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ENHANCING QUALITY IN *Bidens ferulifolia*: INTERPLAY OF LIGHT EXTENSION AND GROWTH RETARDANTS IN GREENHOUSE CULTIVATION

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ABSTRACT

This study examined the effects of photoperiod extension (16-hour day) and growth retardant application during the liner stage (weeks 5–11) on nutrient uptake and plant quality in two *Bidens ferulifolia* cultivars (Fire&Spicy and Hot&Spicy). Treatments included supplemental lighting (L), growth retardant (R), both (L-R), and a control (NL-NR). Mature plants were assessed for plant architecture, flowering, nutrient status, photosynthetic pigments, and soluble sugars. All plants branched vigorously, but L-R produced the most commercially favourable structure, with fewer long shoots and more short ones. L-R also yielded the shortest shoots and highest dry mass, especially in Hot&Spicy alongside increased P and Zn. Retardants reduced fresh mass but increased levels of N, P, K, S, and Cu, while decreasing Fe and Mn. Light-treated plants have more fully open flowers but had similar bud numbers. Supplemental light improved nutrient accumulation, chlorophyll a, carotenoids, and sugar content, indicating better physiological efficiency. Cultivars responded differently to R, with Fire&Spicy showing greater micronutrient uptake. Combining light and retardant during the liner stage enhances visual quality and nutrient efficiency in *B. ferulifolia*, offering growers a strategy to improve crop performance while potentially reducing reliance on chemical growth regulation.

Keywords: balcony plants, macro- and microelements, ornamental plants, photosynthetic pigments, greenhouse plants production, vegetative traits

INTRODUCTION

Bidens ferulifolia, commonly known as Bidens or fern-leaved Bidens, is a vigorous, herbaceous ornamental species that serves as a summer bedding plant, widely appreciated for its bright yellow flowers, trailing habit, and adaptability in containers, hanging baskets, and landscaping. *B. ferulifolia*, a member of the

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Asteraceae family, is classified within the *Bidens* genus, which comprises approximately 280 species globally. The genus originated in Arizona, New Mexico and Northern Mexico, with subsequent diversification across North and South America, indicating a complex phylogenetic relationship with *Coreopsis* [Abdullah et al. 2025]. *B. ferulifolia* has been used as an ornamental plant for nearly three decades, particularly in gardens, containers, and mixed ornamental hanging baskets, despite being a perennial typically discarded after the end of the growing season [Nowak 2003, Walliser et al. 2022]. Its popularity among growers and consumers continues to grow due to its heat tolerance, prolonged flowering, and visual appeal [Dwyer 2022]. Progress in breeding programs has resulted in new cultivars with interesting new colour combinations, ranging from pure yellow to yellow-red, white-red, pure white, and purple, which contain natural pigments including flavonoids, anthochlors, and carotenoids [Walliser et al. 2022]. In commercial horticulture, bidens is propagated through vegetative cuttings, and the initial phase of plant development – liner production – is critical for ensuring uniformity and marketable quality at later stages [Nau et al. 2021].

In modern greenhouse cultivation, achieving compact, well-branched liners is a major production goal. However, cuttings of young balcony plants are prone to excessive elongation and internode extension, particularly under suboptimal light conditions during early spring or in high-density propagation settings [Munir and Alhajhoj 2017, Liebers and Pfannschmidt 2024]. This tendency for unwanted stem elongation not only affects the visual quality of the final product but also increases the need for manual pinching or chemical interventions, both of which add to production costs and labour inputs [Faust et al. 2016].

Light is one of the most potent environmental cues in regulating plant growth, with photoperiod and light intensity influencing both vegetative and reproductive development [Vyavahare et al. 2024, Kowalczyk et al. 2024]. Extending the day length using supplemental lighting to achieve a 16-hour photoperiod has been shown to reduce stem elongation, branching, and biomass accumulation in many bedding plant species that belong to long-day or neutral-day plants [Adams and Langton 2005, Meng and Runkle 2014]. In addition to morphological changes, light can impact physiological processes such as nutrient uptake and assimilation. However, while the role of extended photoperiods in promoting compact growth is well-documented in genus like *Petunia*, *Viola* [Collado and Hernández 2022] the specific effects on *Bidens ferulifolia* – particularly in interaction with growth regulators – remain underexplored.

Chemical growth retardants are widely used in ornamental production to manage plant height and habit. Compounds such as daminozide, paclobutrazol, or chlormequat chloride reduce internode elongation by inhibiting gibberellin biosynthesis, leading to more compact and marketable plants [Pobudkiewicz 2008, Whipker 2019]. In addition to modifying shoot architecture, growth retardants alter physiological processes by reducing water consumption, enhancing root formation, and modifying plant morphology, which affects the root-shoot ratio [Gent and McAvoy 2024]. Despite their routine use, the influence of these compounds on the accumulation of macro- and microelements in liner-stage bidens has not been clearly established.

While both photoperiod manipulation and growth retardants are common strategies in liner production, little is known about their potential interaction effects on nutrient dynamics and overall plant quality. Most existing studies examine these factors in isolation, and few address their combined impact under realistic commercial greenhouse conditions [Munir and Alhajhoj 2017, Collado and Hernández 2022]. Furthermore, growers seek sustainable approaches that minimise chemical inputs while maintaining high production standards, highlighting the need for trials that integrate lighting strategies with moderate plant growth regulator (PGR) use.

We hypothesised that extending the photoperiod to 16 hours and applying growth retardants during the liner stage would not only regulate shoot elongation and branching but also affect nutrient uptake, pigment accumulation, and overall quality of *Bidens ferulifolia*. In particular, we expected that the combined treatment would enhance commercial value by producing compact, well-nourished plants with desirable architecture. Therefore, the objective of this study was to assess the effects of photoperiod extension and growth retardant application during the rooting stage on nutrient status, plant architecture, flowering, and the concentration of photosynthetic pigments. By testing these factors under commercial production conditions, we aimed to provide practical recommendations for optimising young plant quality while reducing reliance on chemical growth regulators.

MATERIAL AND METHODS

The study was carried out in early 2023 at the Plantpol nursery (Jezioro Street, Zaborze, Poland), using two cultivars of *Bidens ferulifolia* Fire&Spicy and Hot&Spicy. Unrooted cuttings were collected from mother plants on February 1, 2023 (week 5) and immediately placed to the greenhouse for the propagation stage of commercial production. The experiment consisted of two successive cultivation phases: young plant production – liners production (where researched treatments were applied) and subsequent finishing to produce market-ready plants (following the observations and tests) [Szewczyk-Taranek et al. 2025].

The cultivation stages are described in detail below.

Stage 1: Liner Production. Cuttings (approx. 2.5 cm) of two cultivars (Fire&Spicy and Hot&Spicy) were planted singly into paper pots filled with a substrate containing 30% coconut fiber, 40% fine peat, 15% polystyrene, and 15% perlite (substrate SoMi 537, producer Hawita, Vechta, Germany). These were arranged in 104-cell trays (HerkuPlant, Germany) and placed on greenhouse benches. During the initial week, the fogging maintained a relative humidity of 70–80%, which was gradually reduced to 55–65%. The temperature was held at 20 °C/18 °C (day/night, ±2 °C) for the first 3 weeks, then lowered to 18 °C/16 °C. After rooting, the cuttings were pinched (week 4), spaced at half density (52 per tray), and grown for an additional 3 weeks.

Stage 2: Finishing. In week 11, rooted liners were transplanted into 12 cm pots (1 dm^3), filled with a growing medium of 70% white peat, 15% coconut fiber, and 15% clay (substrate EP 340, pH 5.8, producer Hawita, Vechta, Germany). Plants were cultivated for 3 weeks until they reached commercial maturity. During both phases, an ebb-and-flow irrigation system was employed with fertigation, using a 0.03–0.05% solution of the soluble fertilizer Granusol 10-30-20 + MgO + TE (Mivena BV, The Netherlands). Environmental conditions were managed via a SERCOM SC800 climate control system (Regeltechniek BV, The Netherlands).

