbols represent means of 8 plants per each of 4 blocks (replicates) and bars indicate + 1 standard error.

Table 2. Effect of foliar fertilizer treatment on total leaf dry weight, total fruit number, and total fruit weight per snapbean plant.

Treatment	Fruit number/plant	Total fresh fruit wt/plant (kg)
Strong Billow	50.3 a	1.88 a
Control	37.6 b	1.04 b
K and Zn	30.6 b	1.53 b

[z]Different letters within columns indicate a significant difference among treatment means according to a Waller-Duncan K ratio test ($P < 0.05$).

have either had a direct effect on plant physiology and growth, or indirectly affected K_2O or Zn in the solution, making it more easily absorbed or metabolized by the plants. Many studies have shown positive results using similar combinations of K_2O and Zn with other substances. For example, K combined with humic acid can facilitate the delivery of high levels of organic soluble K to the plant through foliar or soil applications (Shafeek et al., 2015). In a previous study, the combination of foliar Zn and chitosan had a positive effect on seed yield of dry bean (Ibrahim and Ramadan, 2015). In the present experiment, foliar application of Strong Billow K® on yellow squash and snapbean resulted in an increase in the leaf chlorophyll index and Fv/Fm in both yellow squash and snapbean. Kaya et al. (2002) observed an increase in chlorophyll content in tomato leaves after foliar application of Zn at 0.35 $\mu mol \cdot L^{-1}$ compared with a control treatment with 7.7 $\mu mol \cdot L^{-1}$ Zn in the nutrient solution. Similar results were found in several varieties of mungbean with 2 μM of Zn applied to the foliage (Tayyeba et al., 2013). An increase in the leaf chlorophyll index was observed in green bean, cucumber, and tomato with foliar applications of aminochelate (Souri et al., 2017), which may have chelated Zn to a form more available for plant metabolism. Brennan (1991) showed that foliar application of Zn in a chelated form (ZnEDTA) increased grain yield of wheat compared to foliar application of a non-chelated form of Zn ($ZnSO_4$). The higher Fv/Fm of yellow squash and snapbean the Strong Billow K® treatment compared to the other treatments studied may have also been due, at least in part, to K_2O in the Strong Billow K®. In coriander plants, increased leaf chlorophyll index and Fv/Fm were observed with foliar applications of K (Roosta, 2014).

In both yellow squash and snapbean, foliar applications of Strong Billow K® resulted in higher *A* and *E* compared to foliar application of K_2O and Zn or tap water. Similarly, an increase in leaf gas exchange variables of zucchini was observed with the foliar application of three commercial products with different chemical formulations [Fitona® 3 (5.20% K_2O and 0.007% Zn), Hortigrow® (20% K_2O and 0.02% Zn), and Humustim® (7.83% K_2O and 0.01% Zn)], each containing K and Zn (Haytova, 2015). An increase in *A* and *E* were observed on jatropha plants with the foliar application of BAM-FXTM, containing 7.14% Zn, when the soil application rate of nitrogen (N), phosphorous (P) and potassium (K) were low (Bosco de Oliveira et al., 2019). In coffee plants, *A* and *gs* increased 55% in response to a foliar application of $ZnSO_4$, N and P compared to a control treatment with no foliar fertilizer applied (Rossi et al., 2018).

Fruit number per plant of both yellow squash and snapbean was significantly higher for plants treated with Strong Billow K® than those in the other two treatments. Foliar application of K or Zn has been shown to increase crop reproductive development and yield. For example, the number of seeds and seed weight per plant increased with the combination of Zn and humic acid applied to the foliage of bean plants (Kaya et al., 2005). Also, foliar application of Zn, K, or Mg had a positive effect on yield and growth of several varieties of mungbean (Thalooth et al., 2006) and foliar application of 100 or 200 ppm K increased plant growth and yield of pepper (Hussein et al., 2012). Kaya and Higgs (2002) reported an increase in chlorophyll content, dry weight and fruit yield of tomato with foliar applications of Zn. In contrast to these findings, in the present study, increased yield of yellow squash and growth and yield of snapbean receiving foliar applications of Strong Billow K® was apparently not solely due to K_2O and/or Zn in the formulation, even though leaf Zn concentration (results not shown) was higher in the Strong Billow K® treatment than in the control treatment for both crops, because applying those elements alone was no more effective than applying tap water. Therefore, the positive effects of Strong Billow K® on snapbean growth and squash and snapbean yields may have been due to direct effects of other components in the Strong Billow K® formulation on plant growth and yield or indirect effects of other components in the formulation on Zn and or K absorption through the foliage. Nevertheless, foliar applications Strong Billow K® significantly increased growth of snapbeans and yield of squash and snapbeans.

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