

Arbuscular mycorrhizal fungal inoculation and exogenous phosphate fertilisation in mitigating NaCl induced salinity stress: Effects on growth parameters, mineral balance, and biochemical metabolites in Taro (*Colocasia esculenta* L. Schott Var. Ibo Coco)

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DOI: <https://doi.org/10.38177/ajbsr.2026.8310>

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Article Received: 07 July 2026

Article Accepted: 09 September 2026

Article Published: 23 September 2026

ABSTRACT

Soil salinity is a major constraint to agricultural productivity in several regions of Cameroon. This study evaluates the impact of phosphate fertilisation and mycorrhizal inoculation on the growth, mineral nutrition, and biochemical constituents of taro (*Colocasia esculenta* var. Ibo coco) under salt stress. The experiment, conducted in a greenhouse for five weeks, used a completely randomised block design. Plants were subjected to different NaCl doses (0, 50, 100, and 200 mM), combined with phosphorus inputs (0.1, 0.5, and 1 g) and two mycorrhizal consortia (*Gigaspora margarita* + *Acaulospora tuberculata* (Bio1) and *Scutellospora gregaria* (Bio2)). The results demonstrate that NaCl induced a significant inhibition of growth ($p < 0.001$) and ionic imbalance (Na^+ , K^+ , P). An accumulation of soluble proteins and total phenols was observed from 100 mM NaCl, reflecting a response to osmotic stress. Phosphate input exerted a protective effect by regulating ionic distribution and attenuating growth inhibition. However, a decrease in biomass and chlorophyll only appeared at the 200 mM NaCl threshold with 1 g of phosphate. Finally, mycorrhizal inoculation, particularly with the Bio1+2 consortium associated with phosphate, neutralised the deleterious effects of salinity, improving vegetative vigour and photosynthetic efficiency. In conclusion, this synergy constitutes a sustainable biotechnological strategy to strengthen the resilience and yield of taro in saline areas.

Keywords: *Colocasia esculenta* Var. Ibo Coco; Salinity Stress; Arbuscular Mycorrhizal Fungi; Phosphate Fertilisation; Biofertilisers; Plant Growth; Mineral Nutrition; Biochemical Constituents; Phenols; Soluble Proteins; Cameroon.

1.0. Introduction

Taro (*Colocasia esculenta* (L.) Schott), particularly the Ibo coco variety, is a tuber from the Araceae family widely cultivated for its underground rhizome. Primarily consumed in tropical regions, this herbaceous plant is found in various ecosystems across the Pacific, Southeast Asia, West Africa, and the Caribbean. The genus *Colocasia* is believed to be of Asian origin (Malaysia and Polynesia), the regions from which the name "Taro" originates [1]. Although it is widespread across humid tropical Africa in several species, taro remains an essential staple food for millions of people in Africa, Asia, and Central America [2].

On a global scale, taro is the fifth most produced root and tuber crop. Annual production is estimated at 18 million tonnes. Africa is the world's taro giant, accounting for approximately 80% to 85% of global production, followed by Asia (China, Philippines) and Oceania. African production surpassed 9.5 million tonnes in 2021. Nigeria largely dominates the sector, contributing about 45% to 50% of world production [3]. Nigeria remains the leading global producer, followed by Ethiopia and Cameroon [4].

Cameroon is one of the primary producers in Central Africa. However, the sector faces major sanitary challenges [5]. The annual production of the "Macabo/Taro" group in Cameroon fluctuates between 1.5 and 2 million tonnes. Taro specifically represents a significant portion, though agricultural statistics often group them together. The West, North-West, South-West, and Littoral regions are the areas of high production. The average yield is approximately 7 to 13 tonnes per hectare, depending on agricultural practices and varieties [6].

From a nutritional perspective, many varieties possess tubers rich in highly digestible starches, which are particularly beneficial for infants and convalescents [2, 7]. Their leaves, consumed as green vegetables, have a high thiamine content, favouring the assimilation of refined carbohydrates by populations. They also constitute an excellent source of vitamin C, niacin, and riboflavin [8, 9, 10].

However, the majority of global production relies on traditional subsistence systems on small plots [11]. While taro is widely present in local African and Cameroonian markets, large-scale commercial production remains rare in Africa. In Cameroon, saline soils are concentrated in the Sahelian zone (North) and along the Atlantic coast. In these areas, yields are limited by salinisation, soil overexploitation, and the high cost of inputs [12, 13]. To improve the value of these marginal lands, it is crucial to identify physiological markers of salt tolerance and promote adapted varieties.

Furthermore, the application of arbuscular mycorrhizal biofertilisers [14] combined with phosphorus amendments [15] is essential to enhance mineral nutrition and mitigate the adverse effects of water and salt stress. As a core component of nucleic acids (DNA, RNA) and ATP, phosphorus plays a pivotal role in driving photosynthesis and protein synthesis, providing the metabolic energy required for osmotic adjustment.

The objective of this study is to evaluate the influence of phosphate fertilisation and inoculation with a mycorrhizal complex (*Gigaspora margarita*, *Acaulospora tuberculata*, and *Scutellospora gregaria*) on the growth, mineral nutrition, and biochemical profile of the Ibo coco variety subjected to salt stress.

1.1. Study Objectives

The objectives of this research work are to:

- 1) To assess the effect of increasing NaCl salinity doses (0, 50, 100, and 200 mM) on taro growth.
- 2) To determine the effect of salt stress on mineral nutrition.
- 3) To evaluate the osmotic adjustments and physiological responses of taro.
- 4) To analyse how exogenous phosphate fertilisation (0.1, 0.5, and 1 g) mitigates growth inhibition.
- 5) To test the efficacy of arbuscular mycorrhizal inoculations using Bio1 and Bio2 consortia.
- 6) To establish a sustainable biotechnological strategy for saline areas in Cameroon.

2.0. Materials and methods

2.1. Study Site and Plant Material

The research activities were conducted at the Faculty of Science of the University of Douala (04°3' N/9° 42' W). The experiments took place in a greenhouse under controlled conditions, with an average ambient temperature of 28°C and 92% relative humidity. The plant material used consisted of uniform seeds of red taro (*Colocasia esculenta*), a local variety known as "Makumba (ibo coco)". These seeds were sourced from the Dakar market in Douala, Cameroon (Fig.1).

2.2. Substrate preparation and germination

Before planting, the seeds underwent a disinfection protocol by sterilisation in 3% sodium hypochlorite for 20 minutes, followed by thorough rinsing with distilled water. The culture substrate, consisting of sand, was previously purified by washing it with 1/10 hydrochloric acid and then rinsing it several times with distilled water. The cut seeds were placed to germinate for one week in black plastic nursery bags containing 6kg of this sand (Fig.2). During this phase, distilled water was provided daily until the first shoots appeared.

2.3. Experimental design and treatments

One week after germination, the seedlings received a thrice-weekly application of Wacquant nutrient solution [12]. Nine days after irrigation began, the bags were organised into a randomised block design comprising five treatment levels with four replicates each:

- **NaCl only: Plants were subjected to four salinity levels:** S0 (control without salt), S1 (50 mM), S2 (100 mM), and S3 (200 mM NaCl).
- **NaCl and Phosphate:** Seedlings received a combination of four NaCl doses with three doses of single superphosphate (P_2O_5): 0.1 g, 0.5 g, and 1g respectively.



Figure 1. *Colocasia esculenta* Var. Ibo
Coco Seed.



Figure 2. *Colocasia esculenta* Var. Ibo Coco
Seedlings After One Week of Culture.

- **NaCl, Phosphate, and Biofertiliser 1 (Bio1):** Seedlings received four NaCl doses, three P_2O_5 doses, and were individually inoculated with 50g of mycorrhizal biofertiliser 1 (Bio1), which is a mixture of *Gigaspora margarita* and *Acaulospora tuberculata*.
- **NaCl, Phosphate, and Biofertiliser 2 (Bio2):** Seedlings receiving four NaCl doses and three doses of P_2O_5 were also individually inoculated with 50 g of mycorrhizal biofertiliser 2 (Bio2) (*Scutellospora gregaria*).
- **NaCl, Phosphate, and Mycorrhizal Complex (Bio1+2):** Seedlings receiving four NaCl doses and three P_2O_5 doses were also individually inoculated with the two combined strains of mycorrhizal biofertilisers (Bio1+2) at 50 g each.

2.4. Growth parameters

After five weeks, six plants per lot were separated into roots, stems, and leaves, then dried in an oven at 105°C for 24 hours. Dry matter was determined using a KERN EMB 600-2 precision balance. Number of leaves was determined by manual counting. Stem collar diameter was measured using a pair of callipers. Height was measured with a graduated ruler. Leaf area (S) was calculated using Raunkiaer's formula: $S = 2/3 L \times W$, where L is the maximum length and W is the maximum width, expressed in cm² [16].

2.5. Physiological Parameters

2.5.1. Leaf Chlorophyll Content

Leaf chlorophyll content was extracted in 80 % (v/v) aqueous acetone and absorption was measured in spectrophotometer (Thermospertonic Helios β) at 645 and 663 nm [17]. Chlorophyll was calculated using the formula: Chlorophyll a = 12.7Y – 2.69X; Chlorophyll b = 22.9X – 4.68Y; Chlorophyll (a+b) = 20.2X + 8.02Y. Where X is the absorbance of chlorophyll at $\lambda = 645$ nm and Y is the absorbance of chlorophyll at $\lambda = 663$ nm.