The study followed a 2 × 2 factorial design assessing: (1) photoperiod: natural light only (NL) vs. 16-hour day with supplemental lighting (L) and (2) growth retardants: untreated (NR) vs. chemically treated (R). This yielded four treatment groups: NL-NR: no light, no PGR (Plant Growth Retardants); NL-R: no light, with PGR; L-NR: light only; L-R: light and PGR. Each treatment included four replicates: one tray of 104 plants per replicate in Stage 1 and 52 pots per replicate in Stage 2. Plants remained assigned to the same treatment group throughout both stages.

Extended photoperiod treatment was achieved with the use of supplemental lighting applied from week 5 to 11, extending the day to 16 hours (5–21) using 600W HPS lamps (OSRAM Plantastar, 87,000 lumens, 2000K, OSRAM GmbH, Germany), delivering ~100 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD at 1 m height. Lamps were adjusted to avoid overlap with natural daylight – activated 20 minutes before sunset and deactivated 20 minutes after sunrise. Daylength during the experiment naturally ranged from 8 to 11.5 hours.

Growth retardant application involved weekly sprays of daminozide (Dazide Enhance 85 SG, Fine Agrochemicals The Netherlands), 0.2% solution from week 2 to 11. Additionally, one application of paclobutrazol (BONZI, Syngenta, Switzerland, 0.3%) was applied as a foliar spray. Sprays ensured full shoot coverage without runoff. The application volume was 100 dm^3 per 1,000 m^2. At the end of Stage 2, plant quality traits were assessed, including the number and length of shoots (>5 cm), the number of flowers and buds, and biomass of the aboveground plant part (without flowers and flower buds). The data was subjected to a three-factor analysis of variance.

Biochemical analyses included assessment of photosynthetic pigments and soluble carbohydrate content. Leaf samples from 30 plants per treatment were lyophilised and homogenised. Chlorophyll a, chlorophyll b, and carotenoid contents were determined spectrophotometrically after extraction in 96% ethanol, using absorbance values at 470, 649, and 664 nm, and calculated according to Sumanta et al. [2014]. For the determination of sugars, leaf samples (1 g of tissue) were homogenised for 2 minutes at 25 strokes per second using a steel ball. This was followed by an additional 1-minute homogenization at 20 strokes per second in the presence of 1 mL of deionised water. The resulting mixtures were centrifuged at 15 °C for 10 minutes at 12,800 rpm (15.2 · g). Soluble sugar content was then determined using the anthrone method, as described by Dische [1962]. Absorbance was measured at 620 nm using a spectrophotometer. A standard calibration curve was prepared using glucose solutions of known concentrations, which was then used to calculate the glucose content in the samples.

Matured plants were also tested for nutrient content. For this analysis, above-ground tissues (excluding flowers) from 30 plants per replicate were dried at 75 °C, ground, and analysed following the PN-ISO 6496:2002 and PN-EN-ISO 712:2012 methods. Total nitrogen was measured via the Kjeldahl method [Sáez-Plaza et al. 2013]. Macro- and micronutrient content was quantified by ICP-OES (Prodigy Plus instrument, Teledyne Leemans Labs, USA) following microwave digestion in concentrated HNO_3 (MARS 2 system, CEM Corp., USA). The elemental concentration in plant tissue was expressed on a dry mass basis as a percentage (%) for the macronutrients, N, P, K, Ca, Mg, S. The micronutrients are expressed in parts per million (mg kg^{-1} dry mass) for B, Cu, Fe, Mo, Mn, Zn.

Data were subjected to tree-way ANOVA using Statistica 13.3 (TIBCO Software Inc., USA). Differences among means were assessed via the Duncan's test at $p \leq 0.05$ or Tukey's HSD test at $p \leq 0.01$ (for mineral status).

RESULTS AND DISCUSSION

This study assessed the impact of supplemental lighting (extending the day to 16 hours) and growth retardants on the quality and nutrient status of *Bidens ferulifolia* during greenhouse cultivation. Evaluations included morphological, physiological, and biochemical parameters, with a focus on commercially relevant traits.

Table 1. The effect of supplemental light and retardants on morpho-physiological traits of matured *Bidens ferulifolia* plants; L – prolonged light period 16 h, R – retardant treatment, NL – no supplemental light, NR – no retardant, C – cultivar

Treatment	Short shoots number	Long shoots number	Shoots number (mean)	Shoots length (cm)	Upper part weight (g)
Fire&Spicy:					
NL-NR	18.50 ab*	24.94 c	43.44 ab	14.35 bc	37.48 b
NL-R	27.00 cde	17.50 ab	44.50 b	10.02 a	31.72 a
L-NR	23.38 bcd	17.75 ab	41.13 ab	13.15 bc	47.44 d
L-R	32.00 e	15.25 a	47.25 b	9.52 a	40.83 b
Hot&Spicy:					
NL-NR	13.13 a	21.88 bc	35.00 a	15.09 d	39.87 b
NL-R	20.75 bc	20.63 abc	41.38 ab	9.69 a	29.53 a
L-NR	19.50 ab	24.25 c	43.75 b	12.45 b	46.98 cd
L-R	28.13 de	18.13 c	46.25 b	8.20 a	41.35 bc
Main effects:					
L	***	**	**	***	***
R	***	***	***	***	***
C	***	ns	ns	ns	ns
L × R	ns	ns	ns	ns	ns
L × C	ns	**	**	ns	ns
R × C	ns	ns	ns	ns	ns
L × R × C	ns	***	ns	ns	

* means in columns followed by the same letter do not differ significantly at α = 0.05 according to Duncan's multiple range test. Significant effect: **, $p \leq 0.05$; ***, $p \leq 0.01$; ns – not significant

