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Effect of exogenous CPPU, proline, or potassium on late yield and fruit quality of fig (Ficus carica L.) trees

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ABSTRACT:

This research aimed to examine the impacts of foliar application of CPPU at a rate of 20, 40, or 60 µM, K at a rate of 5, 10, or 15 mM, or proline at a rate of 2, 4, or 6 mM on growth, late fruit yield, and fruit quality of fig trees under adverse conditions of late season (leaf senescence and low temperature). This research was conducted using 4- and 5-year-old fig trees in the 2019 and 2020 seasons, respectively. The obtained findings explore that all the applied concentrations of CPPU, K, or proline markedly improved growth traits such as average leaf number per branch, leaf area per branch, leaf dry weight, and leaf dry matter content. In addition, the late fig yield (average fruit number per branch and fruit weight) and fruit quality traits (average fruit volume, total soluble sugars, total soluble soils, and titratable acidity) were significantly improved compared to the control. Among all applied treatments, including the control, 40 µM CPPU was the best treatment conferring the best growth, yield, and fruit quality traits. Therefore, the findings of this report recommend the use of 40 µM CPPU for promoting late fruit yield and fruit quality traits of fig trees.

KEYWORDS: Cytokinins, K, Proline, growth, late productivity, fruit quality, fig trees

1. INTRODUCTION:

Belonging to the genus "Ficus" and the family "Moraceae", the fig (Ficus carica L.) is the oldest fruit tree grown worldwide. It is native to Western Asia and is widely distributed throughout the Mediterranean region. Egypt is second only to Turkey in terms of fresh fig production globally (**FAO, 2018**). Figs are rich in mineral nutrients, vitamins, dietary fiber, polyphenols, anthocyanins, carotenoids, and sterols. They also provide a high level of sugar, energy, and healthy bioactive ingredients (**USDA, 2002; Wang et al., 2023**).

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Fig trees require warm climates (**Micheloud et al., 2018**), and their growth under semiarid conditions without water limitation is highly required (**Moura et al., 2023**), so the late fruit yield (September–December) becomes less quantity and of lower quality compared to the main fruit yield (June–August) due to the trees being exposed to lower temperatures. The quantitative and qualitative traits of late fig fruit yield can be noticeably improved by using plant growth regulators (PGRs) (**Kurubar et al., 2017**). Among the roles played by PGRs including plant hormones [auxins (AUXs), cytokinins (CKs), and gibberellins (GAs)] are delaying leaf senescence, stimulating plant cell expansion and division, fruit setting and enlargement, and increasing crop yields (**Huang and Jiang, 2012**).

Among the PGRs, N-(2-chloro-4-pyridyl)-N-9-phenylurea (CPPU), also called forchlorfenuron, is a CK-like compound characterized by its potent activity. All parts of the plant, including roots, stems, flowers, and fruits can absorb CPPU (**Adaniya et al., 2004**). As confirmed at the beginning of the third millennium, CPPU can delay fruit maturation and fruit ripening of many horticultural crops, including kiwi, cherries, pineapples, grapes, and strawberries (**Kim et al., 2006; Li et al., 2016; Aloni et al., 2010**). Also, CPPU can increase the fruit set, size, and yield, as well as it can minimize the spoilage of the fruits to maintain their quality during storage (**Guardiola and García-Luis, 2000**). As outlined previously, CPPU can increase fruit sets using pre-bloom treatment, while it can promote fruit color, size, maturity, and quality with post-bloom treatment (**Kim et al., 2006; Li et al., 2016**). Although the efficacy of applying PGRs has been easily, extensively, and comparatively evaluated in terms of increasing fruit size, the same effects may not apply to biochemical properties (**Li et al., 2016**). As reported beforehand, PGRs can reinforce leaf chlorophyll contents and CO_2 assimilation rate, thus improving the fruits' supply of metabolites (**Agustí et al., 2003; Guardiola and García-Luis, 2000**). CPPU treatment exerts virtuous impacts on bananas, strawberries, and broccoli, including limited respiration rate, inhibited natural browning, and retarded fruit maturity and softening (**Huang and Jiang, 2012**). However, the molecular mechanisms belonging to the role of exogenous CPPU treatment in the growth and yield performances of horticultural crops remain not fully understood.