2.5.2. Ion and mineral content

Sodium (Na) and potassium (K) concentrations (of the aerial and root parts) were determined by flame photometer (Jenway 6051). Phosphorus (P) was also measured. The levels of these three mineral elements were determined according to the method described by Wamba [17].

2.6. Biochemical constituents

Soluble protein content was measured according to the method described by Choula [18]. Total phenolic content was determined using the colorimetric method described by Noumo [19]. The principle is based on the reduction of the Folin-Ciocalteu reagent (a mixture of phosphomolybdic and phosphotungstic acids) by the phenolic hydroxyl groups in an alkaline medium. The absorbance of the resulting blue-coloured solution was recorded at 725 nm. Results were expressed as mg of gallic acid equivalents (GAE) per gram of dry matter.

2.7. Statistical Analysis

Data were analysed using GraphPad Prism 8 software. Results are expressed as mean $\pm$ standard deviation (SD). For normally distributed data with equal variances, means were compared using a one-way or two-way analysis of variance (ANOVA) followed by Dunnett's post-hoc test for comparisons against the control group. Where these parametric assumptions were not met, the non-parametric Kruskal-Wallis test was employed. Statistical significance was defined at $p < 0.05$, with levels of significance indicated as * ($p < 0.05$), ** ($p < 0.01$), and *** ($p < 0.001$).

3.0. Results

3.1. Effects of salinity on growth and physio-biochemical parameters

3.1.1. Growth parameters

- Dry biomass

The application of increasing NaCl doses significantly reduced the dry biomass of the plant. This decrease became significant compared to the control group starting at 100 mM for both the root system ($p < 0.05$) and the aerial parts ($p < 0.01$) (Table 1). Furthermore, the dry biomass of the aerial parts remained consistently higher than that of the root system across all treatments.

Table 1. Effect of NaCl Concentration on the Dry Biomass Variation in Different Organs of the Ibo Coco Variety.

RP: Root Part; AP: Aerial Part; Ns = $P > 0.05$; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$.

Organ	NaCl concentration (mM)			
	0	50	100	200
RP dry biomass (g)	5.79±0.56ns	4.40±0.64ns	2.56±0.67*	1.66±0.15**
AP dry biomass (g)	16.44±0.89ns	14.38±0.80*	11.85±1.43**	8.79±0.49***

• Evaluation of leaf number

Although the number of leaves increased throughout the cultivation period, the supplementation of NaCl (50, 100, and 200 mM) in the nutrient medium progressively inhibited leaf formation relative to the control (Fig.3). This inhibitory effect became significant ($p < 0.05$) from the first week of culture at 50 mM. At higher doses (100 and 200 mM), the depressive effect on leaf development was even more pronounced ($p < 0.001$).

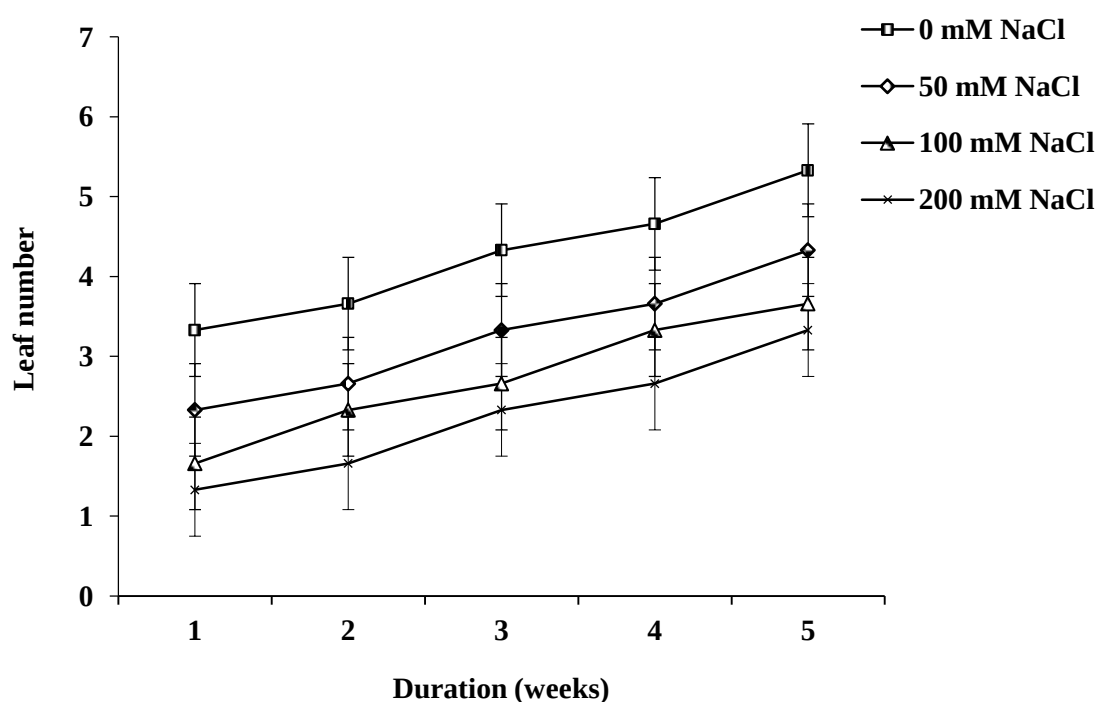


Figure 3. Effect of NaCl Concentration on the Leaf Number of the Ibo Coco Variety.

• Evaluation of stem diameter at the collar

Stem collar diameter increased over time. However, a reduction in diameter at the collar was observed compared to the control as early as the second week of treatment (Fig.4). This decrease was significant from 100 mM ($p < 0.05$) and became very highly significant at 200 mM ($p < 0.001$).

• Evaluation of plant height

The increase in stem height was hindered by the addition of increasing doses of NaCl (Fig.5). This inhibition was significant ($p < 0.01$) at 100 mM from the fifth week onwards. At 200 mM, the impact on height growth manifested earlier, from the third week of culture ($p < 0.01$).

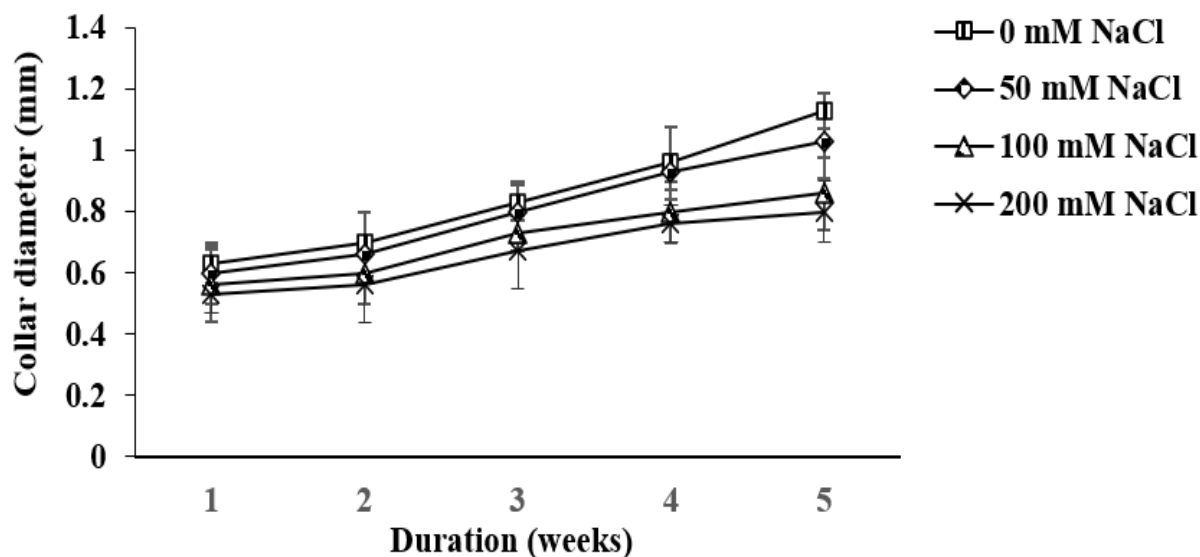


Figure 4. Effect of NaCl Concentration on the Collar Diameter of the Ibo Coco Variety.