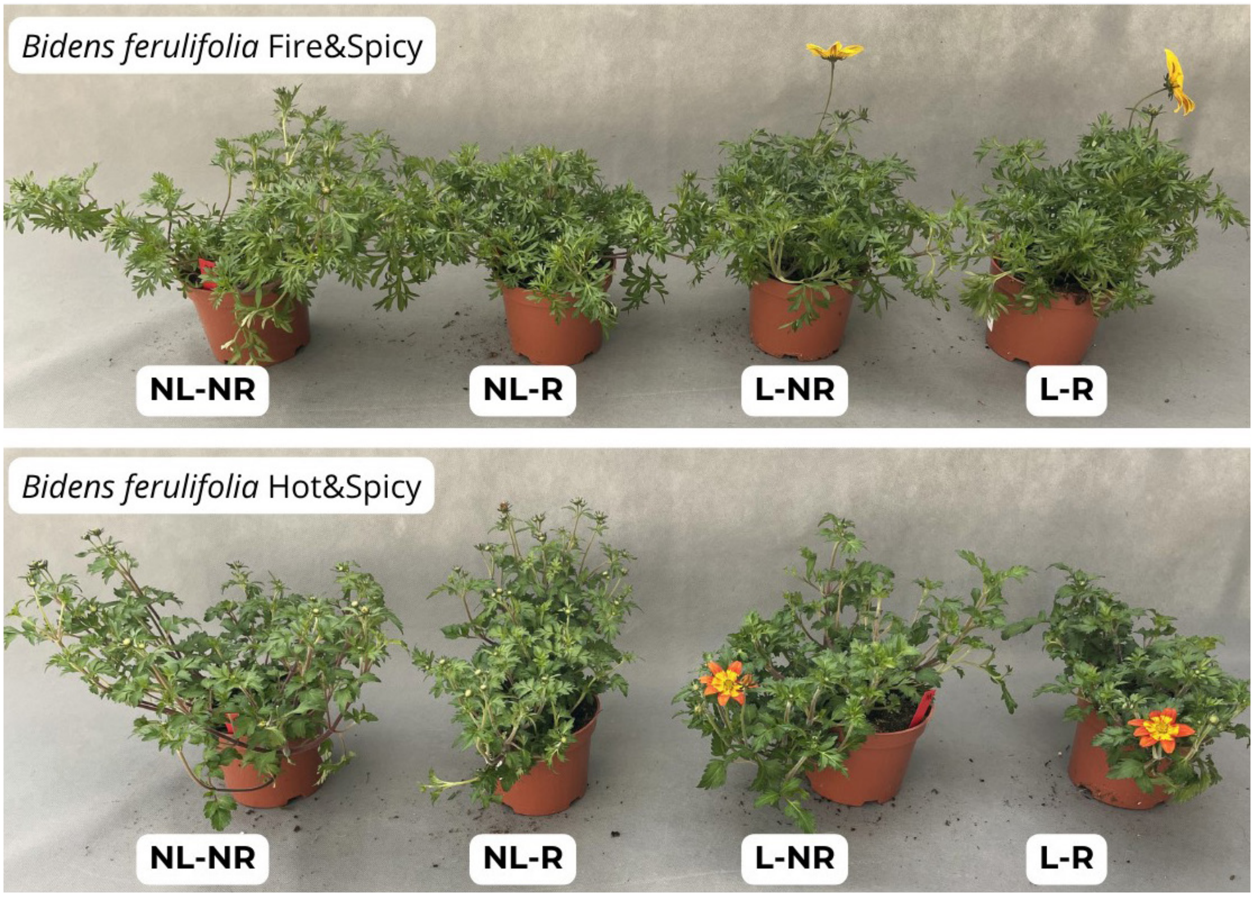


Fig. 1. Mature plants of two cultivars of *Bidens ferulifolia* – final commercial product at the end of stage 2, treated with extended lighting and retardants in stage 1 (liner production). Treatments: L – extended lighting to 16 h, R – retardant treatment, NL – no extended lighting, NR – no retardant

Plant architecture and biomass

Both tested cultivars exhibited prolific branching, with over 40 shoots per plant at maturity (ranging from 41–47), except for Hot&Spicy in the NL-NR treatment, which averaged 35 shoots. The branching pattern was not significantly affected by cultivar (Table 1, Fig. 1). The most compact habit – marked by fewer long shoots – was recorded in the L-R treatment, while the highest number of short shoots occurred in Fire&Spicy under NL-R conditions. From a commercial standpoint, a high number of short, evenly distributed shoots is desirable, as it enhances the plant's visual density and marketability. Both cultivars responded to growth retardants with significantly shorter shoot lengths, regardless of light treatment, suggesting that retardants effectively controlled vegetative elongation across genotypes. No significant interactions between factors were observed in this trait.

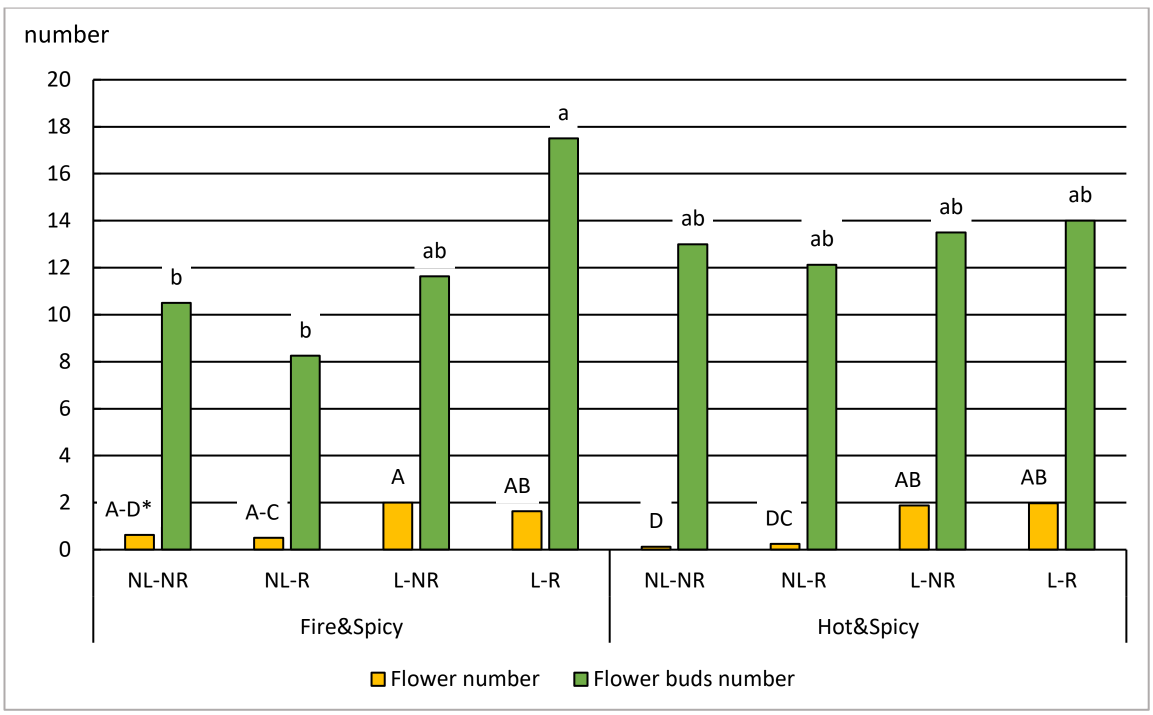
Growth retardants are widely used in bedding plant production to regulate plant height, prevent unwanted elongation, and improve visual compactness. Their mode of action typically involves inhibition of gibberellin biosynthesis, reducing internode extension and promoting lateral branching. However, the final response depends on species sensitivity, environmental conditions, and retardant formulation, concentration, and application schedule [Pobudkiewicz 2008, Bergstrand 2017]. In our study, combining retardant application with supplemental light led to more compact and commercially attractive plants.

Fresh weight measurements indicated that the L-NR treatment resulted in the greatest biomass accumulation in both cultivars (Table 1, Fig. 1). This aligns with previous reports that higher light exposure increases dry mass accumulation by boosting photosynthetic activity [Llewellyn et al. 2020]. Interestingly, while retardants reduced shoot elongation, they also slightly decreased biomass, likely due to restricted growth and reduced leaf area.

Number of flowers and flower buds

At market maturity, plants originating from liners grown under extended photoperiod (L) had a higher number of fully open flowers – typically around two per plant – making them more appealing to potential customers. In contrast, plants from the other treatments flowered only sporadically. Regarding flower buds, Fire&Spicy showed greater responsiveness to treatments, particularly under L-R conditions, where over 17 buds were counted. In comparison, Hot&Spicy exhibited less variation in flower bud number across treatments.

Although the number of flower buds did not differ significantly, supplemental light accelerated flower opening, particularly in Fire&Spicy. This suggests that while bud initiation remained unaffected, the light treatment advanced floral development and phenological progression. These findings are consistent with the behaviour of other bedding plants, such as *Petunia* and *Pelargonium*, where supplemental light or higher daily light integrals (DLI) were shown to accelerate the number of flowers and improve ornamental quality [Runkle et al. 2011, Wollaeger and Runkle 2014]. Prolonged light exposure enhances the total number of shoots, flower buds, and flowers in *Petunia* and *Calibrachoa.* Species classified as long-day plants exhibited the highest total numbers of flowers and flower buds under prolonged lighting [Szewczyk-Taranek et



*means followed by the same letter do not differ significantly at α = 0.05 according to Duncan's multiple range test; uppercase letters indicate differences in flower number; lowercase letters indicate differences in flower buds

Fig. 2. Effect of extended lighting and retardant treatment in stage 1 (liner production) on the number of flowers and flower buds of two cultivars of mature *Bidens ferulifolia* plants. Treatments: L – extended lighting to 16 h, R – retardant treatment, NL – no extended lighting, NR – no retardant

al. 2025]. Although *B. ferulifolia* is considered photoperiod-neutral, our findings imply that light supplementation can positively influence flowering time and floral display, even without altering bud initiation. This highlights the value of manipulating light environments in photoperiod-insensitive species to enhance market quality and shelf appeal.