Potassium in its ionic form (K^+) and proline are among plant osmoprotectants (POPs), which protect plants against water loss under stress (**Rady et al., 2019a; Taha et al., 2020**). As an essential nutrient, K can raise dry matter and the productivity of plants by contributing to the efficiency of physio-biochemical properties, nutrition, chlorophyll synthesis, and stomatal movement, along with reducing the uptake of toxic ions, including Na+ and Cl^- (**Taha et al., 2020**). Proline is essential one of the compatible solutes, contributing to cell turgor, and can serve as a free-radical scavenger by stabilizing proteins and cell membranes (**Rady et al., 2019a**).

Therefore, this paper aimed to study the effect of CPPU, K, or proline on growth, late fruit yield, and fruit quality traits of fig trees in the late seasons of 2019 and 2020.

2. MATERIALS AND METHODS:

The trial site and experimental duration

A two-season experiment was conducted in the 2019 and 2020 seasons to study the effects of CPPU, K, or proline on growth, late fruit yield, and fruit quality traits of fig trees. The experiments were carried out in the Abdelhady Badr-Eldin farm (29°07'04.5" N 31°04'38.9" E), Bani Sweif, Egypt, in an attempt to improve the quantitative and qualitative traits of late fig fruit yield. Fig trees were planted 4 by 4 m at a density of about 600 trees per hectare. The fig trees identified for each studied season underwent systematic horticultural practices, which were generally followed in the examined farm. A surface irrigation system was followed, and hoeing, and weed and pest management were regularly followed. Analysis of some soil physicochemical properties (**Page et al., 1982; Klute, 1986**) is present in **Table 1**.

Table 1. Physicochemical characteristics of clay loam soil of the experimental orchard (for a depth of 0–45 cm)

Treatments	Season 2019	Season 2020
Sand (%)	28.7	28.7
Silt (%)	20.2	20.2
Clay (%)	51.1	51.1
Texture	Clay loam	
pH	7.69	7.69
ECe (dS m^{-1})	1.82	1.82
Organic matter (%)	1.15	1.15
$CaCO_3$ (%)	2.48	2.46

Experimental setup and treatments

For two seasons, a group of 4-year-old fig trees in 2019 and another group of 5-year-old trees in 2020 were selected for this study. Fifty trees were randomly selected uniformly for each season, with 5 trees per treatment. On each tree, 5 random branches were labeled for different assessments. Each season, the trees were sprayed with PGRs (CPPU, K, and proline) three times on 1, 13, and 25 September. CPPU (forchlorfenuron) was applied at a rate of 20, 40, or 60 µM ($CPPU_{(1)}$, $CPPU_{(2)}$, and $CPPU_{(3)}$, respectively), K (potassium in the form of K_2SO_4) was applied at a rate of 5.0, 10.0, or 15.0 mM ($K_{(1)}$, $K_{(2)}$, and $K_{(3)}$, respectively), or proline was applied at a rate of 2.0, 4.0, or 6.0 mM ($Proline_{(1)}$, $Proline_{(2)}$, and $Proline_{(3)}$, respectively). Additionally, control trees were sprayed with distilled water. The spray solutions were supplemented with 0.01% Tween-20 as a surfactant and sprayed early in the morning. Solution volumes of 1.0 and 1.25 L per tree were sprayed in 2019 and 2020, respectively. Leaf and fruit samples were collected on 5 October to analyze the growth, yield, and fruit quality traits 10 days after the third foliar spray.

Growth and fruit yield-related parameters

The average leaves number was recorded for each branch (ALNB). Average leaf area (ALA, cm^2) was measured, using the middle mature leaf on each branch, using a leaf area meter (AT Delta-T Device, Cambridge, UK). Average leaf dry matter content (ALDMC, %) was evaluated using the leaf that was allocated to leaf area measurement. After weighing for average fresh weight (ALFW), the leaf was dried in an oven at 70 °C upon reaching a constant weight, and average leaf dry weight (ALDW) was taken. Then, LDMC was calculated as follows:

$$ALDMC (\%) = (ALDW / ALFW) \times 100$$

The average fruit number per branch (AFNB) and average fruit weight (AFW) were evaluated on 5 October 2019 and 2020.