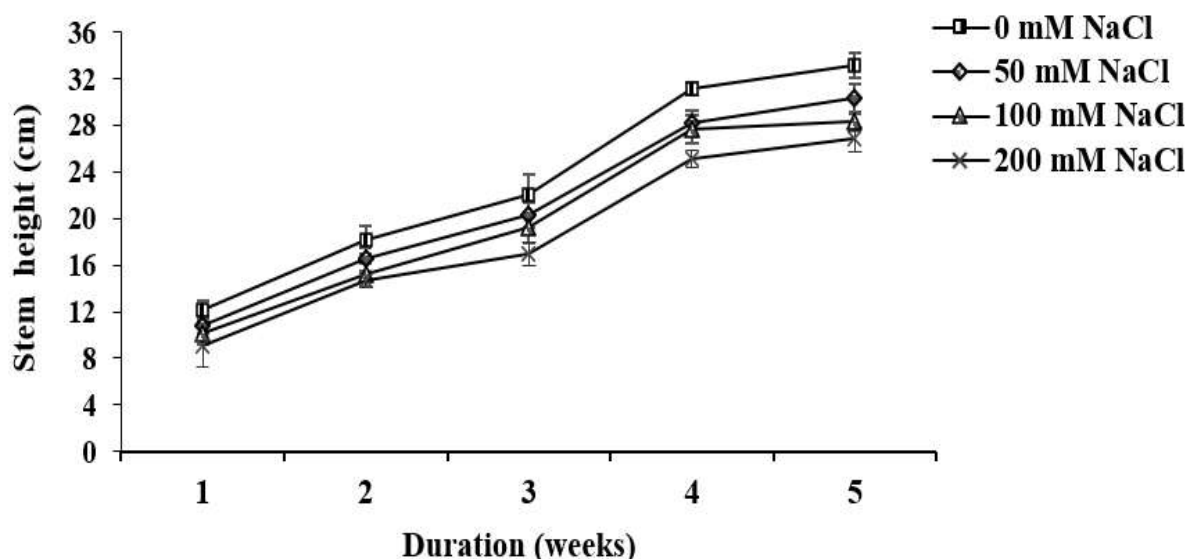


Figure 5. Effect of NaCl Concentration on the Plant Height of the Ibo Coco Variety.

• Evaluation of leaf surface area

Despite a temporal increase in leaf surface area, the addition of NaCl exerted an overall inhibitory effect compared to the control. The reduction in leaf surface area became significant at 50 mM from the third week onwards ($p < 0.05$) and intensified from 100 mM as early as the second week of treatment ($p < 0.01$) (Fig.6).

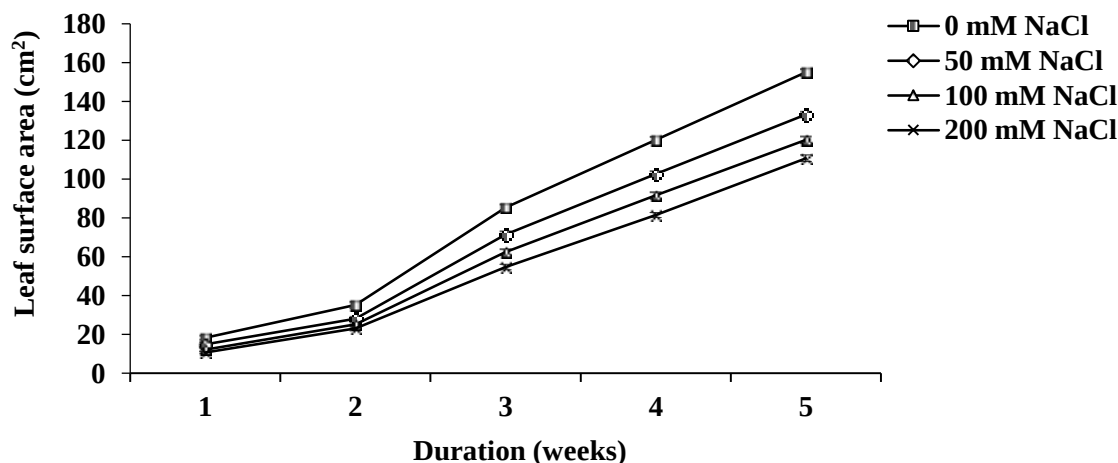


Figure 6. Effect of NaCl Concentration on the Leaf Area of the Ibo Coco Variety.

3.1.2. Physiological parameters

• Chlorophyll content (a, b, and total (a+b))

Analyses revealed that total chlorophyll (a+b) content remained higher than individual chlorophyll a and b levels across all treatments. A reduction in these photosynthetic pigments was observed under salt stress compared to the control group. Chlorophyll b and total (a+b) concentrations decreased significantly ($p < 0.05$) starting at 50 mM, with a critical decline ($p < 0.001$) recorded at 200 mM (Fig.7).

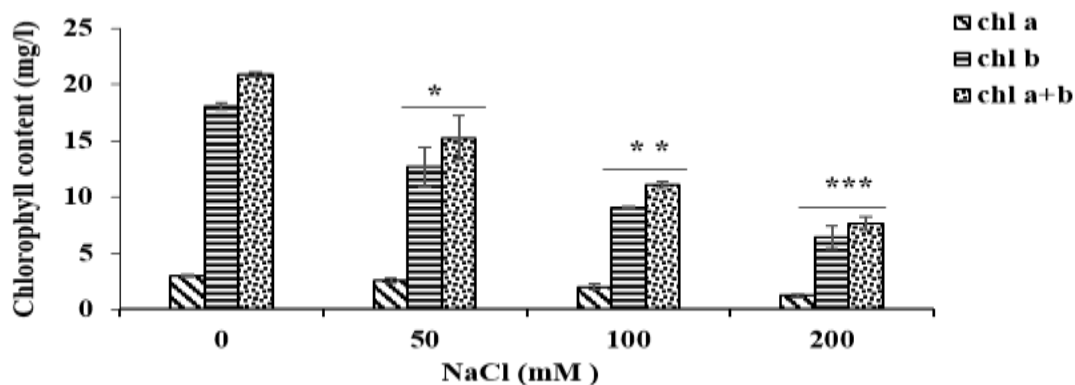


Figure 7. Effect of NaCl Concentration on the Chlorophyll Content of the Ibo Coco Variety after Five Weeks of Treatment. ns = $p > 0.05$; * = $p < 0.05$ and ** = $p < 0.01$.

• Distribution of Na^+ , K^+ and P

The application of NaCl (50, 100, and 200 mM) triggered a highly significant ($p < 0.001$) accumulation of Na^+ ions in both root and aerial parts. Sodium levels were found to be higher in the aerial parts than in the root parts.

Regarding K^+ ions, concentrations were also higher in the aerial parts compared to the root parts. NaCl supplementation induced a significant increase ($p < 0.001$) in K^+ levels within the aerial parts starting from 50 mM (Table 2).

Conversely, phosphorus (P) levels decreased significantly ($p < 0.05$) in both organs from 50 mM NaCl onwards. However, P accumulation remained higher in the aerial parts than in the root parts (Table 2).

3.1.3. Biochemical constituents

• Soluble proteins

Salinity stress induced a significant accumulation ($p < 0.01$) of soluble proteins in the leaves. This increase became statistically significant ($p < 0.01$) at NaCl concentrations of 100 mM and above (Fig.8).

• Total phenols

Similarly, the addition of NaCl led to a significant increase ($p < 0.01$) in foliar phenolic compounds, starting from the 50 mM dose (Fig.9).

3.2. Phosphate application and its influence on growth and physio-biochemical responses under salt stress

3.2.1. Growth parameters

• Dry biomass

After five weeks of cultivation, the dry biomass of the aerial parts (AP) was consistently higher than that of the root parts (RP) for all tested phosphate doses. The application of increasing doses of NaCl led to a significant reduction ($p < 0.05$) in the biomass of all organs starting from a concentration of 50 mM. However, the addition of phosphate mitigated this effect, with optimal biomass accumulation observed in the leaves at a dose of 1 g of P (Table 3).

Table 2. Effect of NaCl Concentration on the Mineral Distribution in Different Organs of the Ibo Coco Variety.

RP: root part; AP: aerial part; * = $p < 0.05$; ** = $p < 0.01$ and *** = $p < 0.001$.

Element	Organ	NaCl concentration (mM)			
		0	50	100	200
Na ⁺ (µg/g DW)	RP	43.15±4.1	89.12±6.5***	125±8.75***	240±15.25***
	AP	130.5±15.25	185.40±12.41***	415.15±22.1***	640.12±35.19***
K ⁺ (µg/g DW)	RP	61.44±5.12	95.22±7.15**	157.15±12.44***	241.38±17.13***
	AP	166.44±13.89	325.11±20.55***	440.56±25.15***	750.12±36.15***
P (µg/g DW)	RP	0.78±0.08	0.65±0.06*	0.45±0.11**	0.28±0.07***
	AP	0.91 ±0.06	0.82±0.04*	0.55±0.20***	0.45±0.12***

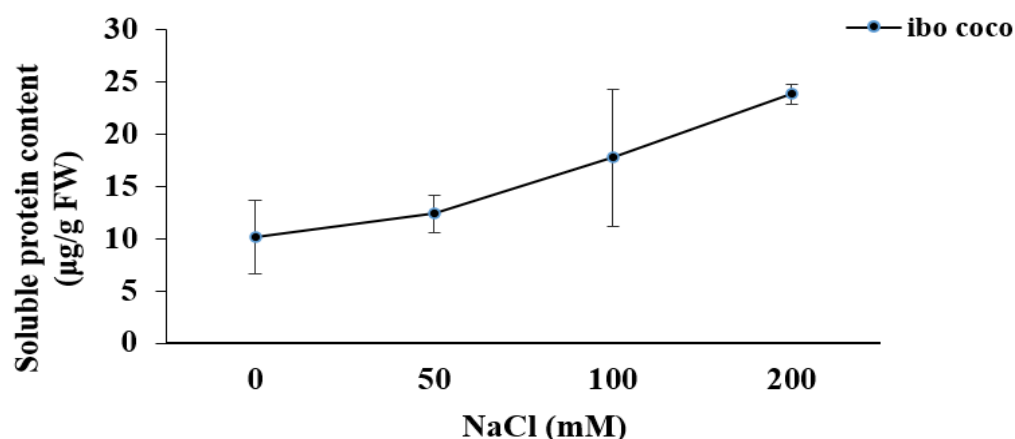


Figure 8. Effect of NaCl Concentration on the Soluble Protein Content in the Leaves of the Ibo Coco Variety.