Photosynthetic pigments and soluble sugars

Supplemental light significantly increased chlorophyll a, chlorophyll b, and carotenoid levels ($p \leq 0.001$), with the strongest effect observed for chlorophyll a under L treatments (Table 2). Retardants slightly enhanced pigment content as well, though not significantly in all cases. Hot&Spicy showed a higher baseline carotenoid content, which was further enhanced by light exposure. Interestingly, while chlorophyll a increased under light in both cultivars, chlorophyll b in Hot&Spicy was higher under natural light, suggesting a genotype-specific light response.

Elevated pigment content under extended photoperiods is typical of plants grown under high light intensity or prolonged photoperiod, as increased DLI promotes chloroplast development and enhances photosynthetic efficiency [Bergstrand and Schüssler 2012, Llewellyn et al. 2020]. The rise in pigment levels also reflects improved plant vigour and a higher capacity for carbohydrate synthesis.

Total soluble sugar content was significantly affected by all factors and their interactions, with the highest concentrations recorded in plants exposed to supplemental light during the liner stage (Table 2). This supports the hypothesis that supplemental light improves assimilate production, contributing to enhanced plant vitality and postharvest performance. High sugar levels may also serve as osmoprotectants, improving stress resilience and post-transplant recovery [Morrow 2008, Runkle 2007].

Table 2. The effect of supplemental light and retardants on photosynthetic pigments and sugar levels in leaves of *Bidens ferulifolia* plants; L – prolonged light 16 h, R – retardant treatment, NL – no supplemental light, NR – no retardant, C – cultivar

Treatment	Chlorophyll a (μg/g d.m.)	Chlorophyll b (μg/g d.m.)	Carotenoids (μg/g d.m.)	Soluble sugars (mg/g d.m.)
Fire&Spicy:				
NL-NR	33.68 a*	18.34 a	6.14 a	86.57 b
NL-R	35.98 b	20.40 abc	6.70 b	76.17 a
L-NR	36.49 bc	19.50 ab	6.44 ab	93.87 c
L-R	37.27 c	19.64 ab	5.92 a	100.00 c
Hot&Spicy:				
NL-NR	36.31 b	27.88 d	8.63 c	75.81 a
NL-R	41.05 d	32.74 e	8.33 c	85.23 b
L-NR	46.90 e	22.41 bc	9.93 d	100.47 c
L-R	48.45 f	22.90 bc	10.21 d	110.87 d
Main effects:				
L	***	***	***	***
R	ns	***	ns	***
C	ns	***	***	***
L × R	ns	***	ns	***
L × C	ns	***	***	***
R × C	ns	ns	ns	***
L × R × C	***	ns	***	***

* explanations as in Table 1

The combined use of supplemental lighting and growth retardants clearly influenced the physiological and morphological traits of *B. ferulifolia*, with differences observed between cultivars. The L-R treatment consistently led to more compact, well-branched plants with better flower display and increased pigment and sugar content – features that enhance commercial value. Particularly favourable responses were recorded in Hot&Spicy under L-R conditions.

Our findings reinforce the importance of managing environmental conditions during the early stages of production. Interventions during the liner phase (weeks 5–11) had lasting effects through to week 15, supporting earlier studies showing that early environmental signals have long-term impacts on development and market performance [Wollaeger and Runkle 2014]. Even though bidens is not classified as photoperiod-sensitive, our data demonstrate that

Table 3. The effect of supplemental light (L) and retardants (R) on mineral profile (macroelements content expressed as % of dry mass) of the plants of two cultivars (C) of *Bidens ferulifolia* in the mature stage

Treatments				d.m.	N	Ca	K	Mg	P	S
Light		L		9.87 b*	5.82 b	1.45 b	5.26 a	0.35 b	0.94 b	0.37 b
		NL		9.53 a	5.50 a	1.32 a	5.32 a	0.33 a	0.86 a	0.30 a
Growth retardation (R)		NR		9.74 a	5.51 a	1.38 a	5.19 a	0.35 b	0.89 a	0.32 a
		R		9.66 a	5.81 b	1.39 a	5.39 b	0.33 a	0.91 b	0.34 b
Cultivar (C)		Fire&Spicy		9.98 b	5.85 b	1.25 a	5.09 a	0.33 a	0.89 a	0.32 a
		Hot&Spicy		9.41 a	5.46 a	1.52 b	5.49 b	0.36 b	0.90 a	0.34 b
L × R	L	NR		9.64 b	5.78 a	1.47 c	5.22 a	0.36 c	0.92 b	0.35 a
		R		10.1 c	5.86 a	1.44 c	5.29 a	0.34 b	0.96 c	0.38 a
	NL	NR		9.83 bc	5.25 a	1.29 a	5.16a	0.33 ab	0.86 a	0.29 a
		R		9.23 a	5.75 a	1.35 b	5.48 b	0.32 a	0.86 a	0.31 a
L × C	L	Fire&Spicy		10.0 c	5.85 b	1.31 a	5.15 a	0.33 a	0.94 c	0.35 b
		Hot&Spicy		9.69 b	5.78 b	1.59 a	5.36 b	0.37 a	0.93 c	0.39 c
	NL	Fire&Spicy		9.92 bc	5.85 b	1.18 a	5.03 a	0.32 a	0.84 a	0.29 a
		Hot&Spicy		9.13 a	5.15 a	1.45 a	5.61 c	0.34 a	0.87 b	0.30 a
R × C	NR	Fire&Spicy		10.0 a	5.78 a	1.24 a	4.95 a	0.34 b	0.87 a	0.30 a
		Hot&Spicy		9.43 a	5.25 a	1.51 a	5.43 a	0.36 d	0.91 b	0.34 b
	R	Fire&Spicy		9.93 a	5.93 a	1.25 a	5.23 a	0.32 a	0.92 b	0.34 b
		Hot&Spicy		9.39 a	5.68 a	1.53 a	5.55 a	0.35 c	0.90 b	0.35 b
L × R × C	L	NR	Fire&Spicy	9.88 a	5.88 a	1.33 a	4.97 a	0.35 bc	0.91 a	0.33 a
			Hot&Spicy	9.40 a	5.68 a	1.60 a	5.47 c	0.38 d	0.93 a	0.38 a
		R	Fire&Spicy	10.2 a	5.82 a	1.29 a	5.33 bc	0.32 a	0.97 a	0.36 a
			Hot&Spicy	9.99 a	5.89 a	1.59 a	5.26 bc	0.36 cd	0.94 a	0.39 a
	NL	NR	Fire&Spicy	10.2 a	5.68 a	1.15 a	4.93 a	0.32 a	0.83 a	0.27 a
			Hot&Spicy	9.46 a	4.82 a	1.42 a	5.39 bc	0.34 b	0.88 a	0.31 a
		R	Fire&Spicy	9.65 a	6.03 a	1.22 a	5.13 ab	0.32 a	0.86 a	0.31 a
			Hot&Spicy	8.80 a	5.48 a	1.47 a	5.83 d	0.34 b	0.86 a	0.30 a

*means in columns for each factor followed by the same letter do not differ significantly at α = 0.01 according to Tukey's test light management during propagation can positively affect flowering behaviour, foliage colouration, and biomass accumulation – traits directly linked to consumer preferences and retail success. These results align with findings in other balcony plants where light and growth regulators were used to optimise aesthetic quality [Llewellyn et al. 2020, Bergstrand and Schüssler 2012].