Fruit quality-related traits

Fruit samples were collected on 5 October for analysis of fruit quality traits 10 days after the third foliar spray. For each treatment, 20 fully colored fruits were randomly collected for the following evaluations. Average fruit volume (AFV, cm^3) was measured using a graduated glass cylinder. Average fruit total soluble solids (TSS, %) was measured in fruit juice using a digital refractometer (PR-100, Atago Co.

Ltd., Tokyo, Japan) (**A.O.A.C., 2000**). Fig fruit juice was used to evaluate titratable acidity (as % citric acid) using a HI-422 digital pH meter (Hanna Instruments Inc., Woonsocket, RI, U.S.A.) with NaOH (0.1 N) titration (**A.O.A.C., 2000**). Fruit total soluble sugar content (%) was evaluated as described in (**Irigoyen et al., 1992**).

Experimental design and statistical analysis

The 2019−2020 experiments were implemented as a completely randomized block design with 5 replicates. Data were analyzed by one-way ANOVA with the SAS statistical software. Significant differences between means were assessed at a 5% level of probability ($P \leq 0.05$) using Tukey's HSD test. The GenStat 17th Ed. (VSN International Ltd., Hemel Hempstead, UK). The software was applied for statistical analysis.

3. RESULTS AND DISCUSSION:

Using fig trees, this study was conducted for two seasons (2019 and 2020) to investigate the effects of three plant growth regulators (PGRs); CPPU (forchlorfenuron), K, and proline on growth, late yield, and fruit quality traits of fig trees. Each of the three PGRs was applied at three concentrations; CPPU at 20.0 µM ($CPPU_{(1)}$), 40.0 µM ($CPPU_{(2)}$), and 60.0 µM ($CPPU_{(3)}$), K at 5.0 mM ($K_{(1)}$), 10.0 mM ($K_{(2)}$), and 15.0 mM ($K_{(3)}$), and proline at 2.0 mM ($Proline_{(1)}$), 4.0 mM ($Proline_{(2)}$), and 6.0 mM ($Proline_{(3)}$).

Growth traits of fig trees

Table 2 displays that all three PGRs (CPPU, K, and proline) at all concentrations significantly increased growth traits of fig trees, with minor exceptions, compared to the control. Among all treatments, $CPPU_{(2)}$, $K_{(2)}$, and $Proline_{(2)}$ were the best concentrations of CPPU, potassium, and proline, respectively, which conferred the best growth traits. However, $CPPU_{(2)}$ was the best concentration ever used in both the 2019 and 2020 seasons, increasing the average leaf number per branch (ALNB) by 104.1 and 71.4%, leaf area (ALA) by 11.2 and 13.1%, leaf dry weight (ALDW) by 89.7 and 92.1%, leaf dry matter content (ALDMC) by 33.3 and 33.3%, respectively, compared to the control.

Table 2. The effect of foliar spraying with CPPU, proline, or potassium on the growth of fig trees in the 2019 and 2020 seasons