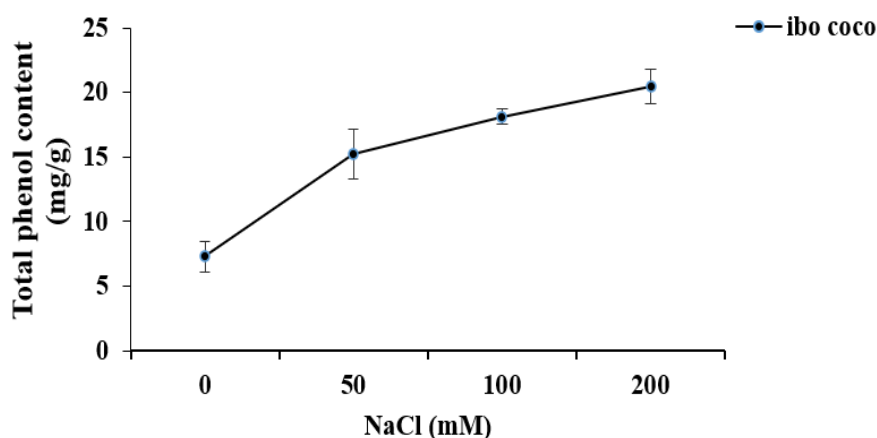


Figure 9. Effect of NaCl concentration on the total phenol content in the leaves of the Ibo coco variety.

Table 3. Effect of NaCl concentration and increasing phosphate doses on the dry biomass of different organs in the Ibo coco variety. RP: root part; AP: aerial part; ns = $p > 0.05$; * = $p < 0.05$; ** = $p < 0.01$; *** = $p < 0.001$.

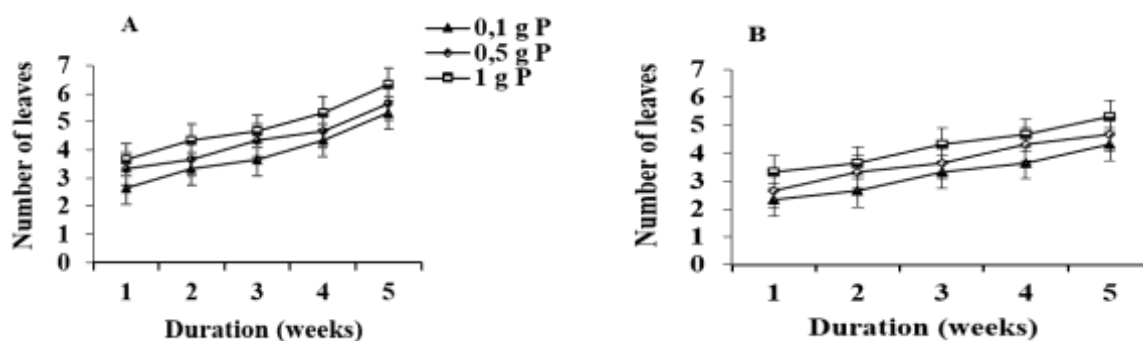
Organ	Phosphate (g)	Concentration NaCl (mM)			
		0	50	100	200
RP dry biomass (g)	0.1	9.55±1.32	8.34±1.08ns	6.80±0.64*	4.87±1.20***
	0.5	11.15±1.14	9.85±1.21*	7.68±0.70**	5.76±0.56***
	1	15.01±0.14	13.27±0.60*	10.81±1.11**	8.81±0.70***
AP dry biomass (g)	0.1	15.33±1.42	12.34±1.25*	9.87±0.70**	7.84±0.57***
	0.5	17.47±1.15	15.79±1.09*	12.17±0.86**	9.34±0.99***
	1	20.63±0.79	17.46±0.66*	15.51±1.58**	12.53±0.76***

• Leaf development, height, and stem collar diameter

Salt stress exerts a general inhibitory effect on the morphological development of *Colocasia esculenta*.

- Number of leaves

Inhibition was significant ($p < 0.05$) from the first week at 100 mM NaCl. The addition of phosphate, particularly at 1 g, inhibited the toxic effects of salt and led to a significant increase ($p < 0.05$) in the number of leaves across all culture media (Fig.10).



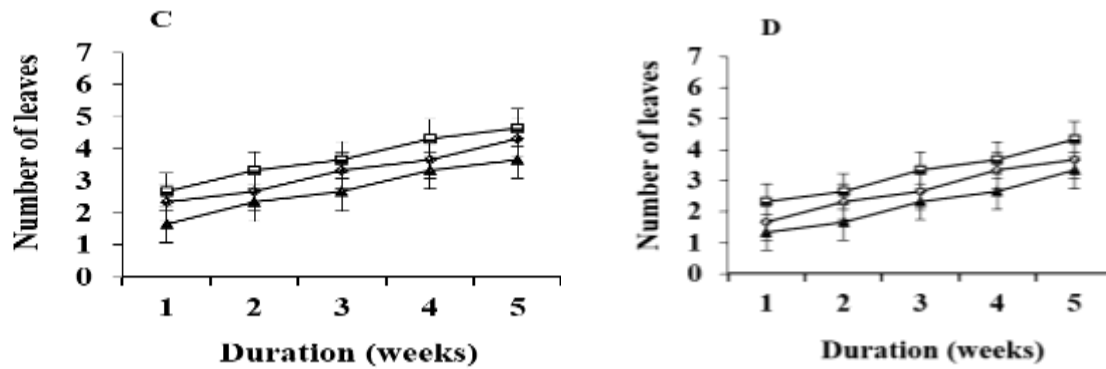


Figure 10. Effect of NaCl Concentration and Increasing Phosphate Doses on the Leaf Number of the Ibo Coco Variety. A: 0 mM, B: 50 mM, C: 100 mM, D: 200 mM NaCl.

- Stem diameter at the collar

The inhibitory effect of salt was only marked at 200 mM NaCl from the fourth week ($p < 0.01$). The application of phosphate helped mitigate these harmful effects, especially at 1 g of P, resulting in a significant increase ($p < 0.05$) in stem diameter at the collar in all media (Fig.11).

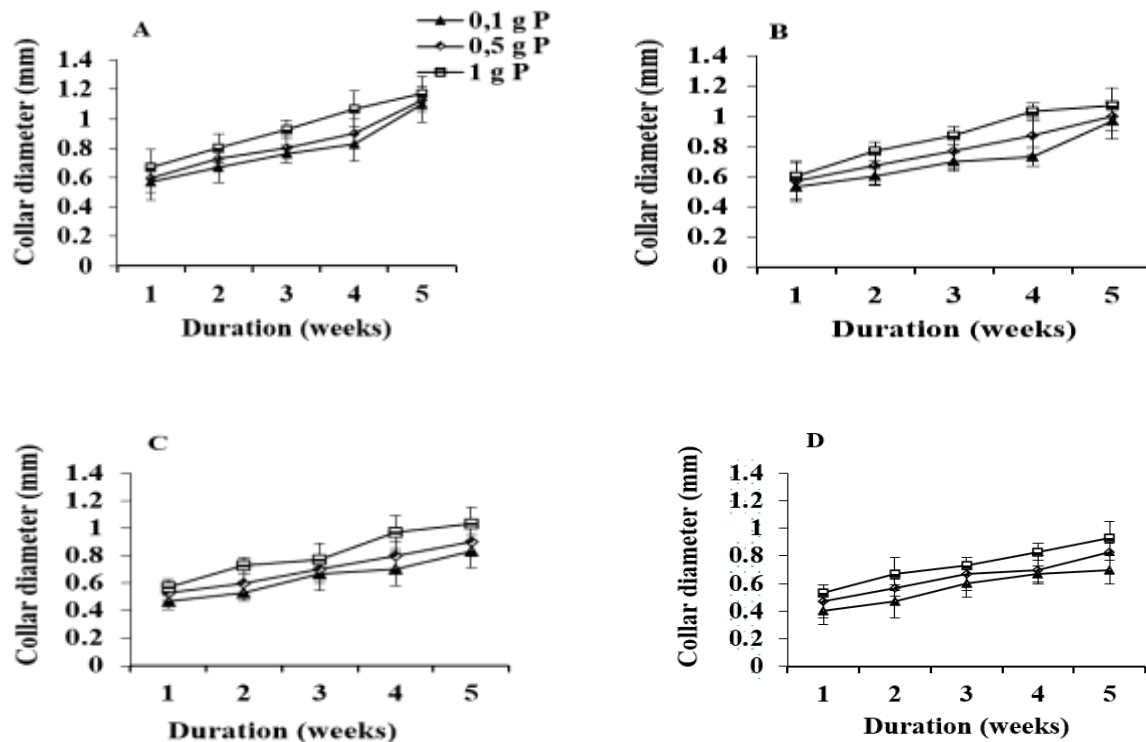


Figure 11. Effect of NaCl concentration and increasing phosphate doses on the collar diameter of the Ibo coco variety. A: 0 mM, B: 50 mM, C: 100 mM, D: 200 mM NaCl.

