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Vanadium differently affects sugarcane bud emergence and early growth

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ABSTRACT
Objective: To evaluate the effect of vanadium on bud emergence and initial growth variables in sugarcane cv. CP 72-2086
Design/methodology/approach: A trial was conducted with sugarcane buds cv. CP 72-2086 in hydroponics under greenhouse conditions. Increasing doses of V (0, 15, and 30 μM) were applied, starting from NH_4VO_3. Bud emergence and initial growth variables were evaluated. A GLM analysis of variance (ANOVA) was performed, comparing means by Tukey ($p \leq 0.05$).
Results: Vanadium demonstrated to have beneficial effects on the germination and initial growth of sugarcane seedlings.
Limitations on study/implications: The evaluations were done with a single source of V and a single variety of sugarcane.
Findings/conclusions: Vanadium showed a tendency to biostimulate bud emergence and initial growth of sugarcane.

Keywords: Poaceae, *Saccharum* spp., beneficial elements, inorganic biostimulation, CP 72-2086.

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INTRODUCTION

In Mexico, the average green sugarcane production volume was 53.6 million Mg for the 2022/23 harvest, and 49.1 million Mg for the 2023/24 harvest, showing a 4.5 million Mg decrease compared to the previous year (SIAP, 2024; SADER, 2024a; Zafranet, 2024; CONADESUCA, 2024). Regarding sugar production, the country produced an average of 5.3 million Mg in the 2022/23 cycle. Meanwhile, in the 2023/24 cycle, 4.7 million Mg were produced, with a deficit of 0.6 million Mg between the two cycles (SIAP, 2024; Zafranet, 2024; CONADESUCA, 2024).

It should be noted that sugarcane cultivation is carried out in 15 states in the country. Among the most productive states are Veracruz, Jalisco, and San Luis Potosí, which in 2023 reached production of 21.2, 7.2, and 5.2 million Mg of green cane, respectively (SIAP, 2024). This activity employs approximately 180,000 families in more than 267 municipalities, generating nearly 500,000 direct jobs and 2.4 million indirect jobs (SADER, 2024b). Within

the agroindustrial sector, sugarcane is the second most economically important product system, only after corn. In 2023, sugarcane production was approximately 53.6 million Mg, placing Mexico as the eighth-largest producer of this crop globally. Also in 2023, Mexico exported (mainly to the United States, Canada, Puerto Rico, Germany, Cuba, and Spain) 997,000 Mg of sugarcane, equivalent to 794 million dollars (SADER, 2024b).

In Mexico, sugarcane production is mainly based on four cultivars: CP 72-2086, Mex 69-290, Mex 79-431, and ITV 92-1424, of which, CP 72-2086 (parents: CP 62-374×CP 63-588) occupies about 36% of the cultivated area in the country (CONADESUCA, 2016). Some of the general botanical characteristics of the cultivar are: semi-erect growth habit of the stems, yellow-green color, internodes with slight zigzag, a round bud without pubescence, and long leaves of medium width. Table 1 shows the active mills in the 2022/2023 harvest and the percentage of use of the four aforementioned cultivars, according to the cultivation area per mill.

Table 1. Percentage of planted area occupied by cultivars CP 72-2086, Mex 69-290, Mex 79-431, and ITV 92-1424, by sugar mill in Mexico.