Treatments	Season 2019	Season 2020	Season 2019	Season 2020
	Average leaf number		Average leaf area (cm^2)	
Control	7.3±0.51f	7.0±0.48f	358±15.4c	366±16.4c
$CPPU_{(1)}$	12.5±0.72b	9.6±0.52e	386±17.0ab	389±18.0b
$CPPU_{(2)}$	14.9±0.84a	12.0±0.70a	398±17.5a	414±18.4a
$CPPU_{(3)}$	11.7±0.69c	10.2±0.65d	376±16.2bc	375±19.0bc
$K_{(1)}$	10.5±0.67d	10.2±0.65d	366±15.8c	377±17.3bc
$K_{(2)}$	11.9±0.71c	11.4±0.70b	376±16.2bc	388±19.0b
$K_{(3)}$	10.1±0.65d	10.0±0.64d	360±15.8c	367±17.3c
$Proline_{(1)}$	9.0±0.54e	9.8±0.60de	362±16.0c	370±16.9bc
$Proline_{(2)}$	10.4±0.61d	10.7±0.68c	375±18.1bc	383±18.6bc
$Proline_{(3)}$	8.9±0.53e	9.6±0.58e	359±16.0c	368±16.7c
	Average leaf dry weight (g)		Average leaf dry matter	
Control	3.49±0.15g	3.53±0.16f	19.8±1.02g	20.1±1.07e
$CPPU_{(1)}$	6.07±0.24b	6.22±0.28b	24.8±1.26b	25.2±1.55b
$CPPU_{(2)}$	6.62±0.26a	6.78±0.30a	26.4±1.30a	26.8±1.57a
$CPPU_{(3)}$	5.20±0.21cd	5.81±0.28c	23.2±1.12cd	23.9±1.52cd
$K_{(1)}$	5.43±0.22c	5.78±0.25c	23.4±1.15cd	23.8±1.40cd
$K_{(2)}$	5.52±0.23c	5.92±0.26bc	24.2±1.20bc	24.9±1.46bc
$K_{(3)}$	5.01±0.20d	5.08±0.23d	22.3±1.06de	23.2±1.34d
$Proline_{(1)}$	4.74±0.19e	4.91±0.22d	21.9±1.05e	23.1±1.24d
$Proline_{(2)}$	5.04±0.20de	5.12±0.23d	22.6±1.08de	23.5±1.30d
$Proline_{(3)}$	4.21±0.18f	4.49±0.20e	20.7±1.02fg	21.4±1.10e

Control; distilled water, $K_{(1)}$, $K_{(2)}$, and $K_{(3)}$; potassium (in the form of K_2SO_4) applied at levels of 5.0, 10.0, and 15.0 mM, respectively, $CPPU_{(1)}$, $CPPU_{(2)}$, and $CPPU_{(3)}$; forchlorfenuron applied at levels of 20, 40, and 60 µM, respectively, and $Proline_{(1)}$, $Proline_{(2)}$, and $Proline_{(3)}$; proline applied at levels of 2.0, 4.0, and 6.0 mM, respectively. All treatments were three foliar sprays performed on 1, 13, and 25 September. All leaf samples were collected on 5 October (10 days after the third foliar spray) to analyze the growth traits.

Late yield of fig trees

Table 3 shows that all concentrations of the three PGRs (CPPU, K, and proline) significantly increased late yield components of fig trees, with minor exceptions, compared to the control. The best treatment concentrations were $CPPU_{(2)}$, $K_{(2)}$, and $Proline_{(2)}$ among all used concentrations of CPPU, potassium, and proline, respectively. However, $CPPU_{(2)}$ was the best concentration ever used in both the 2019 and 2020 seasons, increasing the fruit number per branch (AFNB) by 102.6 and 93%, and fruit weight (AFW) by 69.0 and 54.3%, respectively, compared to the control.

Table 3. The effect of foliar spraying with CPPU, proline, or potassium on the fruit yield of fig trees in the 2019 and 2020 seasons

Treatments	Season 2019	Season 2020	Season 2019	Season 2020
	Average fruit number branch^{-1}		Average fruit weight (g)	
Control	3.9±0.21f	4.3±0.25g	25.2±1.42g	26.9±1.54g
CPPU$_{(1)}$	5.8±0.35c	7.3±0.38b	36.7±1.98c	33.9±2.30de
CPPU$_{(2)}$	7.9±0.49a	8.3±0.49a	42.6±2.21a	41.5±2.46a
CPPU$_{(3)}$	5.0±0.30d	5.0±0.28f	35.1±1.90cd	34.3±2.14cde
K$_{(1)}$	5.8±0.35c	7.0±0.38c	34.1±1.80de	34.9±2.30cd
K$_{(2)}$	7.0±0.42b	7.5±0.41b	39.7±2.12b	38.1±2.44b
K$_{(3)}$	5.7±0.32c	5.3±0.28e	30.3±1.94f	32.9±2.20ef
Proline$_{(1)}$	4.7±0.27e	5.3±0.28e	31.7±1.70ef	32.5±2.17ef
Proline$_{(2)}$	5.7±0.32c	5.8±0.33d	35.3±1.94cd	35.9±2.20c
Proline$_{(3)}$	4.0±0.22f	5.3±0.28e	30.7±1.60f	31.5±2.17f