Mineral nutrient status

Understanding how plants accumulate and store elements is a research topic of current interest, particularly in the context of improving plant nutrition and enhancing plant quality. Our investigations are determining and helping to understand how treatments affect nutrient absorption and accumulation in bidens plants. Though general mineral nutrient guidelines exist for plants, specific sufficiency ranges for macro and micronutrients that define the boundaries of healthy plant growth are often limited and vary by plant species, growth stage, and environmental conditions. There is no data available to establish precise nutrient uptake guidelines and nutrition for interpreting plant analyses of the bidens plant.

Assessment of the two cultivars used in the experiment revealed that Fire&Spicy bidens plants had significantly higher dry mass, nitrogen (N), and boron (B) content in their aboveground biomass (Tables 3 and 4). On the other hand, the Hot&Spicy was distinguished by significantly higher calcium (Ca), potassium (K), magnesium (Mg), and sulfur (S), as well as all micronutrients, regardless of B and molybdenum (Mo) content.

The physiological age of a plant is the main factor influencing the mineral nutrient content in the plant's dry mass. Mineral nutrient concentrations are generally higher in young plants or actively growing tissues than in older ones. As plants develop, the nutrient content per unit of dry mass tends to decline, a phenomenon often described as a dilution effect within the tissue [Bryson and Mills 2014, Barker and Pilbeam 2015].

For most herbaceous plants, the optimal nitrogen content for proper growth typically ranges between 2% and 5% of the plant's dry mass [Barker and Pilbeam 2015]. In our study, the N content in bidens plants ranged from 4.82% (Hot&Spicy NL-NR) to 6.03% dry mass (Fire&Spicy NL-R, the lowest biomass was obtained for this treatment), see Table 3. Herbaceous fertilised plants commonly have a concentration of nitrogen that exceeds 3% of the dry mass in mature leaves. Though in the early stages of growth, concentration is high throughout the plant. The supply of N determines a plant's growth, vigour, colour, and yield [Barker and Pilbeam 2015, Bryson and Mills 2014]. Correspondingly, an enhancement of N assimilation and protein synthesis leads to an increase in chloroplast constituents such as chlorophyll [Marschner 2012]. Chloroplast growth and function were influenced by interactions between light and phytohormones [Brini et al. 2022]. This was confirmed by our study, which showed that the dry mass and chlorophyll content (Tables 2 and 3) increased with the nitrogen content in plants supplemented with additional light. However, excessive N can cause delayed flowering and ripening and increase water content in tissues [Zhang et al. 2023]. Other effects on development (shortening stem length, flowering, etc.) are involved, as would be expected, from the application of growth regulators that interfere with the phytohormone balance in plants by inhibiting the biosynthesis of gibberellins [McLoughlin 2000, Zheng et al. 2012].

The aboveground biomass of bidens plants contained from 4.93% of K (Fire&Spicy NL-NR) to 5.83% of K (Hot&Spicy NL-R) of dry mass (Table 3). Potassium is an important quality agent, both through a direct effect on crop quality and because it strengthens stress resistance. Jiang et al. [2024] revealed that the flower size and yield of chrysanthemum under high potassium treatment were significantly increased compared to using standard fertilisation practice. The K requirement for optimal nutrient status in plants is in the range of 2–5% of the plant's dry mass of vegetative parts. Highest concentrations of K are present in the new leaves, petioles, and stems [Bryson and Mills 2014]. When potassium supply is limited, interference with the uptake and physiological availability of magnesium and calcium can occur. In the presented study, in plants treated with NL-R, the more potassium was determined, the less calcium and magnesium the Hot&Spicy of plants contained (Table 3). In our study, the aboveground bidens biomass concentration of magnesium ranged from 0.32% Mg to 0.38% Mg, and calcium from 1.15% Ca to 1.60% Ca in the dry plant mass (Table 3). The Mg requirement for growth and plant development falls within range in the range of 0.15–0.35% of the dry mass of the vegetative stage [Bryson and Mills 2014]. The optimal calcium content of plants varies between 0.1 and >5% Ca of dry mass, depending on the growing conditions. Its rate of uptake can be strongly depressed by other cations, such as potassium, ammonium, and manganese. Mg deficiency induced by antagonistic cations is a widespread phenomenon [Bryson and Mills 2014].

The phosphorus content in plants sampled for chemical analysis after 2 months of vegetation was high and, depending on the experimental factors, ranged from 0.83% P (Fire&Spicy NL-NR) to 0.97% P (Fire&Spicy L-R) in the dry mass (Table 3). For optimal growth, plants require only 0.3–0.5% of dry mass

Table 4. The effect of supplemental light (L) and retardants (R) on mineral profile (microelements content expressed as mg kg^{-1} of dry mass) of the plants of two cultivars (C) of *Bidens ferulifolia* in the mature stage

Treatments				B	Cu	Fe	Mn	Mo	Zn
Light		L		55.8 b*	12.5 b	175 b	93.4 b	4.69 b	54.0 b
		NL		49.3 a	9.0 a	120 a	64.9 a	1.90 a	45.0 a
Growth retardation (R)		NR		53.0 a	10.3 a	151 b	81.2 b	3.45 a	48.9 a
		R		52.1 a	11.2 b	143 a	77.1 a	3.14 a	50.1 a
Cultivar (C)		Fire&Spicy		54.3 b	9.8 a	123 a	77.0 a	3.41 a	43.3 a
		Hot&Spicy		50.8 a	11.6 b	171 b	81.3 b	3.18 a	55.7 b
L × R	L	NR		56.7 a	12.1 a	190 d	95.7 a	4.90 a	52.4 b
		R		55.0 a	12.9 a	159 c	91.2 a	4.47 a	55.6 c
	NL	NR		49.3 a	8.4 a	112 a	66.7 a	2.00 a	45.5 a
		R		49.3 a	9.6 a	127 b	63.0 a	1.81 a	44.5 a
L × C	L	Fire&Spicy		57.6 a	11.3 c	132 c	90.1 a	5.03 c	46.4 b
		Hot&Spicy		54.1 a	13.7 d	217 d	96.8 a	4.35 b	61.6 d
	NL	Fire&Spicy		51.0 a	8.4 a	115 a	63.8 a	1.79 a	40.2 a
		Hot&Spicy		47.6 a	9.6 b	125 b	65.9 a	2.02 a	49.8 c
R × C	NR	Fire&Spicy		53.8 bc	8.9 a	118 a	77.2 a	3.03 a	41.7 a
		Hot&Spicy		52.3 b	11.7 c	185 d	85.3 b	3.87 b	56.2 c
	R	Fire&Spicy		54.9 c	10.8 b	129 b	76.8 a	3.80 b	44.9 b
		Hot&Spicy		49.4 a	11.6 c	157 c	77.3 a	2.50 a	55.2 c
L × R × C	L	NR	Fire&Spicy	58.1 d	10.2 b	124 b	88.8 a	3.80 c	43.6 a
			Hot&Spicy	55.3 cd	14.0 d	256 e	103 a	6.00 d	61.2 a
		R	Fire&Spicy	57.0 cd	12.5 c	139 c	91.5 a	6.25 d	49.3 a
			Hot&Spicy	52.9 bc	13.3 cd	178 d	90.9 a	2.70 b	61.9 a
	NL	NR	Fire&Spicy	49.4 ab	7.5 a	111 a	65.6 a	2.26 ab	39.9 a
			Hot&Spicy	49.3 ab	9.3 b	113 a	67.9 a	1.73 ab	51.1 a
		R	Fire&Spicy	52.7 bc	9.2 b	119 ab	62.1 a	1.31 a	40.6 a
			Hot&Spicy	45.8 a	9.9 b	136 c	63.8 a	2.30 ab	48.5 a

* explanations as in Table 3

during the vegetative stage of growth [Barker and Pilbeam 2015]. The critical deficiency level of P in the whole plant decreases drastically with age in plants, but remains relatively constant at approximately 1% in young plant tissues [Barker and Pilbeam 2015].

