Pear Performance as Affected by the Application of Some Nano Fertilizers in Combination with Biochar as a Biostimulant Under Drought Conditions

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Drought is an environmental stress that can negatively influence growth and productivity of fruit trees because it decreases the photosynthetic rate and stomatal conductance and raises the rate of water loss from the plant surfaces. Therefore, this study investigated the soil application of biochar individually or in combination with the spraying of boron, silicon, and molybdenum relative to the growth attributes, fruit drop percentages, yield, and fruit quality of Le Conte pear trees grown under drought stress. The trees were fertilized by biochar at 0, 1, and 2 kg per tree individually or in combination with the foliar spraying with 0 mg B_2O_3 + 0 mg SiO_2 + 0 mg MoO_2, 10 mg B_2O_3 + 25 mg SiO_2 + 25 mg MoO_2, 20 mg B_2O_3 + 50 mg SiO_2 + 50 mg MoO_2 and 30 mg B_2O_3 + 75 mg SiO_2 + 75 mg MoO_2 at start of February, start of March and start of April, compared to untreated trees (control). The results showed that the soil addition of biochar or spraying of nano fertilizers individually or in combinations improved the vegetive growth, productivity and fruit quality, and leaf mineral content, meanwhile they reduced the fruit drop. The best results were obtained by the application of 2 kg biochar combined with 30 mg B_2O_3 + 75 mg SiO_2 + 75 mg MoO_2, which was superior to other applied treatments in the two seasons.

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INTRODUCTION

Pear (*Pyrus communis* L.) is a member of Rosaceae and its growing area, as of 2022, in Egypt was 5209 hectare which produced 77643.1 ton (FAO 2022). As drought stress intensifies and prolongs, there is a reduction in net photosynthesis, stomatal conductance, and the transpiration rate (Ghanbary *et al.* 2017). Additionally, drought reduces the size of fruits leading to reducing their marketable values (Lopez *et al.* 2012), the efficacy of water usage by plants, mobility and absorption of nutrients, and the growth of roots (Almutairi *et al*. 2023). Brodribb and McAdam (2017) stated that plants can withstand water stress by decreasing their stomatal conductance, which lowers water outflow, and by developing more effective root systems, which increase water uptake (Kumar *et al.* 2019). The productivity of the trees is frequently restricted by unfavorable weather, inadequate crop nutrition, inadequate pollination, early fruit drop, and low fruit quality (Katayama *et al.* 2019; Trueman *et al.* 2022).

Biochar is a solid that is created when biomass is thermochemically converted in an oxygen-limited atmosphere (García *et al*. 2021). Furthermore, biochar is an eco-friendly method used to improve the chemical and physical properties of soil, including pH levels, cation exchange capacity, bulk density, pore size distribution, soil structure, water retention capacity, and resilience to climate change (Oliveira *et al*. 2017; Godlewska *et al*. 2021) and consequently improve the quality attributes of the products (Medyńska-Juraszek *et al*. 2021). Besides, it can prevent losses of nutritional elements through leakage and improve the bioavailability of soil nutrients (Chen *et al*. 2021). In addition, it is used to increase water conservation, nutrient content, plant growth, crop yield, and quality characteristics (Brtnicky *et al*. 2021; Joseph *et al*. 2021) by improving the cation exchange power and nitrogen content in soil (Adekiya *et al*. 2020), as well as increasing the microbes' activity in the soil (Khadem *et al*. 2021).

Nano fertilizers have become eco-friendly alternatives and a promising option in the production of horticultural crops because of the high cost and potential harm of conventional fertilizers and to increase nutrient-use efficacy (Morab *et al*. 2021). Furthermore, because of their small size and high surface area-to-volume ratio, nano fertilisers have the potential to greatly increase the productivity and quality of fruit trees (Kumar *et al*. 2023; Periakaruppan *et al*. 2023).

Boron (B) plays a crucial role in various plant functions, including hormone transport, pollen germination, the directional growth of pollen tubes, the synthesis of protein, transportation of sugar, and the metabolism of carbohydrate (Hänsch and Mendel 2009), as well as nucleic acid and indole acetic acid (Shireen *et al*. 2018). Boron deficiency in plants causes delayed pollen germination, pollen tube development, flowering, and fruit setting (Brdar-Jokanović 2020), impacting metabolic pathways and leading to decreased shoot development, fruit set %, quality of fruits, and modifying the composition of fruit from nutrients (Özenç and Bender Özenç 2015; Davarpanah *et al*. 2016). Pandey and Gupta (2013) reported that low levels of B negatively affect microsporogenesis, leading to a decrease in the production, size, and viability of pollen grains. Shaban *et al*. (2019) reported that the foliar application of boron effectively enhanced the nutritional status of mango plants by increasing the concentrations of nitrogen, phosphorus, and potassium in the leaves and it also boosted chlorophyll and carbohydrate levels, as well as improved the carbon-to-nitrogen ratio. The spraying of boron greatly improved the fruit set percentages as a result of increasing the development of pollen tube growth (Williams and Reese 2019). Additionally, Sharafi and Raina (2021) documented that B is a crucial essential element for fertilization because it increases the pollen grain germination rate and the development of the pollen tube. Meanwhile, its lack minimizes the elasticity of pollen-tube cell walls and inhibits the pollen-tube development.

After oxygen, silicon (Si) is an effective nutrient for plants because it regulates the minerals uptake under adverse climatic conditions (Elsheery *et al*. 2020), and it is important for ameliorating plant development (López-Pérez *et al*. 2018). Si promotes the absorption of nutrients and water, which boosts cell division and the production of plant pigments, while also improving the plant's resilience to abiotic stresses including nutrient imbalances and drought (Coskun *et al*. 2016). Besides, Si enhances drought tolerance by improving water absorption, sustaining nutrient balance, reducing water loss from leaves, and boosting the rate of photosynthesis (Zhu and Gong 2014). Additionally, Peris-Felipo *et al*. (2020) reported that Si is helpful in increasing pollen grain fertility, fruit productivity, fruit content from sugars, and the shelf life of strawberries. By decreasing Na^+ uptake, the external application of Si-NPs at 150 mg L^{-1} on bananas improved K^+ uptake, photosynthesis, and stomatal conductance (Mahmoud *et al*. 2020).

Molybdenum (Mo) is an essential micronutrient for plants (Imran *et al.* 2019; Siddiqui *et al.* 2021). Its deficiency causes a decline in leaf chlorophyll content, growth, fruit quality and yield in various crops (Liu *et al.* 2020), and nutritional content (Li *et al.* 2017), and in the growth of taproots and lateral roots (Gao *et al.* 2016). It is an element that is required in small amounts for plant development and growth, and it is an essential component of nitrate reductase and nitrogenase, and for the nitrates' assimilation in the soil (Cecílio-Filho *et al*. 2019). Shoaib *et al*. (2020) stated that Mo is necessary for the fixation of nitrogen, which benefits plant performance. A deficiency in Mo can result in the buildup of nitrate within plants (Moussa *et al*. 2022), and nitrogenous mineral fertilizers are well known to increase their weight and productivity (Bekele *et al*. 2019).