- Plant height

Size reduction became significant ($p < 0.01$) at 100 mM NaCl. The addition of phosphate (0.1 to 1 g) promoted a recovery of vertical growth, with a highly significant effect ($p < 0.001$) for the 1 g P dose from the first week (Fig.12).

• **Leaf area**

Although it increased over time, it was strongly reduced by salinity ($p < 0.001$) at 200 mM. The application of 0.5 g and 1 g of P induced a significant increase ($p < 0.001$) in this parameter from the first week of treatment at 100 mM NaCl (Fig.13).

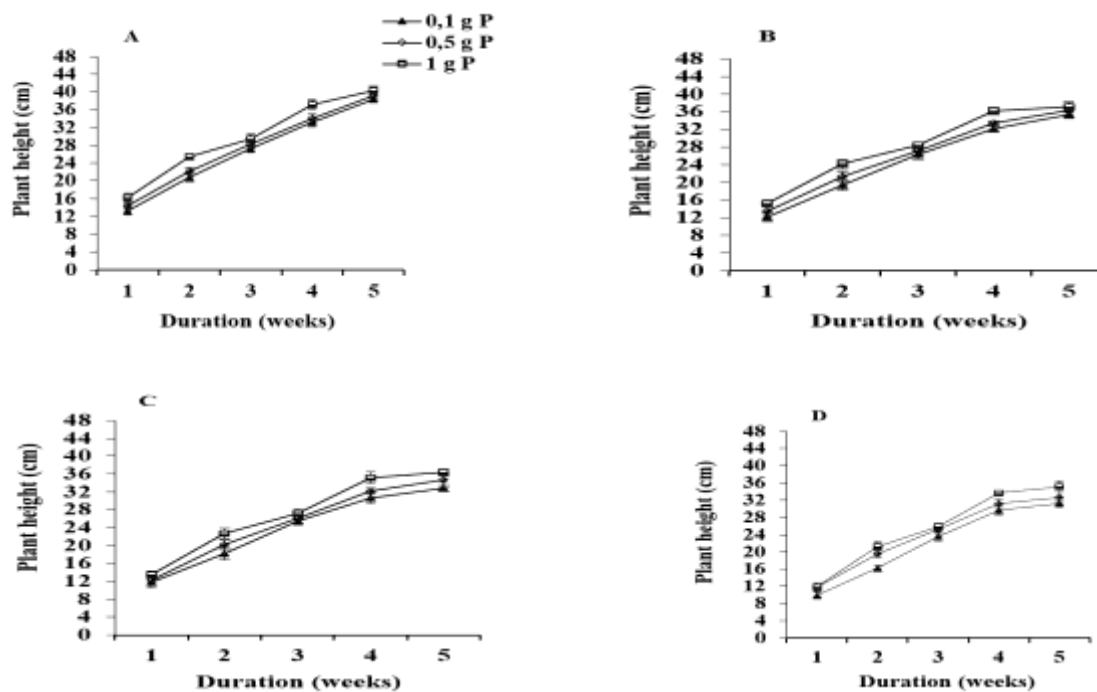


Figure 12. Effect of NaCl Concentration and Increasing Phosphate Doses on Plant Height in the Ibo Coco Variety. A: 0 mM, B: 50 mM, C: 100 mM, D: 200 mM NaCl.

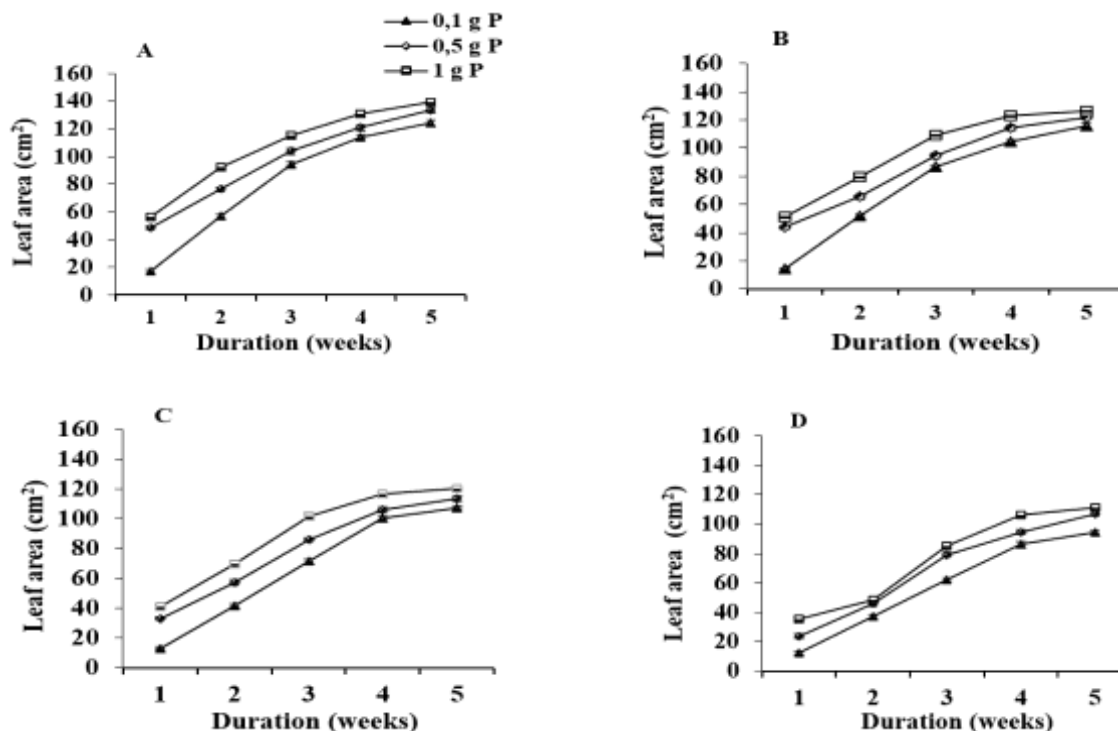


Figure 13. Effect of NaCl concentration and increasing phosphate doses on the leaf area of the Ibo coco variety. A: 0 mM, B: 50 mM, C: 100 mM, D: 200 mM NaCl.

3.2.2. Physiological parameters

• Chlorophyll content

Salt stress reduced the concentrations of chlorophyll a, b, and total (a+b) compared to the control. Phosphate application considerably reduced the drop in chlorophyll levels in all environments. At 1 g of P, the protection was highly significant ($p < 0.001$) for a salinity of 200 mM. At 0.1 and 0.5 g of P, the effect was significant ($p < 0.05$) from 100 mM NaCl. In all media, the chlorophyll (a+b) content remained higher than the individual a and b fractions (Fig.14).