In the studies, the sulphur content in bidens plants, depending on the cultivar, lighting and growth retarding, ranged from 0.27% (Fire&Spicy NL-NR) to 0.39% dry mass (Hot&Spicy L-R), see Table 3. Sulphur is a constituent of the amino acids cysteine and methionine, and hence of protein. Sulfur assimilation also shares many standard features with nitrate assimilation [Barker and Pilbeam 2015]. Plant S requirement varied between 0.1% to 0.5% of the dry mass. Sulphate reduction in leaves is a reaction strongly stimulated by light because ferredoxin is a reductant for the carrier-bound sulfite, and this light enhancement is to be respected. Rapid sulphate reduction stimulated probably S uptake by roots [Marschner 2012].

Not surprisingly, bidens plants exposed to additional light (L), regardless of the cultivar used, had significantly higher dry mass, N, Ca, Mg, P, S, and all micronutrient content in their aboveground biomass (Tables 3 and 4). Light, its intensity and quality affect all life processes of the plant, but mainly photosynthetic production and distribution of assimilates, and consequently, the growth intensity of its specific organs. Maximising the photosynthetic potential of plants is one method for improving yield [Brandon et al. 2018]. Plants receiving additional light assimilate more carbon and use proportionally less assimilates for respiration [Marschner 2012]. This favours the increased growth of shoots and leaves, which, as expected, was confirmed by the study conducted. In such conditions, N-use is also economical, which improves plant productivity. Bueno and Vendrame [2024] revealed that under white light, plants tend to have higher concentrations of K, Mg, and Ca in their biomass due to the increased dry mass, which was also observed in our research.

Chemical growth retardants used in our studies can induce several physiological responses, including reduced hormone biosynthesis, increased chlorophyll content, altered carbohydrate status, delayed flowering and senescence, and increased tolerance to environmental stresses [McLoughlin 2000, Zheng et al. 2012]. Growth retarding (R) treatment, which can decrease gibberellin (GA) synthesis in the subapical meristems of shoot tips [Rademacher 2000], as a consequence, reduced internode extension and altered plant morphology, increased the content of N, K, P, S, and copper (Cu) in bidens plants (Tables 3 and 4). On the other hand, growth retardants significantly reduced the iron (Fe) and manganese (Mn) content in biomass. The effects of paclobutrazol and other plant growth retardants on reproductive growth vary considerably among species, dose rates, and timing of application [McLoughlin 2000]. Plants retarded by exogenously introduced growth regulators or grown under limited light must adopt a survival strategy. The most significant activity in mobilising photosynthetic products and reserve substances is exerted by leaves and shoots, potential donors of assimilates [Epstein and Bloom 2005]. Plants strive to integrate the processes of nutrient synthesis and distribution in a way that ensure maximum plant growth under these stress conditions. Flowers/fruits are then not the primary acceptors of assimilates [Marschner 2012]. The application of growth retardants without light supplementation decreased flower number, flower buds, and upper part weight (Fig. 2, Tables 3 and 4). GA also influences the expression of flowering-initiation genes in both the leaf and shoot apical meristem. GA biosynthesis is activated rapidly after a transition from short to long days [Brini et al. 2022]. Plants constantly adapt to changing environmental conditions, exhibiting a large scale of metabolic and morphological plasticity [Epstein and Bloom 2005, Marschner 2012]. Adaptive responses are regulated by many factors, including sugar content and hormones that regulate gene expression. In the presented research, we detected an increase in sugar content in two cultivars of bidens plants treated with supplemental light and chemically retarded (L-R), see Table 3. The potassium and GA act synergistically. Cell expansion in leaves controlled by GA is closely related to their potassium content. The enhancement of stem elongation by GA is also dependent on the K^+ supply. The highest potassium content was detected in bidens plants underexposed to light and chemically treated (NL-R).

The number of flowers and fruits per plant can be directly affected by the supply of mineral nutrients. This is particularly true for several micronutrients [Epstein and Bloom 2005]. For example, copper deficiency affects the reproductive phase. When the copper supply is adequate, the generative organs have the highest Cu content in the flowers and also the highest Cu demand [Jun et al. 2023]. Similar results are observed for zinc (Zn) and manganese deficiency. Also, low boron supply inhibits flowering and seed development. The review by Jun et al. [2023] discussed the role of micronutrients, such as boron, zinc, iron, and copper, in enzymatic reactions and hormone biosynthesis, which affect flower development and reproduction. The critical deficiency level of copper in vegetative parts is generally in the range 1–5 mg Cu kg^{-1} d.m. [Bryson and Mills 2014]. In our study, copper content in bidens plants was high and varied between 7.5 mg Cu kg^{-1} (Fire&Spicy NL-NR) and 14.0 mg Cu kg^{-1} dry mass (Hot&Spicy L-NR), see Table 4.

In the presented study, the boron content in bidens plants ranged from 45.8 mg B kg^{-1} dry mass (Hot&Spicy NL-R) to 58.1 mg B kg^{-1} dry mass (Fire&Spicy L-NR), see Table 4. A range of values that describe the nutrient status of different bedding plants varies from 15 to 80 mg B kg^{-1} dry mass [Bryson and Mills 2014]. However, the ratio of toxic to adequate boron levels is smaller than for most other nutrient elements. Growth retarding reduces the boron content in Hot&Spicy plants, while it is contrary to the Fire&Spicy plants. Similar relationships were found for Fe and Mo (Table 4). The critical manganese deficiency contents in bidens plants are similar, varying between 10–20 mg Mn kg^{-1} dry mass in fully expanded leaves [Barker and Pilbeam 2015]. In the shown studies, the Mn content was high, ranging from 62.1 mg Mn kg^{-1} in dry mass (Fire&Spicy NL-R) to 103 mg Mn kg^{-1} dry mass (Hot&Spicy L-NR), see Table 4. In general, supplemented light increased the Mn content in bidens plants, and the growth retarding treatment significantly reduced it. Depending on plant species, the critical molybdenum deficiency varies between 0.1 and 1.0 mg kg^{-1} leaf dry mass. The function of molybdenum in plants is closely related to nitrogen metabolism, and the Mo requirement strongly depends on the manner of N supply [Marschner 2012, Jun et al. 2023]. The studies showed that the range of Mo content in bidens plants was between 1.31 mg Mo kg^{-1} dry mass (Fire&Spicy NL-R) and 6.25 mg Mo kg^{-1} dry mass (Fire&Spicy L-R), see Table 4.

A significant interaction between the applied factors, lighting and growth retarding (L × R), was demonstrated on the dry mass content and macro- and micronutrients in the biomass of bidens (Tables 3 and 4). Plant growth and development are strongly influenced by various light signals, as well as plant hormones, which play crucial roles in regulating these responses to light [Brini et al. 2022]. Our study showed that the lowest dry mass (9.23% d.m.) was observed in plants with non-supplemental lighting and retarding treatments (NL-R), while the highest (10.1% d.m.) was found in plants under supplemental light with retarding (L-R). Plants with a 16-hour photoperiod (L), regardless of the growth retardant treatment, had significantly higher Ca, P, and Zn content in their biomass. Conversely, plants without light supplementation (NL) showed the lowest Mg, P, and Fe content. Phosphorus is vital during the development of reproductive organs [Jun et al. 2023]. A lack of P at this growth stage can delay flower initiation and reduce the number of flowers [Zhang et al. 2023]. The highest phosphorus and zinc content was found in light-supplemented and retarded (L-R) bidens plants. This was related to the high number of flower buds and flowers, especially in the Fire&Spicy (Table 3, Fig. 2).

In leaves, the critical deficiency levels are below 15–20 mg Zn kg^{-1} dry mass. In the shoot meristems, a zinc content of at least 100 mg Zn kg^{-1} dry mass is essential for maintaining protein synthesis [Barker and Pilbeam 2015]. Suppression of stem elongation due to Zn-deficiency also reduces flowering because of poor bud development [Marschner 2012]. In the presented research, the microelement content ranged between 39.9 mg Zn kg^{-1} dry mass (Fire&Spicy NL-NR) and 61.2 mg Zn kg^{-1} dry mass (Hot&Spicy L-NR), see Table 4.