This study investigated the role of the addition of biochar to the soil singly or combined with the spraying of boron + silicon + molybdenum nano particles in reducing the fruit drop and consequently improving the productivity and fruit quality of pear cv. 'Le Conte'.

EXPERIMENTAL

Location, Applied Treatments, and Experimental Design

The experiment was conducted in 2022 and 2023 on 8-year-old pear trees budded on *Pyrus betulifolia* rootstock. Trees were planted at 4x4 meters in sandy soil under drip irrigation, in the Nubaria region, El-Beheira governorate, Egypt. The physicochemical analysis of the experimental soil in Table 1 was done as previously outlined by Sparks *et al*. (2020).

Table 1. Analysis of the Soil of the Experiment

Mechanical Analysis						
Clay %	Silt %	Sand %	Soil texture	pH		
3 %	4.5 %	92.5 %	Sandy	8.3		
EC dSm^{-1} (1:5)	$CaCO_3^{-2}$ %	Organic matter %	Available macronutrients (mg/kg soil)			
0.812	4.8	0.275	N	P	K	
			117.5	9.2	297.5	
Soluble Anions (meq/L)			Soluble Cations (meq/L)			
HCO_3^-	Cl^-	SO_4^{-2}	Na^+	Mg^{2+}	K^+	Ca^{2+}
2.12	3.1	3.3	3.66	1.5	0.425	2.7

Table 2. Composition of the Used Biochar in the Experiment

Parameter					Biochar		Unit	
PH (1:10)					6.9		–	
(1:10, water extract) EC soluble ions (1:10)					1.1		dS/m	
N	K	P	Na	C	Fe	Mn	Cu	Zn
%					mg/kg			
0.66	0.74	1.2	0.45	62.25	257	170	65	72

Sixty uniform trees (five trees /replicates for each treatment) were chosen randomly and were approximately the same growth and size. They were subjected to the same horticultural practices applied in the orchard during the two testing years. The trees were fertilized by biochar at 0, 1, and 2 kg/tree in mid of January 2022 and 2023 seasons as the main factor. The pear trees were also sprayed with nanoparticles from boron (B_2O_3) at 0, 10, 20 and 30 mg/L, SiO_2 at 0, 25, 50, and 75 mg/L; molybdenum (MoO_2) at 0, 25, 50 and 75 mg/L three times at start of February, start of March (full bloom) and start of April, comparing the treated trees to not treated trees (control) as the submain factor. The applied treatments are listed in Table 3.

Table 3. Soil Addition of Biochar Individually or in Combination with the Spraying of Some Nano Fertilizers

T1	0 Biochar + 0 mg B_2O_3 + 0 mg SiO_2 + 0 mg MoO_2 (control treatment)	T7	1 kg Biochar + 20 mg B_2O_3 + 50 mg SiO_2 + 50 mg MoO_2
T2	0 Biochar + 10 mg B_2O_3 + 25 mg SiO_2 + 25 mg MoO_2	T8	1 kg Biochar + 30 mg B_2O_3 + 75 mg SiO_2 + 75 mg MoO_2
T3	0 Biochar + 20 mg B_2O_3 + 50 mg SiO_2 + 50 mg MoO_2	T9	2 kg Biochar + 0 mg B_2O_3 + 0 mg SiO_2 + 0 mg MoO_2
T4	0 Biochar + 30 mg B_2O_3 + 75 mg SiO_2 + 75 mg MoO_2	T10	2 kg Biochar + 10 mg B_2O_3 + 25 mg SiO_2 + 25 mg MoO_2
T5	1 kg Biochar + 0 mg B_2O_3 + 0 mg SiO_2 + 0 mg MoO_2	T11	2 kg Biochar + 20 mg B_2O_3 + 50 mg SiO_2 + 50 mg MoO_2
T6	1 kg Biochar + 10 mg B_2O_3 + 25 mg SiO_2 + 25 mg MoO_2	T12	2 kg Biochar + 30 mg B_2O_3 + 75 mg SiO_2 + 75 mg MoO_2

These treatments were examined by investigating their impact on the subsequent parameters:

Vegetative Parameters

At the end of the vegetative time, shoot length in cm and the shoot thickness was measured by using a vernier caliper. Leaf total chlorophyll (SPAD) was measured in the fresh leaves using a Minolta chlorophyll meter (SPAD - 502; Konica Minolta, Osaka, Japan) by taking 10 readings from the mature leaves in the middle part of the shoots around the trees. The average leaf area (cm²) was determined using an equation adapted from (Demirsoy 2009; Mosa *et al*. 2022a),

$$LA = 0.70\ (L \times W) - 1.06 \tag{1}$$

where LA is a leaf area, L is leaf length, and W is leaf width.

Flower Number, Fruit Set, and Fruit Drop Percentages

Four branches from each side of each replicate (tree) were chosen and labelled carefully at the start of the vegetative season, the number of flowers was accounted and then the fruit set % was calculated according to the following Eq. 2.

$$\text{Fruit set \%} = \frac{\text{No.of fruitlets}}{\text{No.of perfect flowers}} \times 100 \tag{2}$$

Fruit drop (%) was estimated by calculating the difference between the number of set fruits and the dropped fruits using Eq. 3.

$$\text{Fruit drop (\%)} = \frac{\text{No.of dropped fruits}}{\text{No.of set fruits}} \times 100 \tag{3}$$

Fruit yield

At July 2022 and 2023 seasons, the yield in kg for each tree was weighted and then by multiplying the yield of each tree by the number of the trees in hectare to calculate the yield of hectare in ton.

Fruit Quality

Fruit physical characteristics

Ten fruits were randomly selected from each replicate (tree). The average of their weight (g), fruit length, and fruit diameter were measured using an electric balance and a vernier caliper gauge. Fruit firmness ($lb/inch^2$) was determined using a Magness and Taylor pressure tester equipped with a 7/18-inch plunger by using the hand refractometer (ATAGO Co. LTD., Tokyo, Japan). Fruit size (cm^3) was assessed by measuring the volume of displaced water after immersing the fruit.

Fruit chemical characteristics

Total soluble solids percentages were measured. Ascorbic acid content (VC) in the juice was assessed through titration with 2,6-dichloro phenol-indo-phenol and expressed in milligrams per 100 mL of juice. Total and reducing sugars were quantified calorimetrically using the Nelson arsenate-molybdate colourimetric method (Nielsen 2010). Non-reduced sugars percentages are the difference between total sugars and reduced sugars. Fruit acidity, measured as a percentage and quantified in terms of malic acid content, was assessed in fruit juice using a titration method with 0.1 N sodium hydroxide, and phenolphthalein was used as an indicator (AOAC 2005).