Control; distilled water, K$_{(1)}$, K$_{(2)}$, and K$_{(3)}$; potassium (in the form of K_2SO_4) applied at levels of 5.0, 10.0, and 15.0 mM, respectively, CPPU$_{(1)}$, CPPU$_{(2)}$, and CPPU$_{(3)}$; forchlorfenuron applied at levels of 20, 40, and 60 µM, respectively, and Proline$_{(1)}$, Proline$_{(2)}$, and Proline$_{(3)}$; proline applied at levels of 2.0, 4.0, and 6.0 mM, respectively. All treatments were three foliar sprays performed on 1, 13, and 25 September. All fruit samples were collected on 5 October (10 days after the third foliar spray) for fig yield.

Fruit quality traits of fig trees

Table 4 reveals that all three PGRs (CPPU, K, and proline) at all concentrations significantly improved fruit quality traits of fig trees, with minor exceptions, compared to the control. CPPU$_{(2)}$, K$_{(2)}$, and Proline$_{(2)}$ were the best concentrations among all used concentrations of CPPU, potassium, and proline, respectively. However, CPPU$_{(2)}$ was the best concentration ever used in both the 2019 and 2020 seasons, increasing the fruit volume (AFV) by 52.4 and 55.1%, fruit total soluble sugar contents by 30.3 and 26.6%, fruit total soluble solids (FTSS) by 23.8 and 21.9%, and fruit titratable acidity (FTA) by 26.7 and 25.0%, respectively, compared to the control.

Table 4. The effect of foliar spraying with CPPU, proline, or potassium on the fruit quality traits of fig trees in the 2019 and 2020 seasons

Treatments	Season 2019	Season 2020	Season 2019	Season 2020
	Average fruit volume (cm^3)		Fruit total soluble sugars (%)	
Control	25.0±1.14f	26.5±1.24g	12.2±0.48f	12.4±0.48e
$CPPU_{(1)}$	36.3±1.31b	37.3±1.41bc	13.4±0.52d	13.2±0.50cd
$CPPU_{(2)}$	38.1±1.39a	41.1±1.61a	15.9±0.68a	15.7±0.65a
$CPPU_{(3)}$	34.6±1.22cd	37.1±1.40bcd	13.1±0.52de	12.8±0.50de
$K_{(1)}$	33.3±1.21d	35.3±1.31de	13.4±0.52d	13.2±0.50cd
$K_{(2)}$	36.9±1.33ab	38.6±1.40b	15.0±0.65b	14.6±0.54b
$K_{(3)}$	35.6±1.30bc	35.2±1.30de	13.1±0.52de	13.0±0.50d
$Proline_{(1)}$	33.7±1.23d	33.7±1.22e	12.9±0.49de	12.8±0.49de
$Proline_{(2)}$	35.6±1.30bc	36.2±1.33cd	14.0±0.54c	13.6±0.50c
$Proline_{(3)}$	27.0±1.17e	28.5±1.29f	12.8±0.50e	12.8±0.49de
	Fruit total soluble solids (%)		Fruit titratable acidity (%)	
Control	14.7±0.49f	15.1±0.51e	0.15±0.007e	0.16±0.008d
$CPPU_{(1)}$	16.5±0.66bc	16.0±0.57cd	0.17±0.009c	0.18±0.010b
$CPPU_{(2)}$	18.2±0.74a	18.4±0.76a	0.19±0.011a	0.20±0.012a
$CPPU_{(3)}$	16.4±0.66cd	15.8±0.69d	0.17±0.009c	0.17±0.009c
$K_{(1)}$	15.8±0.62de	15.5±0.62de	0.16±0.008d	0.17±0.009c
$K_{(2)}$	17.1±0.70b	17.6±0.74b	0.18±0.010b	0.18±0.010b
$K_{(3)}$	14.8±0.48f	15.1±0.47e	0.17±0.009c	0.16±0.008d
$Proline_{(1)}$	15.1±0.55ef	15.8±0.54d	0.15±0.007e	0.16±0.008d
$Proline_{(2)}$	15.8±0.58de	16.5±0.59c	0.17±0.009c	0.17±0.009c
$Proline_{(3)}$	15.2±0.55ef	15.5±0.52de	0.15±0.007e	0.16±0.008d