The highest iron content was determined in plants with additional light and no chemical growth control (L-NR). This was particularly visible in the case of the Hot&Spicy, which contained significantly more Fe in the L-NR (256 mg Fe kg^{-1} in d.m.) treatment than in the NL-NR (113 mg Fe kg^{-1} in d.m.), see Table 4. The same was proved for chlorophyll a, carotenoids, and sugars (Table 3).

Mitochondria and chloroplasts have a high requirement for iron, and the chloroplasts may be the site of storage of Fe. Transport into chloroplasts is stimulated by light. In Fe-deficient leaves, the content of chlorophyll and carotene declines. The lower CO_2 fixation rate per unit of chlorophyll is also possible [Marschner 2012]. There is a close positive correlation between the total Fe content in leaves and the chlorophyll content when the supply of iron is optimal [Jun et al. 2023]. The critical deficiency content of iron in leaves is in the range of 50–150 mg Fe kg^{-1} dry mass [Barker and Pilbeam 2021].

The genetic background for plant nutrition is an area which research interest is still expanding. Different responses of the used cultivars to the light factor (C × L) were noted (Tables 3 and 4). Non-supplemented with light (NL) Hot&Spicy plants had the lowest dry mass (9.13% dry mass), contained the least nitrogen (5.15% N dry mass), phosphorus (0.87% P dry mass), and sulphur (0.30% dry mass), as well as significantly more potassium (5.61% K dry mass), Cu, Fe, Mo, and Zn. On the other hand, Fire&Spicy plants with NL treatment were distinguished by the lowest content of P, S, Cu, Fe, Mo, and Zn. Chemically treated (R) bidens Fire&Spicy resulted in a significant increase in the content of P, S, Cu, Fe, Mo and Zn in plants. On the other hand, retarded plants of the Hot&Spicy showed significantly lower content of Mg, B, Fe, Mn and Mo in biomass (Tables 3 and 4).

CONCLUSION

The results of this study demonstrate that both supplemental lighting and growth retardant application significantly influence the architecture, nutritional status, and physiological quality of *Bidens ferulifolia* plants during greenhouse cultivation. Both tested cultivars, Fire&Spicy and Hot&Spicy, exhibited strong branching, typically producing around 40 shoots per plant in the final stage. Plant architecture, characterised by a high number of short shoots and reduced elongation, was achieved when liners were produced under extended day conditions combined with growth retardant application (L-R treatment). Plants from this treatment not only exhibited the most compact and logistically suitable form but also had the shortest shoots and the fewest long ones. Furthermore, these plants recorded the highest dry mass as well as elevated phosphorus and zinc content, indicating a favourable balance between biomass production and mineral nutrient accumulation. In the absence of growth retardants, plants accumulated more fresh mass, regardless of lighting conditions. However, chemical growth regulation enhanced the concentrations of nitrogen, potassium, phosphorus, sulfur, and copper, while reducing the levels of iron and manganese. These findings suggest that retardants may modify nutrient uptake patterns by altering plant morphology and metabolic activity.

Flower development was strongly influenced by supplemental lighting during the liner stage. Only plants exposed to light during early propagation had already opened flowers by the end of production – typically two per plant – whereas others exhibited mostly buds. Importantly, the number of buds did not significantly differ among treatments, indicating that light accelerates flower opening rather than initiation. Regardless of cultivar, plants grown under extended daylength also had greater dry mass and significantly higher concentrations of macronutrients (N, Ca, Mg, P, S) and all tested micronutrients, confirming the positive effect of light on nutrient acquisition and assimilation. Moreover, light supplementation during the early growth phase led to an increase in chlorophyll a and soluble sugar content in the final plants. This suggests enhanced photosynthetic capacity and carbohydrate accumulation – traits that contribute to improved overall plant vigour and post-transplant performance. The findings support the conclusion that nutrient availability and plant architecture are tightly linked to environmental regulation and growth control strategies. Supplemental lighting, particularly in combination with growth retardants, can optimise nutrient use efficiency, coordinate flowering, and promote compact, high-quality ornamental plants. While both cultivars responded to the treatments, their reactions to growth retardants differed. Fire&Spicy tended to accumulate higher levels of minerals – especially micronutrients – under growth regulation, whereas Hot&Spicy showed the opposite trend. These cultivar-specific differences highlight the importance of tailoring production strategies to individual genetic responses.

In summary, integrating supplemental lighting and chemical growth regulation during the liner phase offers a practical approach to enhance the commercial quality of *Bidens ferulifolia*, influencing not only plant form and flowering behaviour but also internal nutrient composition and physiological condition.

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CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

Abdullah, S., Munir, M., Javed, B., Ahmad, M., Abbasi, B.A., Dawood, S., Zhang, L. (2025). The systematics and biogeography of genus Bidens. In: Bibi, Y., Zahara, K., Qayyum, A., Jenks, M.A. (eds). The genus Bidens chemistry and pharmacology, Springer, Singapore, 3–20. https://doi.org/10.1007/978-981-96-4257-1_1

Adams, S.R., Langton, F.A. (2005). Photoperiod and plant growth: a review. J. Hortic. Sci. Biotechnol., 80(1), 2–10. https://doi.org/10.1080/14620316.2005.11511882

Barker, A.V., Pilbeam, D.J. (2015). Handbook of plant nutrition. 2nd ed. CRC Press, Taylor & Francis Group: Boca Raton–London–New York.

Bergstrand, K.J.I. (2017). Methods for growth regulation of greenhouse produced ornamental pot-and bedding plants – a current review. Folia Hortic., 29(1), 63–74. https://doi.org/10.1515/fhort-2017-0007

Bergstrand, K.J.I., Schüssler, H.K. (2012). Growth and photosynthesis of ornamental plants under different light qualities. Acta Hortic., 956, 109–115. https://doi.org/10.17660/ActaHortic.2012.956.13

Brandon, M., Kozai, T., Lu, N., Yamaguchi, T., Takagaki, M., Maruo, T., Yamori, W. (2018). Next revolution of agriculture. A review of innovations in plant factories. In: Pessarakli, M. (eds). Handbook of Photosynthesis. 3rd ed. CRC Press, Taylor & Francis Group, Boca Raton–London–New York, 723–737.

Brini, F., Mseddi, K., Brestic, M., Landi, M. (2022). Hormone-mediated plant responses to light quality and quantity. Environ. Exp. Bot. 202, 105026. https://doi.org/10.1016/j.envexpbot.2022.105026

Bryson, G.M., Mills, H.A. (2014). Plant analysis handbook. A guide to plant nutrition and interpretation of plant analysis for agronomic and horticultural crops. Micro-Macro Publishing, Inc. Georgia.

Bueno, P.M.C., Vendrame W.A. (2024). Wavelength and light intensity affect macro- and micronutrient uptake, stomata number, and plant morphology of common bean (*Phaseolus vulgaris* L.). Plants 13(3), 441. https://doi.org/10.3390/plants13030441

Collado, C.E., Hernández, R. (2022). Effects of light intensity, spectral composition, and paclobutrazol on the morphology, physiology, and growth of petunia, geranium, pansy, and dianthus ornamental transplants. J. Plant Growth Regul. 41, 461–478. https://doi.org/10.1007/s00344-021-10306-5

Dische, Z. (1962). General color reactions. In: Whistler R.L., Wolfram, M.L. (eds). 187 Carbohydrate chemistry. Academic Press, New York, 477–512.

Dwyer, M. (2022). Bidens spp. Greenhouse management. Available: https://www.greenhousemag.com/article/bidens-durable-annuals/ [date of access: 26.07.2025].

Epstein, E., Bloom, A.J. (2005). Mineral nutrition of plants: principles and perspectives. 2nd ed. Sunderland, Mass Sinauer Associates, Inc.