Estimating the mineral content in the pear leaves

From the middle part of the shoots, 30 leaves were taken from each tree (Arrobas *et al*. 2018) to determine the leaf macronutrients such as nitrogen, phosphorous, and potassium, as well as leaf micronutrients from iron, zinc, manganese, and boron. After the leaves were thoroughly cleaned with tap and distilled water, they were dried at 70 °C in an oven until they reached a constant weight, and last they were ground into a fine powder, and then they were digested by using H_2SO_4 and H_2O_2. The leaf content from nitrogen was measured by using the micro-Kjeldahl method (Wang *et al*. 2016), phosphorus by using the Vanadomolybdate method (Weiwei *et al*. 2017), and potassium by using the flame photometer (SKZ International Co., Ltd., Jinan Shandong, China) (Chapman 2021).

Microbial biomass in soil

The biomass carbon measurement methods followed the procedures outlined by Vance *et al*. (1987). Each soil sample was divided into six 17.5 g replicates. Three of these replicates were subjected to chloroform fumigation for 24 h. Following chloroform removal, carbon was extracted from both fumigated and unfumigated samples using 0.5 M K_2SO_4 solution for one hour on an end-over-end shaker. Subsequently, the samples were sequentially filtered through Whatman filter grade 42 paper. The resulting supernatant was then analyzed at 280 nm using a compact spectrophotometer.

Estimation of the available nitrogen, phosphorus, and potassium

Available phosphorus was extracted using 0.5 N $NaHCO_3$ following the protocol by Song *et al*. (2019). The phosphorus content in the $NaHCO_3$ extract was determined calorimetrically using the ascorbic acid-molybdenum blue method, with measurements taken at a wavelength of 406 nm (Cho and Nielsen 2017). Available nitrogen was determined calorimetrically using the Nessler method (Jeong *et al*. 2013). For estimating available potassium, soil samples were extracted with 1 N ammonium acetate extractant at pH 7.0, and the available potassium was measured using a flame photometer following the method detailed by Jackson (2005).

Statistical Analysis

The obtained results were subjected to statistical analysis using Split Plot Design by using CoHort Software (Pacific Grove, CA, USA). The least significant difference at 0.05% ($LSD_{0.05}$) was used to compare the means of treatments (Snedecor 2021). One-Way ANOVA in a randomized complete block design (RCBD) was used to analyze the data regarding microbial biomass and available nutrients in the soil and Duncan's test was used at 0.05 to compare between the means of the treatments.

RESULTS

Vegetative Growth

The addition of biochar to the soil combined with the spraying of nano-fertilizers increased the shoot length, shoot diameter, leaf area, and leaf chlorophyll content in pear (Table 4). The most significant impact resulted from the application of T12 in comparison to the control. Additionally, T11 and T8 were also effective in improving the measured growth vegetative attributes compared to the treatments that were used during the two seasons. There are no significant differences between the influence of T12 and the influence of T11 on shoot length, diameter, and leaf chlorophyll.

Fruit Set, Fruit Drop Percentages, and Fruit Number

T12 treatment significantly raised percentage of fruit set and fruit number rather than the other treatments that were used during the two seasons (Figs. 1, 2 and 3). The treatments of T11 and T8 also noticeably improved the percentages of fruit set, and the number of fruits in contrast to the other treatments. On the opposite side, these treatments greatly lessened the fruit drop percentages on the opposite of control treatment effect.

Fruit Yield

The results indicated that T12 led to a significant increase in fruit yields, either in kilograms per tree or tons per hectare, and this treatment resulted in the highest productivity compared to the other treatments applied in both seasons (Figs. 4 and 5). Besides, the soil application of T 11 and T 8 respectively, which raised the yield.

Fruit Quality

Fruit physical characteristics

Tables 5 and 6 highlight that the use of T12 significantly enhanced fruit weight, size, length, and diameter rather than the other treatments applied across both seasons. Additionally, T11 treatment slightly outperformed the other applied treatments. Fruit firmness was improved by the usage of T12, which was the superior treatment. The treatments of T11, T8 and T7 also improved the fruit firmness compared to control. The spraying of T4 and T3 positively improved fruit firmness in comparison with non-treated trees.

Fruit chemical characteristics

The soil application of T12 significantly improved the fruit content from TSS percentage and vitamin C in the second season (Table 7). The differences between the influence of the treatments of T12, T11, T8, and T7 in the first seasons was so slight not enough to be significant. The fruit content from acidity was significantly reduced when T12 and T11 were applied. The highest fruit acidity % was markedly noticed in the treatments of control, T2, T5 and T9.

Table 4. Effect of the Soil Addition of Biochar in Combination with the Spraying of Some Nano Fertilizers on the Shoot Length, Shoot Diameter, Leaf Area, and Leaf Chlorophyll in 'Le Conte' Pear Trees during the 2022 and 2023 Seasons

Treatments	Shoot Length (cm)		Shoot Diameter (cm)		Leaf Area (cm^2)		Leaf Chlorophyll (SPAD)	
	2022	2023	2022	2023	2022	2023	2022	2023
T1	69.32d ±2.82	72.28d ±1.99	0.83c ±0.01	0.80e ±0.01	38.54e ±1.57	39.50d ±1.62	43.54c ±2.01	45.56f ±0.98
T2	71.52d ±2.11	72.62d ±1.97	0.83c ±0.02	0.83de ±0.02	38.66e ±0.93	40.17d ±1.81	44.18c ±1.58	45.64f ±1.21
T3	74.86c ±0.9	73.28d ±1.03	0.83c ±0.03	0.84de ±0.03	41.46cd ±1.35	41.03d ±0.99	48.34b ±1.45	49.74de ±1.92
T4	75.24c ±1.14	75.64cd ±1.32	0.86c ±0.03	0.97b ±0.02	41.77cd ±1.48	44.91bc ±0.96	48.86b ±0.95	50.08c-e ±1.55
T5	71.54d ±1.19	73.76d ±2.42	0.85c ±0.02	0.86de ±0.02	39.18e ±0.73	41.82d ±0.79	44.76c ±0.53	48.06e ±2.01
T6	75.38c ±1.02	75.68cd ±1.58	0.88c ±0.02	0.88cd ±0.03	43.17bc ±1.27	45.52bc ±2.45	49.48b ±1.87	51.16cd ±1.36
T7	76.64c ±1.50	77.24c ±1.19	0.95b ±0.04	0.98b ±0.05	45.29ab ±2.01	45.67bc ±1.73	49.62b ±1.84	52.52bc ±1.64
T8	82.36a ±0.51	82.90ab 2.04	0.97b ±0.05	1.00b ±0.05	45.37ab ±1.16	46.38b 1.73	50.92b ±2.60	52.58bc ±0.58
T9	74.20c ±0.97	74.96cd ±1.19	0.88c ±0.04	0.92c 0.04	40.02de ±1.86	42.48cd ±0.61	45.40c ±1.67	49.50de ±1.63
T10	79.65b ±1.11	82.06b ±1.67	0.95b ±0.03	0.99b ±0.03	43.74bc ±1.03	45.64bc ±1.71	50.36b ±0.48	52.24bc ±1.61
T11	83.46a 2.13	84.36ab ±1.47	1.03a ±0.05	1.06a ±0.02	45.41ab ±1.14	46.77b ±1.78	53.22a ±2.06	54.34ab ±0.82
T12	84.06a ±1.11	85.16a ±0.74	1.04a ±0.04	1.09a ±0.02	47.36a ±2.30	51.21a ±2.86	54.70a ±0.66	55.98a ±1.20
$LSD_{0.05}$	1.90	2.30	0.04	0.04	1.85	2.34	1.97	1.88

Note: The treatments sharing the same letters are not significantly different at the 0.05 level of significance.