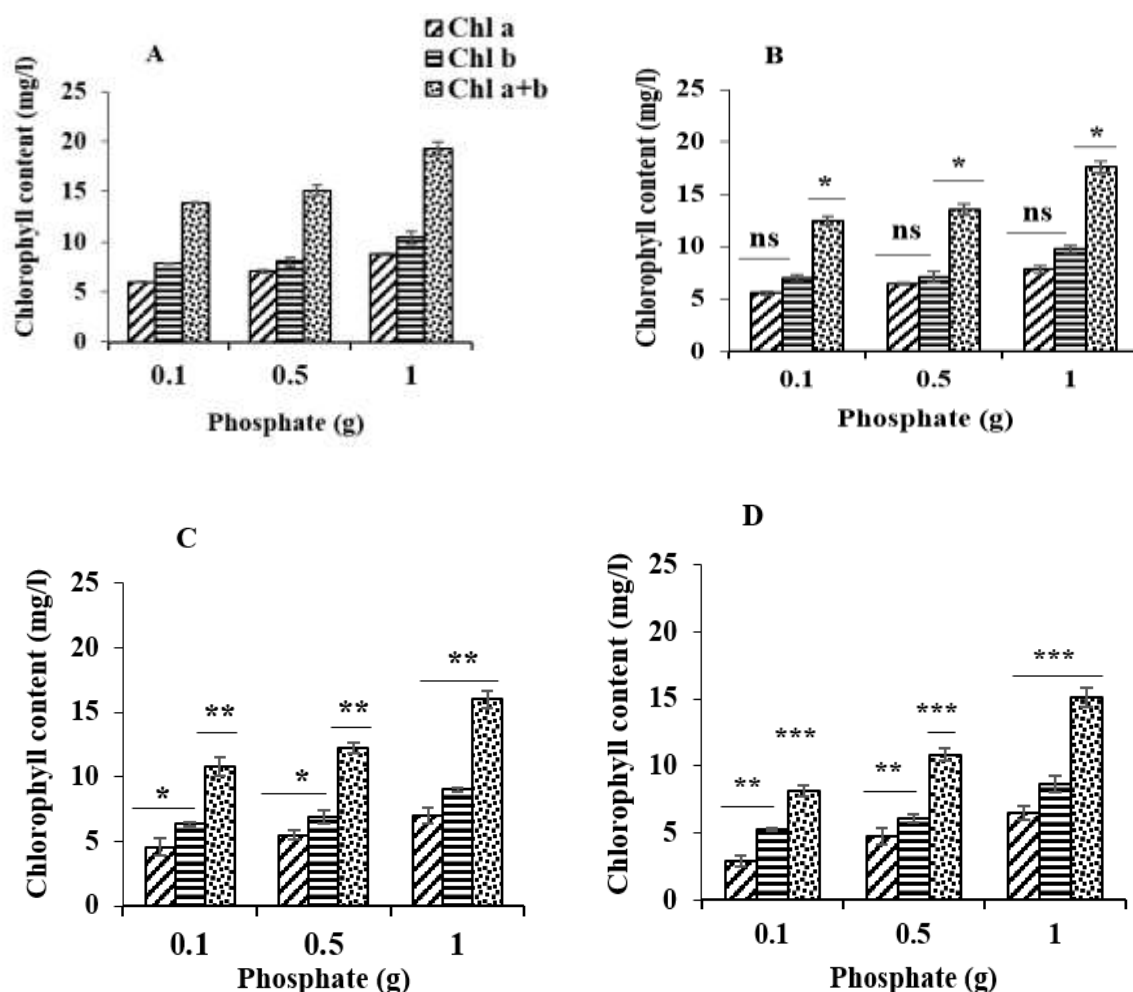


Figure 14. Effect of NaCl concentration and phosphate dosage on chlorophyll content in the Ibo coco variety.

A: 0 mM, B: 50 mM, C: 100 mM, D: 200 mM NaCl; ns = $p > 0.05$; * = $p < 0.05$;

** = $p < 0.01$; *** = $p < 0.001$.

• Phosphorus (P) distribution

Phosphorus levels in the different organs were lower in saline environments than in the control. The exogenous supply of phosphate neutralised this inhibition, particularly at 1 g of P under 200 mM NaCl ($p < 0.001$). Furthermore, phosphorus accumulated preferentially in the aerial parts compared to the root parts (Table 4).

3.2.3. Biochemical constituents

• **Soluble proteins**

Salinity strongly influenced protein metabolism, causing a significant accumulation of soluble proteins at 200 mM NaCl ($p < 0.001$). While the application of 0.1 g of P accentuated this increase, higher doses (0.5 and 1 g) significantly inhibited ($p < 0.001$) this salt effect, suggesting a regulation of metabolic stress (Fig.15).

Table 4. Effect of NaCl on Phosphorus Distribution in Different Organs of the Ibo Coco Variety.

RP: root part; AP: aerial part; ns = $p > 0.05$; * = $p < 0.05$; ** = $p < 0.01$ and *** = $p < 0.001$.

Phosphorus content ($\mu\text{g/g DW}$)		Concentration NaCl (mM)			
Organ	Phosphate (g)	0	50	100	200
RP	0.1	26.11 $\pm$ 1.02	24.75 $\pm$ 1.98ns	21.12 $\pm$ 1.38*	18.42 $\pm$ 1.51***
	0.5	23.80 $\pm$ 1.04	21.23 $\pm$ 0.91ns	18.78 $\pm$ 0.70*	13.85 $\pm$ 1.03***
	1	20.59 $\pm$ 2.25	16.19 $\pm$ 0.72*	12.98 $\pm$ 1.82**	10.89 $\pm$ 1.93***
AP	0.1	32.22 $\pm$ 2.85	30.83 $\pm$ 1.89ns	27.48 $\pm$ 1.50**	24.52 $\pm$ 1.40***
	0.5	29.08 $\pm$ 1.01	27.40 $\pm$ 1.43ns	24.30 $\pm$ 1.58**	21.89 $\pm$ 1.29***
	1	27.43 $\pm$ 1.58	25.12 $\pm$ 0.83ns	22.37 $\pm$ 1.62**	17.29 $\pm$ 1.59***

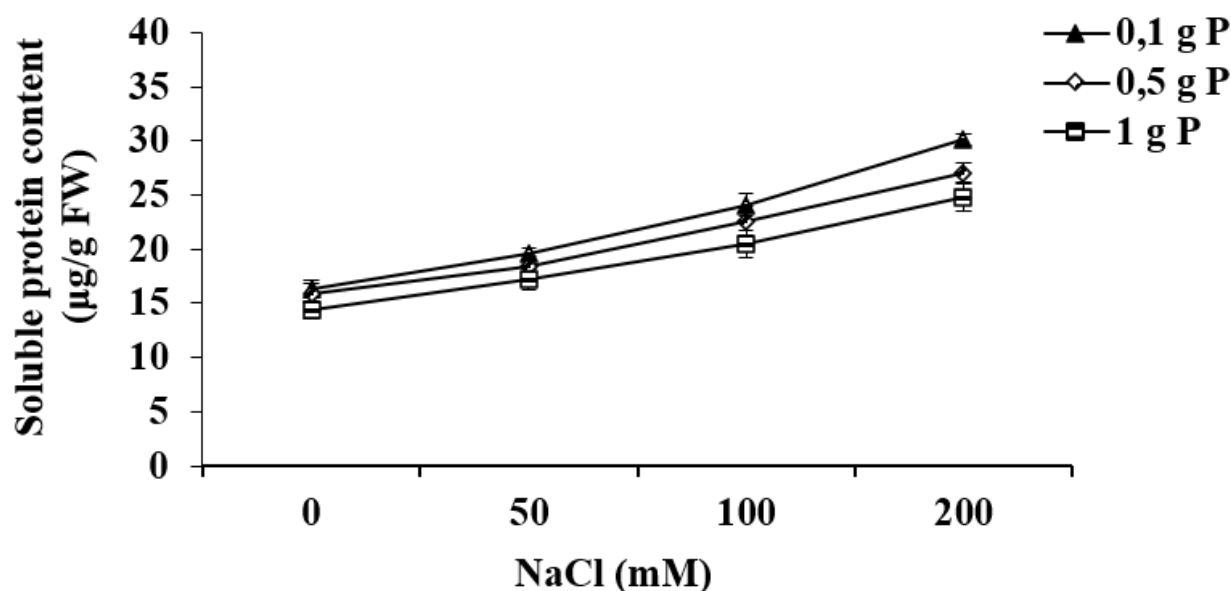


Figure 15. Effect of NaCl Concentration and Increasing Phosphate Doses on Soluble Protein Content in the Leaves of the Ibo Coco Variety.

• **Total phenols**

An accumulation of total phenols was observed proportional to the intensity of salt stress ($p < 0.01$ at 100 mM and $p < 0.001$ at 200 mM). The addition of phosphate (0.1 to 1 g) significantly amplified ($p < 0.001$) this production of phenolic compounds, potentially reinforcing the plant's antioxidant defence mechanisms (Fig.16).

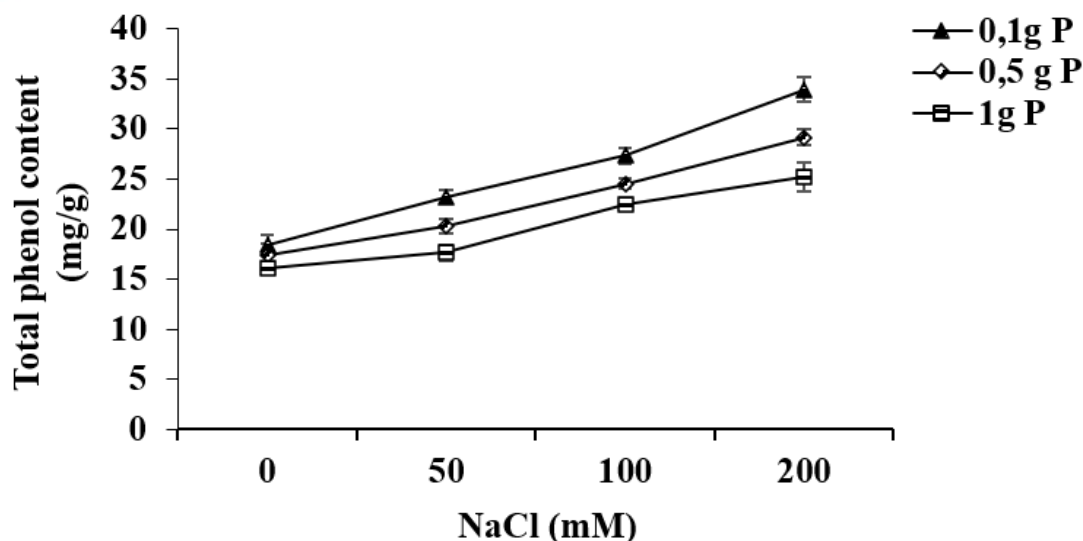


Figure 16. Effect of NaCl Concentration and Increasing Phosphate Doses on Total Phenol Content in the Leaves of the Ibo Coco Variety.