Faust, J.E., Dole, J.M., Lopez, R.G. (2016). The floriculture vegetative cutting industry. Hortic. Rev. 44(44), 121–172. https://doi.org/10.1002/9781119281269.ch3

Gent, M.P., McAvoy, R.J. (2024). Plant growth retardants in ornamental horticulture: A critical appraisal. In: Basra, A. (ed.). Plant growth regulators in agriculture and horticulture, CRC Press, Taylor & Francis Group, Boca Raton–London–New York, 89–145. https://doi.org/10.1201/9781003578505

Jiang, K., Peng, S., Yin, Z., Li, X., Xie, L., Shen, M., Li, D., Gao, J. (2024). Effects of N, P, K nutrition levels on the growth, flowering attributes and functional components in *Chrysanthemum morifolium*. Horticulturae, 10(3), 226. https://doi.org/10.3390/horticulturae10030226

Jun, S.E., Shim, J.S., Park, H.J. (2023). Beyond NPK: mineral nutrient-mediated modulation in orchestrating flowering time. Plants 12, 3299. https://doi.org/10.3390/plants12183299

Kowalczyk, K., Mirgos, M., Sobczak-Samburska, A., Przybył, J.L., Kowalczyk, W., Geszprych, A., Kalisz, S., Łaźny, R., Gajewski, M., Gajc-Wolska, J. (2024). Effect of growing pink tomato plants with LED supplementary lighting in a greenhouse covered with diffusion glass on post-harvest fruit quality. Acta Sci. Pol. Hortorum Cultus, 23(6), 57–74. https://doi.org/10.24326/asphc.2024.5374

Liebers, M., Pfannschmidt, T. (2024). New horizons in light control of plant photomorphogenesis and development. Front. Photobiol. 1, 1346705. https://doi.org/10.3389/fphbi.2023.1346705

Llewellyn, D., Schiestel, K., Zheng, Y. (2020). Increasing levels of supplemental LED light enhances the rate of flower development of greenhouse-grown cut gerbera. Agronomy, 10(9), 1332. https://doi.org/10.3390/agronomy10091332

Marschner, P. (2012). Mineral nutrition of higher plants. Academic Press Elsevier. https://doi.org/10.1016/C2009-0-63043-9

McLoughlin, K.T. (2000). Tree growth regulators for management of trees in electric utility rights-of-way. A literature review and current status. Final Report. Electric Power Research Institute, Inc., Pleasant Hill, USA. Available: https://www.epri.com/research/products/1000317 [date of access: 26.07.2025].

Meng, Q., Runkle, E.S. (2014). Controlling flowering of photoperiodic ornamental crops with light-emitting diode lamps: a coordinated grower trial. HortTechnology, 24(6), 702–711. https://doi.org/10.21273/HORTTECH.24.6.702

Morrow, R.C. (2008). LED lighting in horticulture. HortScience, 43(7), 1947–1950. https://doi.org/10.21273/HORTSCI.43.7.1947

Munir, M., Alhajhoj, M.R. (2017). Plant height control of obligate long day herbaceous annuals using plant growth retardants and light. J. Appl. Hortic., 19(3), 241–244.

Nau, J., Calkins, B., Westbrook, A. (2021). Crop culture Bidens. In: Nau, J., Calkins, B., Westbrook, A. (eds). Ball RedBook Crop culture and production. Ball Publishing, Chicago.

Nowak, J. (2003). Wpływ stężenia pożywki i retardantów wzrostu na wzrost i kwitnienie uczepu złocistego (*Bidens aurea* (Ait.) Scheriff) [The effect of nutrient solution concentration and growth retardants on growth and flowering of bidens (*Bidens aurea* (Ait.) Scheriff)]. Zesz. Probl. Postęp. Nauk Rol. 491, 181–186. [In Polish].

PN-ISO 6496:2002. Pasze. Oznaczanie wilgoci i innych substancji lotnych. Polski Komitet Normalizacyjny. [Feed. Determination of moisture and other volatile substances. Polish Committee for Standardization].

PN-EN ISO 712:2012. Zboża i przetwory zbożowe. Oznaczanie wilgotności. Rutynowa metoda odniesienia. Polski Komitet Normalizacyjny. [Cereals and cereal products. Determination of moisture. Routine reference method. Polish Committee for Standardization].

Pobudkiewicz, A. (2008). The influence of growth retardants and cytokinins on flowering of ornamental plants. Acta Agrobot., 61(1), 137–141. https://doi.org/10.5586/aa.2008.018

Rademacher, W. (2000). Growth retardants: effects on gibberellin biosynthesis and other metabolic pathways. Ann. Rev. Plant Biol., 51(1), 501–531. https://doi.org/10.1146/annurev.arplant.51.1.501

Runkle, E.S. (2007). Maximizing supplemental lighting for greenhouse crops. Michigan State University MSU Extension. Available: https://www.canr.msu.edu/resources/maximizing_supplemental_lighting [date of access: 26.07.2025].

Runkle, E.S., Blanchard, M.G., Faust, J.E. (2011). Energy-efficient greenhouse lighting of ornamentals. Acta Hortic. 907, 37–44. https://doi.org/10.17660/ActaHortic.2011.907.4

Sáez-Plaza, P., Navas, M.J., Wybraniec, S., Michałowski, T., Asuero, A.G. (2013). An overview of the Kjeldahl method of nitrogen determination. Part II. Sample preparation, working scale, instrumental finish, and quality control. Crit. Rev. Anal. Chem. 43(4), 224–272. https://doi.org/10.1080/10408347.2012.751787

Sumanta, N., Haque, C.I., Nishika, J., Suprakash, R. (2014). Spectrophotometric analysis of chlorophylls and carotenoids from commonly grown fern species by using various extracting solvents. Res. J. Chem. Sci., 4(9), 63.

Szewczyk-Taranek, B., Domagała-Świątkiewicz, I., Kapczyńska, A., Marcinkowski, P., Pawłowska, B. (2025). Supplementary light and retardant application during the rooting stage improve the final performances of *Petunia* and *Calibrachoa* plants. Agronomy, 15(7), 1644. https://doi.org/10.3390/agronomy15071644

Vyavahare, G.D., Kim, J.Y., Kim, H.N., Sin, S.K., Kim, E.J., Park, J.H. (2024). Evaluating the effect of supplementary lighting on the growth and physiological activity of roses during winter by plant-induced electrical signal. Folia Hort., 36(4), 1–13. https://doi.org/10.2478/fhort-2024-0033

Walliser, B., Marinovic, S., Kornpointner, C., Schlosser, C., Abouelnasr, M., Hutabarat, O.S., Haselmair-Gosch, Ch., Molitor, Ch., Stich, K., Halbwirth, H. (2022). The (Bio) chemical base of flower colour in *Bidens ferulifolia*. Plants, 11(10), 1289. https://doi.org/10.3390/plants11101289

Whipker, B.E. (2019). Plant growth regulators for annuals. Grower Talks Mag. Ball Publishing, West Chicago, IL. Available: https://www.growertalks.com/pdf/Annuals_PGR_Guide_2019.pdf [date of access: 20.07.2025].

Wollaeger, H.M., Runkle, E.S. (2014). Producing commercial-quality ornamental seedlings under sole-source LED lighting. Acta Hortic. 1037, 241–248. https://doi.org/10.17660/ActaHortic.2014.1037.31

Zhang, Y., Liu, B., Kong, F., Chen, L. (2023). Nutrient-mediated modulation of flowering time. Front. Plant Sci. 14, 1101611. https://doi.org/10.3389/fpls.2023.1101611

Zheng, R., Wu, Y., Xia, Y. (2012). Chlorocholine chloride and paclobutrazol treatments promote carbohydrate accumulation in bulbs of Lilium oriental hybrids 'Sorbonne'. J. Zhejiang Univ. Sci. B, 13(2), 136–144. https://doi.org/10.1631/jzus.B1000425