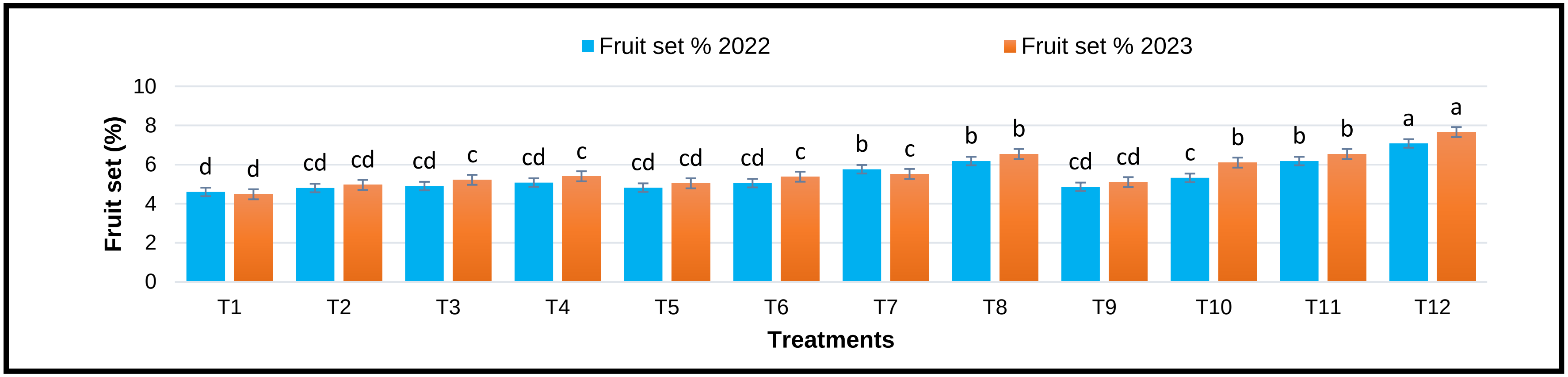

Fig. 1. Effect of the soil addition of biochar in combination with the spraying of some nano fertilizers on fruit set percentages in 'Le Conte' pear trees during the 2022 and 2023 seasons

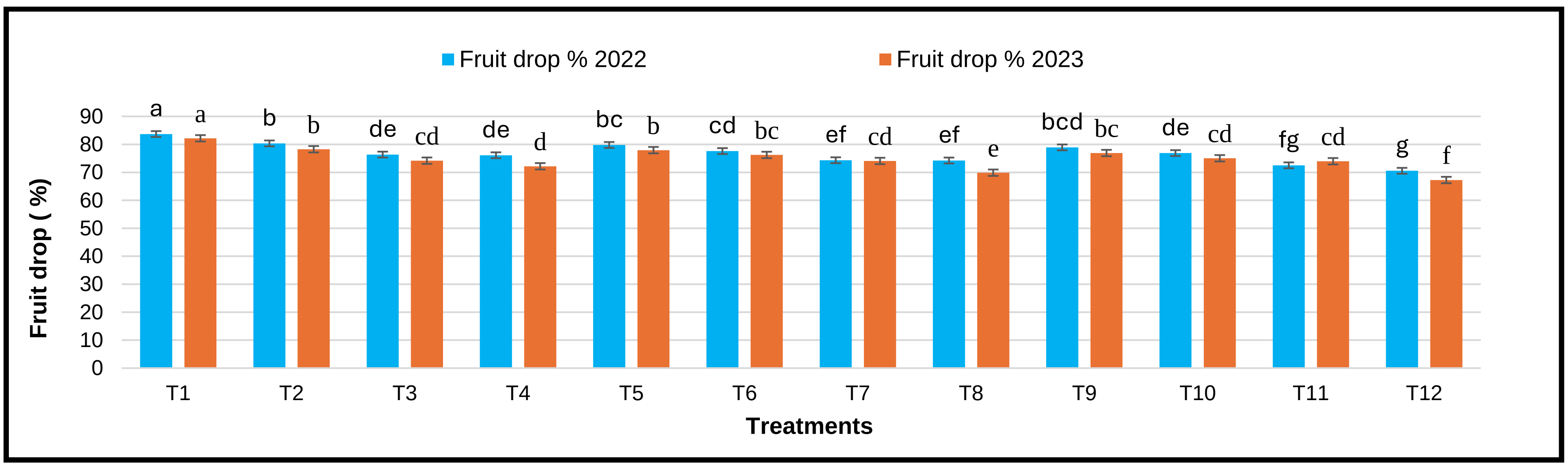

Fig. 2. Effect of the soil addition of biochar in combination with the spraying of some nano fertilizers on fruit drop percentages in 'Le Conte' pear trees during the 2022 and 2023 seasons