3.3. Impact of arbuscular mycorrhizal fungi and increasing phosphate doses on growth and chlorophyll content under salinity stress

3.3.1. Growth parameters

• Dry Biomass

Salinity stress significantly reduced the dry biomass of all organs of the *Colocasia esculenta* var. Ibo Coco. This decrease was significant ($p < 0.01$) at 100 mM NaCl and highly significant ($p < 0.001$) at 200 mM NaCl. Conversely, the application of phosphate (P) and mycorrhizal biofertilisers mitigated this effect. Specifically, the treatment combining 1 g of P with the dual mycorrhizal inoculum (Bio1+2) promoted the highest biomass accumulation, particularly in the aerial parts. Furthermore, the bio 2 treatment resulted in a significantly ($p < 0.01$) higher biomass compared to Bio1 (Table 5).

• Number of leaves

While the number of leaves increased across all treatments during the trial, salinity stress significantly hindered leaf development. This inhibitory effect was statistically significant at 100 mM ($p < 0.05$) and 200 mM ($p < 0.001$) NaCl from the first week onwards. The application of phosphate and mycorrhizal biofertilisers significantly ($p < 0.001$) reduced this inhibition throughout the growth period, particularly with a 1 g dose of P at 200 mM NaCl. Compared to single-strain treatments, the dual-inoculum (Bio 1+2) consistently produced the highest leaf counts at all salinity levels (Table 6).

• Stem collar diameter

The stem collar diameter increased over time under all experimental conditions. However, salinity stress generally inhibited the expansion of the stem collar. This effect was significant ($p < 0.05$) from the first week and became highly significant ($p < 0.001$) across the 50 to 200 mM NaCl range by the fifth week. Integrating phosphate with mycorrhizal biofertilisers (Bio1, 2, and 1+2) significantly ($p < 0.001$) lowered this inhibitory effect. This

improvement was observed as early as week one for the 200 mM NaCl treatments and by the final week for the 50 mM NaCl treatments (Table 7).

• Plant height

Plant height increased progressively with culture duration across treatments. Increasing NaCl concentrations generally inhibited stem elongation. The application of phosphate and mycorrhizal biofertilisers significantly attenuated the negative impact of salinity on plant height at the final week of culture, specifically at 100 mM ($p < 0.05$) and 200 mM ($p < 0.01$) NaCl. The greatest plant heights were recorded in media enriched with 1 g of P and the dual biofertilisers inoculum (Bio1+2) (Table 8).

• Leaf area

Leaf area increased throughout the trial period. NaCl stress generally hindered leaf area expansion, with significant inhibition ($p < 0.01$) observed starting at 50 mM NaCl. Phosphate and mycorrhizal biofertilisers supplementation significantly ($p < 0.001$) alleviated the salt-induced reduction in leaf area from the first week of treatment at concentrations between 100 and 200 mM NaCl. The largest leaf areas were consistently obtained in media containing 1 g of phosphate and the dual-biofertilisers (Bio1+2) mixture (Table 9).

3.3.2. Chlorophyll content (a, b and a+b)

Salinity stress consistently reduced the chlorophyll a, b and total (a+b) contents across all culture media compared to the control group. The decline in chlorophyll levels was statistically significant ($p < 0.05$) starting at 50 mM NaCl. At 200 mM NaCl, highly significant decreases ($p < 0.001$) were observed, even in the presence of 1 g of phosphate. The application of phosphate (at doses of 0.1, 0.5, and 1 g) and mycorrhizal biofertilisers (Bio1, 2, and 1+2) effectively mitigated these salt-induced losses across all test environments. Notably, plants treated with the dual-inoculum (Bio1+2) maintained the highest total chlorophyll concentrations across all salinity levels (Table 10).

Table 5. Effect of NaCl Concentration, Phosphate Doses, and Mycorrhizal Inoculation on the Dry Biomass of Different Organs of the Ibo Coco Cultivar. RP: root part; AP: aerial part; Bio: Biofertilisers;

ns = $p > 0,05$; * = $p < 0,05$; ** = $p < 0,01$; *** = $p < 0,001$.

Dry biomass (g)		Concentration NaCl (mM)			
NaCl+P+Bio1	Phosphate (g)	0	50	100	200
Organs					
RP	0.1	9.58±0.64	7.76±0.84ns	5.26±1.16**	3.79±1.29***
	0.5	11.67±1.16	9.18±1.16ns	7.70±0.95**	5.76±0.92***
	1	15.23±0.77	11.51±0.80*	9.58±0.87**	6.79±0.38***
AP	0.1	13.41±0.72	11.52±1.39ns	9.61±0.62**	6.50±0.67***
	0.5	16.37±0.76	13.87±1.07ns	11.82±0.95**	9.41±0.57***

	1	19.22±1.22	16.57±0.74*	15.39±0.63**	11.73±0.43***
NaCl+P+Bio2					
RP	0.1	11.71±0.86	9.87±1.15ns	7.77±0.87**	4.98±1.08***
	0.5	13.84±1.09	11.53±0.83ns	9.55±0.43**	6.44±0.85***
	1	16.80±1.09	14.41±0.74ns	11.10±1.10**	8.84±0.44***
AP	0.1	15.42±0.59	13.56±1.74ns	11.53±0.93**	8.61±0.36***
	0.5	18.83±1.25	16.53±1.39ns	13.66±0.66**	10.58±0.76***
	1	22.41±0.61	19.52±1.39*	16.48±1.20**	13.68±1.14***
NaCl+P+Bio1+2					
RP	0.1	13.16±0.41	11.39±1.12ns	8.69±0.63**	5.69±0.86***
	0.5	16.04±1.13	13.47±0.72*	10.57±0.70**	7.65±1.47***
	1	19.15±0.41	16.19±1.07*	13.71±1.17**	9.45±1.09***
AP	0.1	17.95±1.69	15.37±1.83ns	12.20±1.06**	9.52±0.82***
	0.5	21.12±0.81	18.56±1.25*	16.51±1.25**	13.25±1.15***
	1	24.18±0.75	21.95±1.80*	18.28±1.07**	14.13±0.86***

Table 6. Effect of NaCl, Increasing Phosphate Doses, and Mycorrhizal Biofertilisers Application on Leaf Number in the Ibo Coco Variety. N leaves: Number of leaves; Bio: Biofertilisers; P: Phosphate; ns = $p > 0.05$; * = $p < 0.05$ and *** = $p < 0.001$.

Bio	NaCl (mM)	P	1	2	3	4	5 Weeks
Bio1	0	0.1	2.66±0.58	3.33±0.58	3.66±0.58	4.33±0.58	4.66±0.58
		0.5	3.33±0.58	3.66±0.58	4.33±0.58	4.66±0.58	5.33±0.58
		1	3.66±0.58	4.33±0.58	4.66±0.58	5.33±0.58	5.66±0.58
Bio2		0.1	2.66±0.58	3.66±0.58	4.33±0.58	4.66±0.58	5.33±0.58
		0.5	3.33±0.58	4.33±0.58	4.66±0.58	5.33±0.58	5.66±0.58
		1	3.66±0.58	4.66±0.58	5.33±0.58	5.66±0.58	6.33±0.58
Bio1+2		0.1	3.33±0.58	4.33±0.58	4.66±0.58	5.33±0.58	5.66±0.58
		0.5	3.66±0.58	4.66±0.58	5.33±0.58	5.66±0.58	6.33±0.58
		1	4.33±0.58	5.33±0.58	5.66±0.58	6.33±0.58	6.66±0.58
Bio1	50	0.1	2.33±0.58ns	2.66±0.58ns	3.33±0.58ns	3.66±0.58ns	4.33±0.58ns
		0.5	2.66±0.58ns	3.33±0.58ns	3.66±0.58ns	4.33±0.58ns	4.66±0.58ns
		1	3.33±0.58ns	3.66±0.58ns	4.33±0.58ns	4.66±0.58ns	5.33±0.58ns
Bio2		0.1	2.33±0.58ns	3.33±0.58ns	3.66±0.58ns	4.33±0.58ns	4.66±0.58ns
		0.5	2.66±0.58ns	3.66±0.58ns	4.33±0.58ns	4.66±0.58ns	5.33±0.58ns
		1	3.33±0.58ns	4.33±0.58ns	4.66±0.58ns	5.33±0.58ns	5.66±0.58ns
		0.1	2.66±0.58ns	3.66±0.58ns	4.33±0.58ns	4.66±0.58*	5.33±0.58ns