STATE		**Sown Surface (%)**			
		CP 72-2086	**Mex 69-290**	**Mex 79-431**	**ITV 92-1424**
CAMPECHE	LA JOYA	34.20	18.40	5.90	1.80
CHIAPAS	PUJILTIC	31.00	14.20	-	-
CHIAPAS	HUIXTLA	55.53	34.07	0.28	-
COLIMA	QUESERÍA	15.65	30.76	0.39	26.31
JALISCO	BELLAVISTA	33.64	7.29	8.69	27.89
JALISCO	JOSÉ MARÍA MORELOS		22.04	21.49	19.19
JALISCO	MELCHOR OCAMPO	13.22	-	-	23.23
JALISCO	SAN FRANCISCO AMECA	21.06	29.14	2.22	18.96
JALISCO	TALA	28.40	9.60	7.20	3.20
JALISCO	TAMAZULA	20.82	2.22	-	23.22
MICHOACÁN	LÁZARO CÁRDENAS	0.17	9.98	19.03	26.80
MICHOACÁN	PEDERNALES	1.00		2.00	3.00
MICHOACÁN	SANTA CLARA	1.50	2.00	15.00	66.00
MORELOS	CASASANO	48.52	-	-	14.99
MORELOS	EMILIANO ZAPATA	46.15	-	-	38.84
NAYARIT	EL MOLINO	2.98	7.46	2.16	14.13
NAYARIT	PUGA	4.61	18.26	-	-
OAXACA	ADOLFO LÓPEZ MATEOS	41.68	12.86	1.58	0.28
OAXACA	EL REFUGIO	4.94	33.29	0.82	32.17
OAXACA	LA MARGARITA	32.91	37.75	4.95	2.89
PUEBLA	ATENCINGO	15.36	15.27	20.96	9.93
PUEBLA	CALÍPAM		0.07	2.74	0.56
QUINTANA ROO	SAN RAFAEL PUCTÉ	50.73	46.45	-	0.81
SAN LUIS POTOSÍ	ALIANZA POPULAR	15.00	-	1.00	18.00
SAN LUIS POTOSÍ	PLAN DE AYALA	36.03	-	1.00	2.09
SAN LUIS POTOSÍ	SAN MIGUEL EL NARANJO	61.37	-	3.85	0.52

Table 1. Continues....

STATE		**Sown Surface (%)**			
		CP 72-2086	**Mex 69-290**	**Mex 79-431**	**ITV 92-1424**
SAN LUIS POTOSÍ	PLAN DE SAN LUIS	34.84	0.01	0.40	12.90
SINALOA	EL DORADO	95.60	-	-	-
TABASCO	SANTA ROSALÍA	42.96	41.00	10.84	-
TABASCO	BENITO JUÁREZ	8.74	21.58	11.07	-
TAMAULIPAS	EL MANTE	94.05	-	-	-
VERACRUZ	SAN JOSÉ	7.64	44.60	6.73	16.38
VERACRUZ	EL POTRERO	20.37	50.52	9.09	5.23
VERACRUZ	PROVIDENCIA	3.00	55.00	3.00	9.00
VERACRUZ	SAN MIGUELITO	4.58	68.29	15.50	1.52
VERACRUZ	CUAUTOTOLAPAM	23.51	50.05	0.79	14.93
VERACRUZ	SAN PEDRO	36.00	8.00	21.00	-
VERACRUZ	SAN CRISTOBAL	22.00	24.00	23.00	2.00
VERACRUZ	EL MODELO	67.50	43.50	51.30	20.00
VERACRUZ	CENTRAL MOTZORONGO	4.30	37.00	1.10	7.60
VERACRUZ	EL PROGRESO	28.65	38.89	-	13.87
VERACRUZ	CONSTANCIA	18.24	28.77	0.33	39.20
VERACRUZ	DEL CARMEN	4.82	64.56	8.27	-
VERACRUZ	EL HIGO	97.26	-	-	-
VERACRUZ	LA GLORIA	17.19	55.63	5.20	3.93
VERACRUZ	MAHUIXTLÁN	9.00	22.00	-	40.00
VERACRUZ	PÁNUCO	83.30	6.80	4.30	4.30
VERACRUZ	SAN NICOLÁS	13.00	71.00	3.00	1.00
VERACRUZ	TRES VALLES	34.00	24.00	6.00	2.00

Prepared by the authors using data from MAM (2024) corresponding to the 2022/2023 harvest cycle.

Despite its agricultural, economic, and social importance, sugarcane is a crop that employs little modern technology, which has led to pollution, loss of biodiversity, and low yields both in the field and in the factory (Herrera-Reyes *et al.*, 2023). These problems are being exacerbated by the impact of global climate change, which is expected to cause reductions in sugarcane productivity of nearly 20% of the current average in the state of Veracruz (Brígido-Morales *et al.*, 2023). Therefore, the implementation of sustainable measures to address these climate challenges is urgent. One of these alternatives that could contribute to the sustainability of agriculture is biostimulation (Di Sario *et al.*, 2025).

Inorganic biostimulation with beneficial elements, applied via leaf or root application in low doses, can improve physiological, biochemical, and molecular parameters in plants, allowing greater tolerance to abiotic stress factors and increasing productivity (du Jardin, 2015). Among the beneficial elements, vanadium stands out (Gómez-Merino *et al.*, 2021).