Control; distilled water, $K_{(1)}$, $K_{(2)}$, and $K_{(3)}$; potassium (in the form of K_2SO_4) applied at levels of 5.0, 10.0, and 15.0 mM, respectively, $CPPU_{(1)}$, $CPPU_{(2)}$, and $CPPU_{(3)}$; forchlorfenuron applied at levels of 20, 40, and 60 µM, respectively, and $Proline_{(1)}$, $Proline_{(2)}$, and $Proline_{(3)}$; proline applied at levels of 2.0, 4.0, and 6.0 mM, respectively. All treatments were three foliar sprays performed on 1, 13, and 25 September. All fruit samples were collected on 5 October (10 days after the third foliar spray) to analyze fruit quality traits.

Sufficient water is required along with warm climates for fig trees (**Micheloud et al., 2018; Moura et al., 2023**). So, in fig cultivations, the late fruit yield (September–December) in Egypt, becomes less quantity and of lower quality compared to the main fruit yield (June–August) due to the trees being exposed to lower temperatures and senescence. This negative result may be attributed to the reduced photosynthetic capacity under stress, which has a direct link with fruit yield and fruit quality (**Hudecek et al., 2023**). However, the quantitative and qualitative traits of late fig fruit yield can be noticeably improved by using plant growth regulators (PGRs) (**Kurubar et al., 2017**). Among the roles played by PGRs including plant hormones [auxins (AUXs), cytokinins (CK), and gibberellins (GAs)] are delaying leaf senescence, stimulating plant cell expansion and division, fruit setting and enlargement, and increasing crop yields (**Schaller et al., 2015; Tarfayah et al., 2023**). These useful roles played by PGRs could help improve the late fig fruit yield quantitatively and qualitatively along with prolonging the fruiting period.

Through an experiment that lasted for two years (2019 and 2020), among the PGRs, 10.0 mM K, 4.0 mM proline, or 40.0 μM CPPU (forchlorfenuron; N-(2-chloro-4-pyridyl)-N-9-phenylurea) contributed in this study to the improvement in the late fig fruit yield quantitatively and qualitatively (**Tables 2−4**).

Potassium regulates many plant physio-biochemical responses, including uptake of water, translocation of nutrients and sugars, photosynthesis, synthesis of protein, leaf integrity, nutrient balance, hormonal homeostasis, activation of many antioxidative enzymes, etc. (**Hemida et al., 2017; Taha et al., 2020; Mekdad et al., 2021; Abdelfattah et al., 2021; Sardans and Peñuelas, 2021; Johnson et al., 2022; Rady et al., 2023**). So, a K management strategy for fig cultivation systems is required to enhance the late fig fruit yield quantitatively and qualitatively. An adequate amount of K in the plant can regulate the stomatal opening/closing system, cell integrity, turgidity, and elongation (**Sardans and Peñuelas, 2021**). A sufficient K dose in the plant can optimize plant growth by producing ATPase at an optimal level in the plasma membrane (**Siddiqui et al., 2021**). Leaf photosynthetic activities are improved by sufficient K in plant tissues through improving CO_2 fixation, transportation, and photo-assimilate consumptions, regulating the PSII light energy (**Thornburg et al., 2020**), controlling ATP synthesis along with the activation of enzymes involved in photosynthesis (primary metabolism) (**Li et al., 2016; Chen et al., 2016**), and antagonizing light-stimulated due to H^+ flux within the thylakoid membranes (**Anschütz et al., 2014**). An adequate dose of K in the plant induces the reaction center structure and function optimizing the fluorescence kinetics of chlorophyll (**Römheld and Kirkby, 2010**). Also, K can contribute to optimizing stomatal conductance, electron transfer energy, and photosynthetic rate (**Marschner, 2011**). K can regulate water influx to guard cells and enhance the osmotic adjustment to retain a suitable cell turgor pressure and its relative water content and stability of its membranes (**Johnson et al., 2022**). Since K can improve water uptake, it can enhance the uptake of other nutrients through water movement, through the regulatory role of K in trans-membrane potential and osmotic pressure in xylem tubules (**Abd El - Mageed et al., 2023**). **Misskire et al. (2019)** signalized that having adequate K in a plant can optimize its uptake of nutrients, including N, P, K, Ca, and Mg.