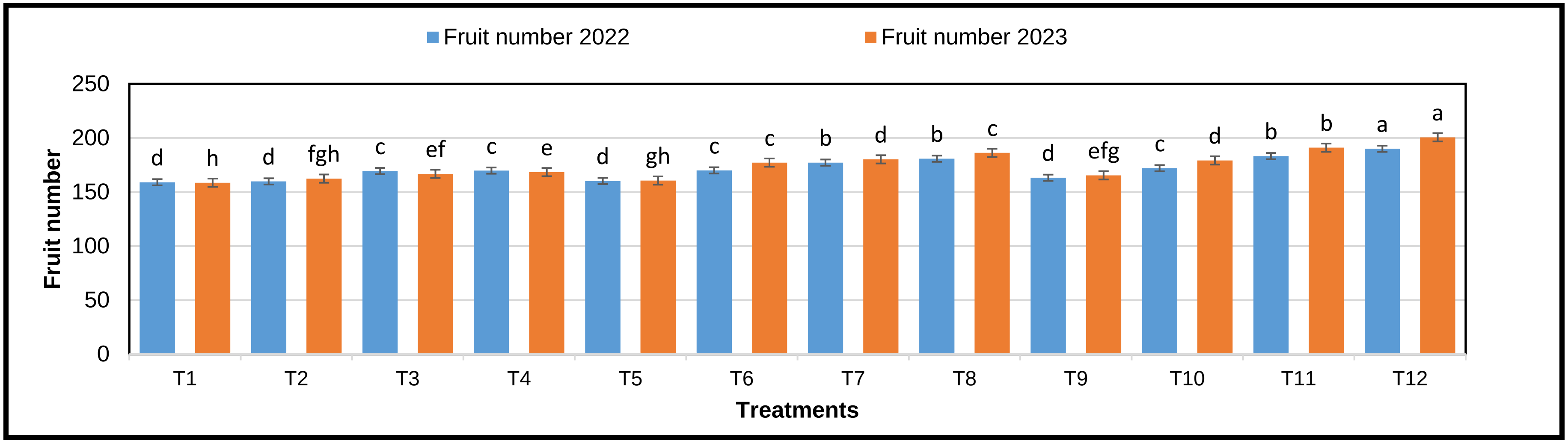

Fig. 3. Effect of the soil addition of biochar in combination with the spraying of some nano fertilizers on fruit number in 'Le Conte' pear trees during the 2022 and 2023 seasons

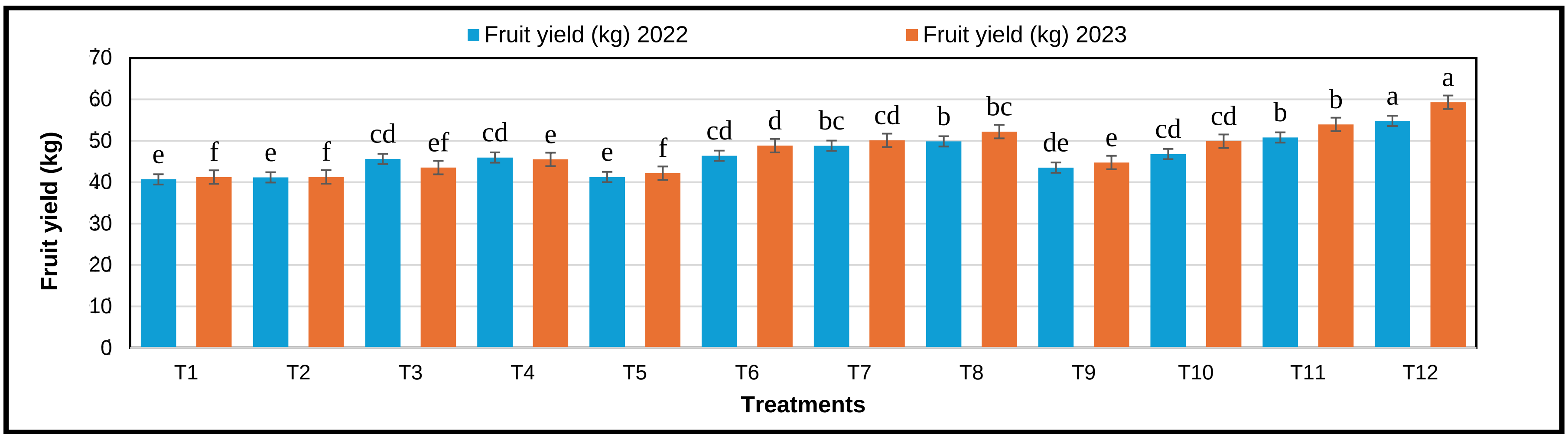

Fig. 4. Effect of the soil addition of biochar in combination with the spraying of some nano fertilizers on the fruit yield in kg per tree in 'Le Conte' pear trees during the 2022 and 2023 seasons

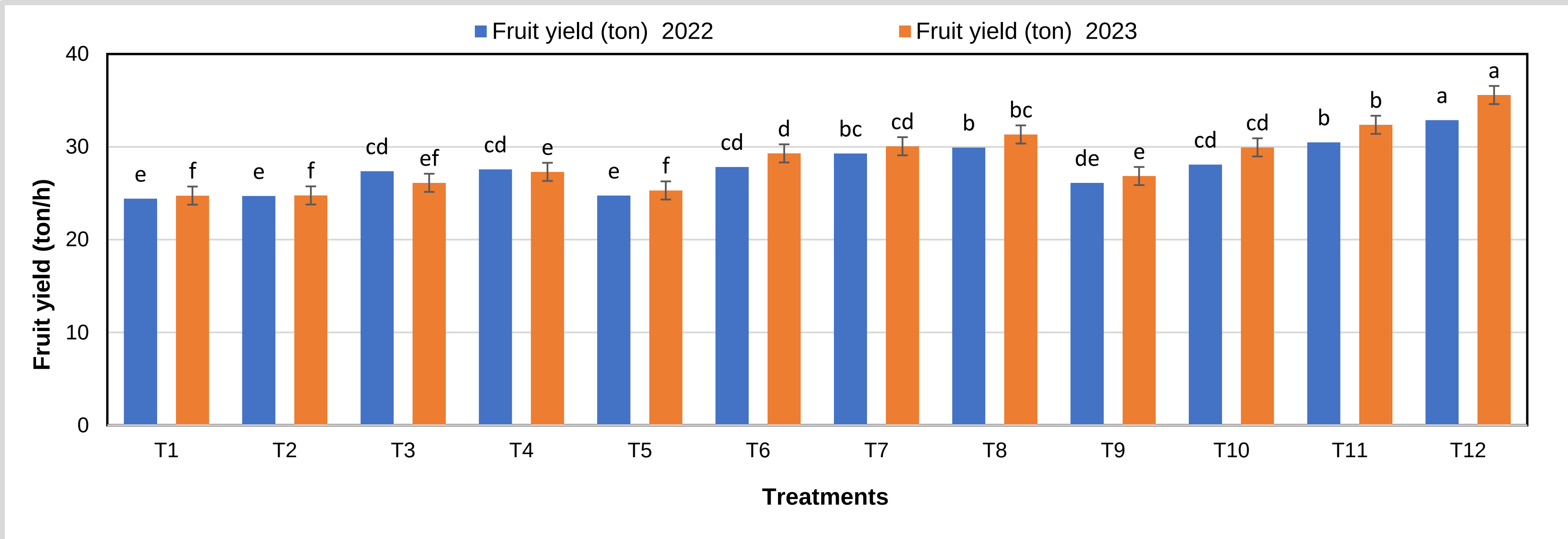

Fig. 5. Effect of the soil addition of biochar in combination with the spraying of some nano fertilizers on the fruit yield in ton per hectare in 'Le Conte' pear trees during the 2022 and 2023 seasons

Table 5. Effect of the Soil Addition of Biochar in Combination with the Spraying of Some Nano Fertilizers on the Fruit Weight and Fruit Firmness in ‘Le Conte’ Pear Trees during the 2022 and 2023 Seasons