Located in group five of the periodic table and with an atomic weight of 23, V is a soft and ductile metal. It occupies the 22nd place in abundance in the Earth's crust, representing an average of 0.02% in soils and a concentration of 35 nM in seawater (Rehder, 2012). Its biologically active oxidation states are 3^+, 4^+, and 5^+. Some of the species that hyperaccumulate V are beans (*Phaseolus vulgaris* L.) and maize (*Zea mays* L.), which can absorb and translocate V through transpiration to the aerial parts (Ameh *et al.*, 2019). Although overaccumulation of V in plant tissue has been documented to inhibit plant metabolism, there is evidence that low doses of this metal can have potentially beneficial effects (Chen *et al.*, 2020).

In seeds of chili peppers (*Capsicum annuum* L.) cv. Jalapeño Emperador and Poblano Capulín, doses of 25 and 50 μM V, respectively, benefited germination variables (Buendía-Valverde *et al.*, 2018). In seedlings of peppers (*Capsicum annuum* L.) cv. Mysterio F1, root supplementation with 5 μM V improved initial growth, biochemical, and nutritional variables (García-Jiménez *et al.*, 2018). In maize seedlings cv. Xincaitian 1, treated with different doses of V, it was observed that V promotes the synthesis of thiol groups and reduces Hg toxicity by inhibiting its uptake (Hou *et al.*, 2019). In sugarcane (eight-month-old plants), doses of 10 and 20 μM V inhibit flowering and pith formation in cv. CP 72-2086; increases stem height and diameter in cv. Mex 79-341; and increases height in cv. Mex 69-290 (Sentíes-Herrera *et al.*, 2018). The objective of this study was to evaluate the effect of vanadium on bud emergence and initial growth variables in cv. CP 72-2086.

MATERIALS AND METHODS

Characteristics of the plant material and location of the experiment

The plant material used in this study was obtained from the seed banks of the Colegio de Postgraduados, Campus Córdoba, located at Carretera Federal Córdoba-Veracruz km 348.5, Manuel León congregation, Amatlán de los Reyes, Veracruz, Mexico (18° 86' N, 96° 85' W, at an altitude of 650 m). Sugarcane buds were obtained from 11-month-old plants. The cultivar CP 72-2086 (early maturing) was used. The experiment was carried out in a tunnel-type greenhouse (6.5x4.3x1.9 m and 2.8 m at the zenith) with plastic cover, anti-aphid mesh on the sides, and a white tarp on the soil surface. This facility belongs to the Plant Nutrition area of the Soil Science program at the Colegio de Postgraduados, Campus Montecillo (19° 46' 13" N and 98° 90' 90" W, at an altitude of 2,220 m).

Imbibition, Planting, and Treatment Application

The buds were separated from the sugarcane stems by making 8-10 cm cuts and imbibed for 18 h, depending on the treatment. The buds were treated with 0, 15, and 30 μM V, using ammonium metavanadate (NH_4VO_3, Merk, Darmstadt, Germany) as a source. Buds were planted for study in 0.8 L black pots (13x14x18.5 cm) previously filled with a substrate mixture of white peat (Super Terra ST1 Hawita; Vechta, Germany) and tezontle volcanic rock (1:1/v:v). After sowing, the pots were watered with tap water, 200 mL per day, every two days. Five treatments with V directly applied to the substrate (50 mL per container) were made at 10-d intervals. The duration of this stage was 60 d.

Bud emergence and initial growth variables

Bud emergence data were collected daily for 30 days. The following variables were calculated from the germination data: 1) percentage of bud emergence (BE), 2) speed coefficient of bud emergence (SCBE), and 3) speed of bud emergence (SBE), according to the following formulas (González-Zertuche and Orozco-Segovia, 1996):

$$BE = \frac{\sum n_i}{\sum (n_i t_i)} \times 100 \tag{1}$$

$$SCBE = \frac{\sum n_i}{\sum (n_i t_i)} \times 100 \tag{2}$$

$$SBE = \sum \frac{n_i}{t_i} \tag{3}$$

Where: n_i=number of buds emerged on day i, t_i=number of days after sowing.