As an osmoprotectant and/or antioxidant, proline regulates many plant physio-biochemical responses, including photosynthetic efficiency, carbon assimilation pathway, primary metabolism-related enzymes, including RubisCO, cell membrane structural and leaf integrity, osmotic pressure regulation, nutrient and hormonal homeostasis, antioxidant capacity, etc. (**Li et al., 2015; Merwad et al., 2018; Ould said et al., 2021; Yang et al., 2022; Gao et al., 2023**). So, proline can be used as a management strategy for fig cultivation systems to enhance the late fig fruit yield quantitatively and qualitatively. Sufficient proline protects the structural integrity of plant cell membranes, regulates stomatal movement and osmoregulation, and improves the relative electron transfer rate, the efficiency of the Calvin cycle pathway, carbon assimilation pathway, photosynthetic systems, and the activities of RubisCO, FBPase, and FBA enzymes in plants (**Li et al., 2015; Gao et al., 2023**). Also, proline markedly enhances antioxidant enzyme activities and non-enzymatic antioxidant contents (AsA–GSH cycle), which are scavengers for ROS and are essential for plant resilience (**Rady et al., 2019b; Ould said et al., 2021**).

However, 40.0 µM CPPU exceeded K and proline in enhancing the late fig fruit yield quantitatively and qualitatively. In this study, CPPU efficiently regulated fig tree growth (**Table 2**), late fruit yield (**Table 3**), and fruit quality traits (**Table 4**).

The leaf's main function is to provide different assimilates for the normal growth of crop plants through photosynthesis. As reported in a review (**Hönig et al., 2018**), CK, at various levels, positively affects the functional and structural aspects of photosynthesis and increases the number of chloroplasts. This result is in favor of delaying leaf senescence by stopping the loss of chlorophyll and thus keeping leaf greenness (data not shown), which was reflected in the increased fruiting period of fig trees and also increased assimilates resulting from the improved photosynthesis in favor of the increased late fruit yield quantitatively and qualitatively (**Tables 3 and 4**).

Primary metabolism-related gene expressions contributed to increased fruit yield components and fruit quality traits (**Wang et al., 2023**). **Zeng et al. (2016)** revealed that CPPU treatment augmented fruit set and fruit yield in Macadamia integrifolia because CPPU was effective in minimizing fruit drop. Fruit is a strong sink for metabolites, and fruit set is strongly related to soluble sugar availability and CPPU regulates soluble sugar distribution (**Li et al., 2001; McFadyen et al., 2012**). CPPU enhanced the export of soluble sugars from leaves to fruits and promoted carbohydrate utilization in bearing branches. Therefore, CPPU augmented the sugar availability in the bearing branches to improve fruit retention and quality (**Zeng et al., 2016**). Our findings signalized an improvement in all fig fruit quality traits (fruit length, fruit diameter, fruit volume, FTSS, FTA, fruit soluble sugars, and fruit K and Ca) by CPPU treatment, all are consistent with those of **Matsumoto et al. (2018)** and **Tyagi et al. (2021)**. **Matsumoto et al. (2018)** reported that CK treatment increases the sink sturdiness and the impact varies depending on the stage of cell development. Also, CPPU treatment can stimulate strong fruit sink strength that can compensate for the high fruit growth and not reduce the fruit's total soluble solids. In addition, CPPU treatment stimulates cell division and higher cell numbers in fruits.

CONCLUSION:

The results of this study signalized that the application of 40 µM CPPU (forchlorfenuron) in three foliar sprays could improve the growth, late fruit yield, and fruit quality traits of fig trees. These positive findings open the way for further scientific investigation using CPPU and to explore more precise explanations for the increase in late fruit yield and fruit quality traits. The results of this study confirmed the hypothesis that the application of the plant growth regulator CPPU at 40 µM in three foliar sprays could stimulate the defensive response of the fruit to overcome the adverse conditions causing low late fruit yield and fruit quality traits.

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