Treatments	Fruit Weight (g)		Fruit Firmness (lb/inch^2)	
	2022	2023	2022	2023
T1	251.40c ±3.13	253.20e ±4.66	12.16f ±0.39	12.14d ±0.47
T2	263.40b ±14.84	262.00de ±13.34	12.94de ±0.43	12.86cd ±0.43
T3	271.00b ±2.91	273.40bc ±4.16	14.36bc ±0.41	14.42b ±0.39
T4	271.80b ±4.65	275.80bc ±7.15	14.44bc ±0.38	14.52b ±0.63
T5	252.60c ±4.88	253.20e ±4.66	12.62ef ±0.29	12.34cd ±0.57
T6	268.40b ±2.19	266.80cd ±4.66	13.38d ±0.44	13.12c ±0.63
T7	272.60b ±3.97	277.00bc ±5.29	14.56bc ±0.52	14.70b ±0.82
T8	274.00b ±3.74	277.60bc ±4.83	14.86b ±0.42	14.94b ±0.39
T9	253.40c ±4.67	255.40e ±3.58	12.68ef ±0.41	12.86cd ±0.65
T10	269.40b ±6.61	268.40cd ±3.21	14.04c ±0.41	14.40b ±0.38
T11	274.80b ±3.90	281.60b ±3.05	14.86b ±0.34	15.02b ±0.62
T12	287.80a ±8.90	293.80a ±10.16	15.82a ±0.69	15.86a ±0.42
$LSD_{0.05}$	8.58	8.07	0.54	0.67

The treatments sharing the same letters are not significantly different at the 0.05 level of significance.

Table 6. Effect of the Soil Addition of Biochar in Combination with the Spraying of Some Nano Fertilizers on the Fruit Size, Fruit Length and Fruit Diameter in 'Le Conte' Pear Trees during the 2022 and 2023 Seasons

Treatments	Fruit Size (cm^3)		Fruit Length (cm)		Fruit Diameter (cm)	
	2022	2023	2022	2023	2022	2023
T1	262.60d ±2.97	264.80e ±4.20	8.13d ±0.09	8.13f ±0.13	7.68d ±0.26	7.96e ±0.36
T2	274.80bc ±15.41	273.60de ±13.45	8.49d ±0.26	9.02e ±0.40	8.16cd ±0.27	8.19de ±0.26
T3	282.40b ±2.51	284.40b-d ±3.78	9.31c ±0.21	9.62d ±0.36	8.42c ±0.24	8.26de ±0.28
T4	284.80b ±4.09	288.00bc ±7.31	9.33c ±0.16	9.80cd ±0.20	8.46c ±0.40	8.40de ±0.38
T5	264.60cd ±5.12	265.20e ±4.97	8.21d ±0.14	8.53ef ±0.37	7.96cd ±0.26	7.98e ±0.45
T6	280.40b ±3.13	278.60cd ±4.98	8.60d ±0.38	9.04e ±0.36	8.28cd ±0.22	8.22de ±0.23
T7	285.40b ±3.58	289.00bc ±4.69	10.02b ±0.32	10.04b-d ±023	8.46c ±0.32	8.68cd ±0.26
T8	286.00b ±4.94	289.20bc ±5.89	10.10b ±0.42	10.32bc ±0.54	9.06b ±0.19	8.90c ±0.36
T9	265.60cd ±4.77	267.20e ±4.09	8.43d ±0.16	8.64ef ±0.27	8.06cd ±0.26	8.14de ±0.26
T10	281.00b ±7.35	280.20cd ±3.34	8.62d ±0.41	9.08e ±0.23	8.42c ±0.38	8.23de ±0.12
T11	286.80b ±4.15	293.60b ±2.51	10.30b ±0.43	10.40b ±0.43	9.10b ±0.62	9.36b ±0.29
T12	299.00a ±8.86	306.00a ±9.97	10.96a ±0.17	11.18a ±0.49	9.82a ±0.20	10.23a ±0.27
$LSD_{0.05}$	8.93	8.31	0.34	0.44	0.43	0.36

The treatments sharing the same letters are not significantly different at the 0.05 level of significance.

Table 7. Effect of the Soil Addition of Biochar in Combination with the Spraying of Some Nano Fertilizers on the Fruit Content from TSS %, Acidity %, and Vitamin C in 'Le Conte' Pear Trees during the 2022 and 2023 Seasons

Treatments	TSS %		Acidity %		VC (mg/100 mL juice)	
	2022	2023	2022	2023	2022	2023
T1	12.48c ±0.27	12.62e ±0.24	0.42a ±0.01	0.39a ±0.02	9.76c ±0.32	9.94c ±0.19
T2	13.62b ±0.22	13.46d ±0.73	0.40a ±0.01	0.37ab ±0.02	9.98bc ±0.29	10.36bc ±0.41
T3	13.86b 0.80	13.76cd ±0..26	0.31cd ±0..02	0.34c ±0.02	10.28bc ±0.33	10.52bc ±0.36
T4	13.88b ±0.30	13.78cd ±0..58	0.30cd ±0..01	0.29d ±0.02	10.32bc ±0.26	10.52bc ±0..54
T5	12.84c ±0.33	12.96de ±0.30	0.41a ±0.02	0.38ab ±0.01	9.90bc ±0.26	10.30bc ±0.28
T6	13.68b ±0.46	13.54d ±0.45	0.37b ±0.01	0.35bc ±0.01	10.18bc ±0.41	10.44bc ±0.40
T7	14.80a ±0.32	14.48bc ±0.37	0.29d ±0.02	0.28d ±0.01	10.60b ±0.70	10.80b ±0.24
T8	14.84a ±0.52	14.48bc ±0..51	0.29d ±0.01	0.28d ±0.03	11.20a ±0.37	10.90b ±0.69
T9	13.36b ±0.54	13.30d ±0.53	0.40a ±0.01	0.37ab ±0.01	9.94bc ±0.19	10.32bc ±0.34
T10	13.82b ±0.36	13.72cd ±0.36	0.32c ±0.02	0.34c ±0.02	10.18bc ±0.41	10.48bc ±0.37
T11	14.88a ±0.18	14.80b ±0.28	0.28de ±0.01	0.26e ±0.02	11.28a ±0.39	11.10b ±0.47
T12	15.34a ±0.22	15.50a ±0.32	0.26e ±0.01	0.25e ±0.01	11.64a ±0.52	12.03a ±0.15
$LSD_{0.05}$	0.49	0.56	0.02	0.02	0.48	0.51

The treatments sharing the same letters are not significantly different at the 0.05 level of significance.