After harvest (60 das), plant height (PH) was measured from the base of the substrate to the tallest leaf using a tape measure (Wiseup, ART-080102; Yiwu, China). Stem diameter (SD) was measured 5 cm from the base of the substrate using a digital caliper (Truper-14388; Shanghai, China). The number of leaves (NL) was measured by manual counting, and leaf area (LA) was determined using a leaf area integrator (LI-COR, model LI-3100C Area Meter; Lincoln, NE, USA). Fresh biomass weight (FB) was determined using an analytical balance (Adventurer Ohaus Pro AV213C; Parsippany, NJ, USA).

SPAD Units

At 60 days of age, SPAD (Soil Plant Analysis Development) units were measured using a portable SPAD-502® meter (Minolta, Tokyo, Japan).

Statistical Analysis

A GLM analysis of variance was performed using a randomized block treatment design and means comparison tests were performed using Tukey ($p \leq 0.05$).

RESULTS AND DISCUSSION

The results obtained are presented below, describing the variables evaluated in cultivar CP 72-2086.

Table 2 presents the results obtained with the variables measured in bud emergence in cultivar CP 72-2086. Regarding the percentage of BE variable, both doses of V allowed buds to reach 100% emergence, compared to the control treatment, which only reached 90%; the 15 μM V dose improved SCBE by 177% compared to the control treatment; no significant differences were found between treatments in SBE, although both doses tended to improve the variable.

Table 3 shows the effect of V on initial growth variables in cultivar CP 72-2086. No significant differences were observed in the variables evaluated. However, both doses (15

Table 2. Effect of vanadium (V) on bud emergence variables of sugarcane (*Saccharum* spp.) cv. CP 72-2086.

V (μM)	Bud Emergence (%)	Speed Coefficient Bud Emergence	Speed Bud Emergence (day^{-1})
0	90 b	2.78±0.47 b	1.88±0.22 a
15	100 a	4.92±0.43 a	3.15±0.24 a
30	100 a	1.85±0.40 b	2.13±0.57 a

Means ± SD with different letters in each column indicate statistically significant differences between treatments (Tukey, $p \leq 0.05$).

Table 3. Effect of vanadium (V) on initial growth variables of sugarcane (*Saccharum* spp.) seedlings cv. CP 72-2086.

V (μM)	Steam Diameter (mm)	Plant Heigth (cm)	Number of Leaves
0	4.52±0.34 a	34.9±1.58 a	3.52±0.11 a
15	4.85±0.07 a	35.2±0.33 a	3.88±0.09 a
30	4.76±0.08 a	34.5±0.19 a	3.38±0.17 a

Means ± SD with different letters in each column indicate statistically significant differences between treatments (Tukey, $p \leq 0.05$).

and 30 μM V) show a tendency to increase SD; whereas, the 15 μM V dose tends to improve PH and NL, in both cases compared to the control treatment.

No significant differences were observed in the SPAD units and LA variables (Figure 1). In SPAD units, doses of 15 and 30 μM V tended to increase the variable by 8 and 12%, respectively. However, in LA, the 30 μM V dose reduced the variable by 20% compared to the control treatment, although this was not significant. Regarding fresh biomass (FB), the highest dose of V applied (30 μM V) reduced the variable by 18% compared to the control.

A significant portion of bioavailable V concentrations in soils, both for agricultural use and irrigation water, is a consequence of activities such as the burning of fossil fuels, wastewater, and the use of fertilizers containing V compounds. Soil V concentrations can range from less than 1 mg kg^{-1} to 9,200 mg kg^{-1} (Shaheen *et al.*, 2022), and such concentrations can have positive, null, or negative effects on plant biology. In this study, a higher percentage of bud emergence was observed in cv. CP 72-2086 with both V doses tested (15 and 30 μM V), which were statistically different from the control treatment, in which only 90% bud emergence was observed; that is, V enhanced total bud emergence (Table 2).

The SCBE and SBE variables examine both the speed and quantity of buds emerging in a given time; high values indicate greater short-term emergence (Sobarzo-Bernal *et al.*, 2021). In our study, both the SCBE and SBE values were higher at the 15 μM V dose compared to the control (Table 2), although only the SCBE was statistically different. The above may indicate possible interventions of V in the biosynthetic pathways of phytohormones (auxins, abscisic acid, gibberellins, and strigolactones) that influence cell elongation and/or division, in addition to developmental processes (Bajguz and Piotrowska-Niczyporuk, 2023).