Table 8. Effect of the Soil Addition of Biochar in Combination with the Spraying of Some Nano Fertilizers on the Percentages of Total, Reduced and Non-reduced Sugars in 'Le Conte' Pear Trees during the 2022 and 2023 Seasons

Treatments	Total Sugars %		Reduced sugars%		Non reduced sugars %	
	2022	2023	2022	2023	2022	2023
T1	9.13e ±0.42	9.35f ±0.27	6.22e ±0.34	6.52e ±0.24	2.90a ±0.33	2.83a ±0.26
T2	9.57cde ±0.24	10.15de ±0.57	6.56e ±0.26	7.19d ±0.57	3.01a ±0.41	2.97a ±0.04
T3	9.81cd ±0.20	10.47cd ±0.21	6.57e ±0.04	7.08d ±0.18	3.24a ±0.16	3.40a ±0.12
T4	10.22c ±0.15	10.32cde ±0.29	7.58c ±0.09	6.95de ±0.32	2.64a ±0.20	3.37a ±0.17
T5	9.31de ±0.10	9.77ef ±0.27	6.46e ±0.14	6.53e ±0.22	2.85a ±0.18	3.24a ±0.14
T6	10.14c ±0.35	10.42cd ±0.40	7.15d ±0.19	7.14d ±0.17	2.99a ±0.22	3.28a ±0.25
T7	10.79b ±0.58	10.94bc ±0.37	7.59c ±0.21	7.46cd ±0.31	3.20a ±0.72	3.48a ±0.19
T8	11.07b ±0.46	11.10b ±0.25	7.74bc ±0.56	7.79bc ±0.22	3.33a ±0.88	3.31a ±0.23
T9	10.00c ±0.23	10.13de ±0.47	6.53e ±0.08	7.24d ±0.32	3.47a ±0.29	2.89a ±0.52
T10	10.13c ±0.48	10.47cd ±0.31	7.38cd ±0.06	7.29d ±0.32	2.75a ±0.47	3.19a ±0.04
T11	11.07b ±0.46	11.41b ±0.22	8.02ab ±0.29	8.01b ±0.13	3.04a ±0.33	3.40a ±0.23
T12	11.66a ±0.17	11.94a ±0.19	8.31a ±0.23	8.60a ±0.20	3.35a ±0.27	3.34a ±0.16
$LSD_{0.05}$	0.44	0.44	0.32	0.39	0.54	0.60

The treatments sharing the same letters are not significantly different at the 0.05 level of significance.

Table 9. Effect of Biochar Soil Addition in Combination with the Spraying of Some Nano Fertilizers on Leaf Mineral Content (Nitrogen, Phosphorous, Potassium, and Calcium) in 'Le Conte' Pear Trees during the 2022 and 2023 Seasons

Treatments	N %		P %		K %		Ca %	
	2022	2023	2022	2023	2022	2023	2022	2023
T1	2.21e ±0.06	2.23d ±0.04	0.27e ±0.02	0.30e ±0.02	1.35f ±0.03	1.40e ±0.03	1.19f ±0.01	1.22f ±0.03
T2	2.21e ±0.05	2.27cd ±0.05	0.28e ±0.03	0.30e ±0.02	1.36f ±0.02	1.41e ±0.03	1.20f ±0.01	1.25ef ±0.05
T3	2.26de ±0.05	2.26cd ±0.03	0.30de ±0.04	0.31de ±0.04	1.38ef ±0.02	1.41e ±0.03	1.24e ±0.02	1.26ef ±0.03
T4	2.36bcd ±0.03	2.32bcd ±0.06	0.31de ±0.04	0.35cd ±0.03	1.40def ±0.03	1.43de ±0.03	1.27de ±0.04	1.29de ±0.04
T5	2.30cde ±0.04	2.35bc ±0.06	0.32de ±0.04	0.32de ±0.02	1.42de ±0.03	1.45de ±0.03	1.23e ±0.03	1.28de ±0.02
T6	2.30cde ±0.05	2.35bc ±0.03	0.35cd ±0.04	0.33cde ±0.03	1.44d ±0.03	1.45de ±0.01	1.26de ±0.02	1.31cde ±0.03
T7	2.35bcd ±0.04	2.37bc ±0.03	0.35cd ±0.03	0.34cde ±0.03	1.48c ±0.04	1.47cd ±0.02	1.29cd ±0.03	1.31cde ±0.03
T8	2.37bc ±0.03	2.39b ±0.05	0.37bc ±0.02	0.35cd ±0.03	1.50c ±0.03	1.50c ±0.02	1.29cd ±0.03	1.34bcd ±0.02
T9	2.34bcd ±0.08	2.36bc ±0.06	0.38bc ±0.02	0.34cde ±0.02	1.50c ±0.05	1.52bc ±0.03	1.31bc ±0.01	1.35bcd ±0.06
T10	2.41bc ±0.06	2.37bc ±0.04	0.40ab ±0.02	0.36c ±0.02	1.53bc ±0.02	1.55b ±0.04	1.34ab ±0.02	1.37bc ±0.04
T11	2.42b ±0.08	2.44b ±0.04	0.43a ±0.02	0.42b ±0.03	1.56b ±0.05	1.60a ±0.04	1.34ab ±0.04	1.39b ±0.05
T12	2.50a ±0.08	2.55a ±0.05	0.45a ±0.01	0.46a ±0.01	1.60a ±0.04	1.63a ±0.02	1.36a ±0.03	1.45a ±0.04
$LSD_{0.05}$	0.07	0.07	0.04	0.03	0.04	0.04	0.03	0.05

The treatments sharing the same letters are not significantly different at the 0.05 level of significance.

Table 10. Effect of Biochar on the microbes' Biomass and on the Available N, P and K in the Experimental Soil during 2022 and 2023

Treatments	Microbial Biomass In Soil		P (mg/kg)		N (mg/kg)		K (mg/kg)	
	2022	2023	2022	2023	2022	2023	2022	2023
Zero biochar	141.33c ±0.47	141.83c ±0.43	10.16c ±0.13	11.03c ±0.34	123.19c ±0.70	122.96c ±0.28	304.75c ±1.52	307.92c ±0.83
1 kg biochar	189.75b ±0.99	209.58b ±2.11	16.25b ±0.68	17.50b ±0.64	134.00b ±0.61	141.47b ±0.57	341.25b ±1.10	349.25b ±0.88
2 kg biochar	205.75a ±1.52	220.17a ±1.03	20.67a ±0.47	23.32a ±0.72	160.83a ±0.69	171.25a ±1.03	388.91a ±2.10	393.33a ±0.98
$LSD_{0.05}$	1.69	1.64	0.80	1.01	1.08	0.95	1.51	1.53

The treatments sharing the same letters are not significantly different at the 0.05 level of significance.

Total and reduced sugars were enhanced by the use of T12 compared to the other applied treatments (Table 9). Moreover, the soil application of T11 and T8, respectively, successfully increased the fruit content from total sugars in 2022-2023. There was no discernible difference in the fruit content from the non-reduced sugar percentages across all applied treatments.

Nutritional status

The data in Table 9 showed that the influence of biochar on raising the composition of leaves from N, P, K and Ca was considerably raised by the spraying of B_2O_3 + SiO_2 + MoO_2 as compared to untreated trees. The most positive impact resulted from the application of T12 which is the superior treatment during the study time.

Microbial Biomass and the Available N, P, and K in the Soil

Analysis of the experimental soil indicated that the application of the biochar significantly improved the microbial biomass in the soil and consequently remarkably increased the available phosphorus, nitrogen, and potassium (Table 10). The addition of 2 kg was superior to the usage of 1 kg throughout the experimental times.

DISCUSSION

The addition of biochar to soil remarkably improved the microbial biomass in the soil and the available nitrogen, phosphorous, and potassium, which improved 'Le Conte' pear growth, productivity, fruit quality, and the leaf mineral content. Many authors have previously documented that applying biochar to the soil increases the nutrients K, Mg, and Ca, making them more available to the plants (Lentz and Ippolito 2012; Wang *et al*. 2014). Furthermore, adding biochar to the soil considerably reduces the soil's propensity to leak nitrogen, nitrate, magnesium, calcium, phosphorus, and potassium (Gautam *et al*. 2017) and raises the nitrogen content in the soil (Xia *et al*. 2020; Hamidzadeh *et al*. 2023) and microbial biomass in the soil (Pokharel *et al*. 2020). Besides, it can absorb and retain nutrients and the soil water holding capacity through increased pore size and aggregate stability (Al-Wabel *et al*. 2018; Kang *et al*. 2022), and beneficial microbial activity (Tan *et al*. 2022), therefore, it improves crop, soil quality and fertility and ultimately improves crop yields (Yao *et al*. 2021; Wong *et al*. 2022). Furthermore, Kumari and Rajan (2019) reported that by boosting soil fertility and improving soil nutrient content, cation exchange capacity, and soil water preservation in citrus, banana, and passion plants, adding biochar to the soil enhanced the root system, fruit productivity, fruit quality, and productivity. Additionally, Harhash *et al*. (2022) found that adding biochar to the soil of mango trees boosted various growth parameters, including trunk thickness, shoot length and diameter, inflorescence numbers, fruit set percentage, productivity of each tree, and fruit characteristics. It also increased fruit weight, size, firmness, and biochemical attributes such as TSS%, total, reducing, and non-reducing sugars, total acidity, vitamin C, and carotene content. Moreover, it enhanced leaf composition, specifically nitrogen, phosphorus, potassium, iron, zinc, manganese, copper, molybdenum, and boron. Simultaneously, this treatment reduced fruit drop percentages.

According to the results, the spraying of nano fertilizers positively increased the vegetative growth, fruit quality in pear, and its productivity by reducing the fruit drop percentage. Numerous authors interpreted these results by stating that boron is a necessary element for the construction of the cell wall, the stiffness of the plasma membrane, cell division, the transfer of sugars, the production of hormones, and the activation of numerous enzymes (Fareeha *et al*. 2018; Landi *et al*. 2019). Boldingh *et al*. (2016) stated that in almond, apple, avocado, olive, and sour cherry, increasing the concentration of boron in flowers improves the fruit set, fruit retention percentages, and productivity. The spraying of B_2O_3 NPs at 0, 250, 500, and 1000 ppm on pomegranate cv. 'Wonderful' improved the leaf chlorophyll content, length of shoots, leaf surface area, number of leaves, the percentages of fruit set and retention, fruit productivity, and leaf composition from macro or micro minerals, meanwhile the application decreased the percentage of fruit drop (Abd El-wahed *et al*. 2024).

Si can reduce water stress by minimizing the rate of transpiration (Luyckx *et al*. 2017), increasing water reservation, the levels of photosynthesis (Maghsoudi *et al*. 2015; El-Naggar *et al*. 2020) and chlorophyll content, thus raising the crop productivity and its quality (Balakhnina and Borkowska 2013; Mosa *et al*. 2022b). Si influences the structure of xylem vessels, particularly under conditions of high transpiration levels (Liang *et al*. 2015), improving the development of plants and their productivity (Patil *et al.* 2017). Additionally, spraying Si-NPs has been shown to be more effective in regulating stomatal conductance and respiration rate (Boutchuen *et al*. 2019) and causes a significant increment in plant growth by enhancing increased water and nutrient intake under abiotic stress conditions (Santos *et al*. 2014), and also by improving the concentrations of photosynthetic pigments (Siddiqui *et al*. 2020) as well as photosynthetic efficacy (Siddiqui *et al*. 2018). Si plays a crucial role in ameliorating the development of plants and their productivity and raises the resistance to drought by increasing the rate of photosynthetic, cell division, pigment number, root growth, and the move and uptake of water and nutrients (Hussain *et al*. 2021) and by promoting root elongation, enabling stronger roots to extract water under drought stress (Perez *et al.* 2014). Si improves the availability and accumulation of nitrogen, potassium, calcium, sulphur, iron, and manganese and raises the resistance to drought stress by raising the plant water usage efficacy and minimizing water loss during transportation (Rea *et al*. 2022). Spraying mango cultivar Keitt with Si nanoparticles at 50, 100, and 150 mg/L enhanced the fruit's mineral content from K, N, and P, yields, and vegetative development qualities under drought conditions (Almutairi *et al*. 2023).

The role of Mo is strongly related to nitrogen metabolism, and its lack causes N deficit in plants (Pollock *et al*. 2002). Additionally, Kaiser *et al*. (2005) stated that the external spraying of Mo is an effective way to increase its concentration inside the plants and to enhance the activity of molybdo-enzymes. Additionally, the deficiency of Mo negatively influences the rate of flower opening, and the formation, production, and germination rate of pollen grains (Marschner 2011). Wu *et al*. (2014) stated that Mo NPs improve soil water uptake by increasing water use efficiency and osmotic adjustment ability, which may facilitate the efficacy of nutrients transfer. Eshghi *et al*. (2010) stated that Mo stimulated pollen germination in pomegranate and strawberry. Besides, the exogenous application of Mo on grapevines cv. 'Merlot' notably increased the yield and berry size (Longbottom *et al.* 2010). Spraying apple trees cv. 'Red Jonaprince' with Mo before, during, and after bloom at 286 g/ha increased the leaf content of N, Mg, Fe, and Mo, and chlorophyll (Wójcik 2020).

CONCLUSIONS

1. The application of biochar to the soil individually improved the available nutrients and microbial biomass in the soil, which led to improving the soil fertility. The treatment improved the vegetative growth, yield, and fruit quality and reduced the fruit drop percentage of 'Le Conte' pear.
2. The effect of biochar was increased by the combination of spraying of B_2O_3 + SiO_2 + MoO_2 compared to the untreated trees.
3. The application of T12 kg (2 kg Biochar + 30 mg B_2O_3 + 75 mg SiO_2 + 75 mg MoO_2), followed by T11 (2 kg Biochar + 20 mg B_2O_3 + 50 mg SiO_2 + 50 mg MoO_2) produced the best results, and their effects were greater in the second season than in the first.

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