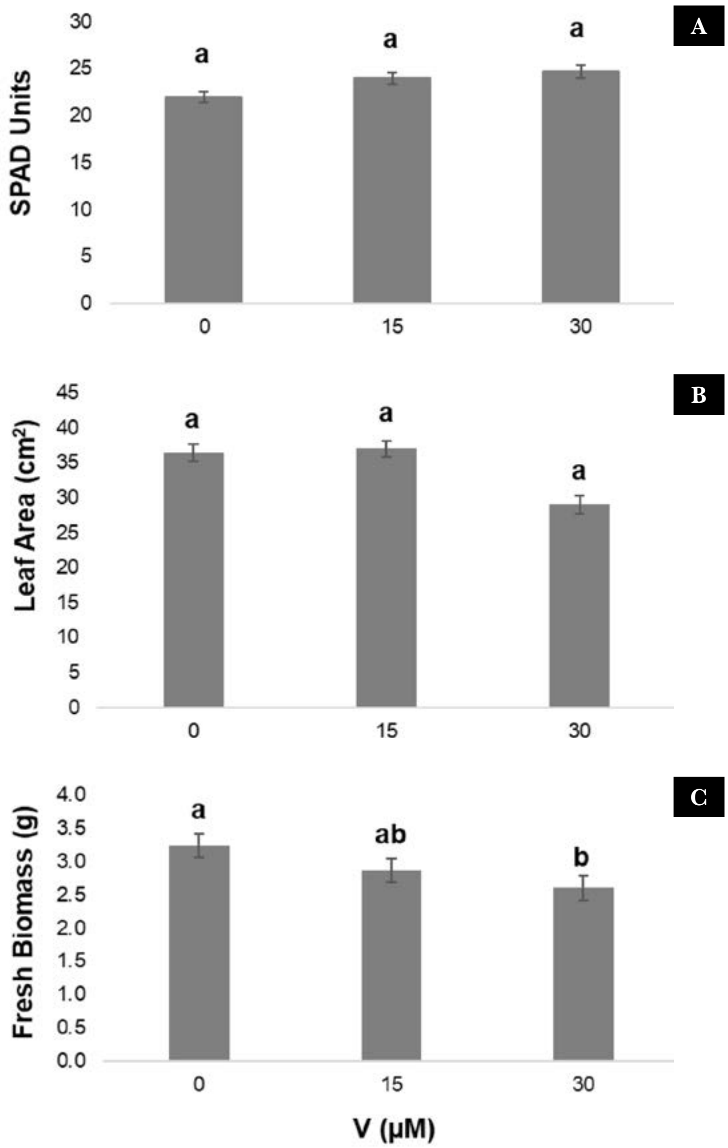

Figure 1. Effect of vanadium (V) on 60-day-old sugarcane (*Saccharum* spp.) seedlings cv. CP 72-2086. A) SPAD units; B) leaf area and C) fresh biomass. Means ± SD with different letters indicate statistically significant differences (Tukey, $p \leq 0.05$).

V may be essential in the photosynthetic processes of different species, allowing increases in growth and development variables (Nalewajko *et al.*, 1995). The variables stem diameter, plant height, and number of leaves did not show significant effects compared to the control. However, slight tendencies for V to increase stem diameter and plant height were observed with doses of 15 μM (Table 3). Similar effects were observed in the same cultivar (CP 72-2086) when treated with 20 μM (Sentíes-Herrera *et al.*, 2018). Regarding SPAD Units, the trend is upward, confirming that V can differentially influence the production of photosynthetic products among species.

V may influence tissue elasticity, allowing greater cell expansion and acting as a growth promoter, mainly because it is metabolized using the iron transport and storage proteins transferrin and ferritin (Gresser and Tracey, 1990; García-Jiménez *et al.*, 2018). V has also been documented to regulate plant growth, acting mainly as a cofactor that enhances or inhibits the enzymatic activity of proteins, such as kinases and phosphatases (Harland and Harden-Williams, 1994). In our study, a tendency toward increased growth variables was observed with the low dose (15 μM V), but LA and FB were also reduced with the high dose (30 μM V), as shown in Figure 1.

CONCLUSIONS

In the CP 72-2086 variety, applying vanadium in irrigation water and as leaf sprays improved bud emergence and initial seedling growth, resulting in greater seedling vigor. These results may have important applications in sugarcane production systems and should be extended to a larger number of varieties, both commercial and those undergoing selection for validation in the laboratory, greenhouse, and field.

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