Bio1+2		0.5	3.33±0.58ns	4.33±0.58ns	4.66±0.58ns	5.33±0.58*	5.66±0.58ns
		1	3.66±0.58ns	4.66±0.58ns	5.33±0.58ns	5.66±1.58*	6.33±0.58ns
Bio1	100	0.1	1.66±0.58*	2.33±0.58*	2.66±0.58*	3.33±0.58*	3.66±0.58*
		0.5	2.33±0.58*	2.66±0.58*	3.33±0.58*	3.66±0.58*	4.33±0.58*
		1	2.66±0.58*	3.33±0.58*	3.66±0.58*	4.33±0.58*	4.66±0.58*
Bio2		0.1	1.66±0.58*	2.66±0.58*	3.33±0.58*	3.66±0.58*	4.33±0.58*
		0.5	2.33±0.58*	3.33±0.58*	3.66±0.58*	4.33±0.58*	4.66±0.58*
		1	2.66±0.58*	3.66±0.58*	4.33±0.58*	4.66±0.58*	5.33±0.58*
Bio1+2		0.1	2.33±0.58*	3.33±0.58*	3.66±0.58*	4.33±0.58***	4.66±0.58***
		0.5	2.66±0.58*	3.66±0.58*	4.33±0.58*	4.66±0.58***	5.33±0.58***
		1	3.33±0.58*	4.33±0.58*	4.66±0.58*	5.33±0.58***	5.66±0.58***
Bio1	200	0.1	1.33±0.58***	1.66±0.58***	2.33±0.58***	2.66±0.58***	3.33±0.58***
		0.5	1.66±0.58***	2.33±0.58***	2.66±0.58***	3.33±0.58***	3.66±0.58***
		1	2.33±0.58***	2.66±0.58***	3.33±0.58***	3.66±0.58***	4.33±0.58***
Bio2		0.1	1.33±0.58***	2.33±0.58***	2.66±0.58***	3.33±0.58***	3.66±0.58***
		0.5	1.66±0.58***	2.66±0.58***	3.33±0.58***	3.66±0.58***	4.33±0.58***
		1	2.33±0.58***	3.33±0.58***	3.66±0.58***	4.33±0.58***	4.66±0.58***
Bio1+2		0.1	1.66±0.58***	2.66±0.58***	3.33±0.58***	3.66±0.58***	4.33±0.58***
		0.5	2.33±0.58***	3.33±0.58***	3.66±0.58***	4.33±0.58***	4.66±0.58***
		1	2.66±1.58***	3.66±0.58***	4.33±0.58***	4.66±0.58***	5.33±0.58***

Table 7. Effect of NaCl, Increasing Phosphate Doses, and Mycorrhizal Biofertilisers Application on Stem Collar Diameter in the Ibo Coco Variety. C diameter: Collar diameter; Bio: Biofertilisers; P: Phosphate;
ns = $p > 0.05$; * = $p < 0.05$; ** = $p < 0.01$; and *** = $p < 0.001$.

Bio	NaCl (mM)	P	1	2	3	4	5 Weeks
Bio1	0	0.1	0.63±0.06	0.77±0.12	0.83±0.06	0.93±0.06	1.13±0.12
		0.5	0.70±0.10	0.83±0.06	0.87±0.12	1.07±0.12	1.20±0.10
		1	0.73±0.12	0.87±0.12	1.03±0.06	1.10±0.10	1.23±0.06
Bio2		0.1	0.67±0.06	0.80±0.10	0.90±0.10	1.03±0.06	1.23±0.06
		0.5	0.73±0.06	0.83±0.06	0.97±0.12	1.10±0.10	1.27±0.12
		1	0.77±0.12	0.87±0.12	1.06±0.06	1.13±0.06	1.30±0.10
Bio1+2		0.1	0.73±0.06	0.86±0.06	0.97±0.06	1.13±0.06	1.27±0.12
		0.5	0.77±0.12	3.93±0.06	1.03±0.12	1.17±0.12	1.30±0.10
		1	0.80±0.10	0.97±0.12	1.10±0.10	1.23±0.06	1.33±0.06
Bio1		0.1	0.60±0.10ns	0.73±0.06ns	0.80±0.10ns	0.87±0.12ns	0.90±0.10**
		0.5	0.67±0.12ns	0.80±0.10ns	0.83±0.06ns	0.93±0.06ns	0.97±0.06**

Bio2	50	1	0.70±0.10ns	0.83±0.06ns	0.93±0.06*	0.97±0.12*	1.03±0.06**
		0.1	0.63±0.06ns	0.80±0.10ns	0.90±0.10ns	0.93±0.06*	0.97±0.12***
		0.5	0.70±0.10ns	0.80±0.10ns	0.93±0.06ns	1.03±0.06ns	1.10±0.10***
Bio1+2	50	1	0.73±0.12ns	0.80±0.10ns	0.97±0.12*	1.07±0.12ns	1.13±0.06*
		0.1	0.70±0.10ns	0.83±0.06ns	0.93±0.06ns	1.10±0.10ns	1.13±0.06**
		0.5	0.73±0.06ns	0.90±0.10ns	0.97±0.12ns	1.13±0.06ns	1.17±0.12**
Bio1	100	1	0.80±0.10ns	0.93±0.06ns	1.03±0.12ns	1.17±0.12ns	1.20±0.10**
		0.1	0.57±0.12ns	0.70±0.10ns	0.73±0.06*	0.80±0.10**	0.83±0.06***
		0.5	0.63±0.06ns	0.77±0.12*	0.80±0.10ns	0.87±0.06ns	0.90±0.10***
Bio2	100	1	0.67±0.06ns	0.80±0.10ns	0.87±0.06ns	0.93±0.06ns	0.97±0.12***
		0.1	0.60±0.10ns	0.77±0.06ns	0.83±0.06ns	0.87±0.12**	0.90±0.10***
		0.5	0.67±0.06ns	0.77±0.12ns	0.87±0.12ns	0.93±0.12**	0.97±0.12***
Bio1+2	100	1	0.73±0.12ns	0.80±0.10ns	0.90±0.10ns	1.03±0.06**	1.06±0.06***
		0.1	0.67±0.06ns	0.77±0.06ns	0.87±0.12*	0.93±0.06**	0.97±0.12***
		0.5	0.70±0.10ns	0.87±0.12ns	0.90±0.10*	0.97±0.12**	1.03±0.06***
Bio1	200	1	0.77±0.06ns	0.90±0.10ns	0.97±0.06*	1.07±0.12**	1.10±0.10***
		0.1	0.53±0.06*	0.63±0.06**	0.70±0.10*	0.73±0.06ns	0.80±0.10***
		0.5	0.57±0.12*	0.73±0.06*	0.76±0.06**	0.83±0.06ns	0.87±0.06***
Bio2	200	1	0.60±0.10*	0.77±0.12*	0.80±0.10***	0.87±0.12***	0.90±0.10***
		0.1	0.57±0.12*	0.70±0.10*	0.77±0.06**	0.80±0.10***	0.83±0.06***
		0.5	0.63±0.06*	0.73±0.06*	0.80±0.10**	0.83±0.06***	0.87±0.06***
Bio1+2	200	1	0.66±0.10*	0.77±0.12*	0.87±0.12**	0.93±0.06***	0.97±0.12***
		0.1	0.63±0.06*	0.73±0.06*	0.80±0.10**	0.87±0.12***	0.90±0.10***
		0.5	0.67±0.12*	0.83±0.06*	0.86±0.06**	0.93±0.06***	0.97±0.12***
Bio1	0	1	0.73±0.06*	0.87±0.12*	0.90±0.10**	0.97±0.12***	1.03±0.06***
		0.1	13.17±0.76	19.17±0.76	27.17±1.04	34.33±0.58	40.33±1.26
		0.5	14.17±1.04	21.50±1.32	28.33±1.15	35.17±0.76	41.17±1.04
Bio2	0	1	15.17±1.26	23.17±0.76	30.17±0.76	39.50±0.87	43.50±0.87
		0.1	14.16±0.76	21.17±1.04	29.17±1.04	36.17±1.04	41.16±1.04
		0.5	15.50±0.87	23.33±1.26	31.33±1.26	36.33±1.15	42.33±1.26
Bio1+2	0	1	16.17±0.76	24.66±1.15	33.17±0.76	40.33±0.76	45.17±0.76
		0.1	15.00±1.00	22.33±0.76	30.50±1.50	37.17±0.76	42.67±1.15
		0.5					

Table 8. Effect of NaCl, Increasing Phosphate Doses, and Mycorrhizal Biofertilisers Application on Plant Height in the Ibo Coco Variety. P height: Plant height; Bio: Biofertilisers; P: Phosphate;
ns = $p > 0.05$; * = $p < 0.05$; and ** = $p < 0.01$.

Bio	NaCl (mM)	P	1	2	3	4	5 Weeks
Bio1	0	0.1	13.17±0.76	19.17±0.76	27.17±1.04	34.33±0.58	40.33±1.26
		0.5	14.17±1.04	21.50±1.32	28.33±1.15	35.17±0.76	41.17±1.04
		1	15.17±1.26	23.17±0.76	30.17±0.76	39.50±0.87	43.50±0.87
Bio2	0	0.1	14.16±0.76	21.17±1.04	29.17±1.04	36.17±1.04	41.16±1.04
		0.5	15.50±0.87	23.33±1.26	31.33±1.26	36.33±1.15	42.33±1.26
		1	16.17±0.76	24.66±1.15	33.17±0.76	40.33±0.76	45.17±0.76
Bio1+2	0	0.1	15.00±1.00	22.33±0.76	30.50±1.50	37.17±0.76	42.67±1.15
		0.5					
		1					

Bio1+2		0.5	16.33±0.76	23.50±1.73	32.33±1.04	37.17±1.04	43.17±1.04
		1	17.17±1.04	25.17±0.76	34.33±0.76	41.17±1.04	46.33±0.76
Bio1	50	0.1	12.17±1.26ns	18.50±1.32ns	26.17±0.76ns	33.17±0.76ns	35.17±0.76*
		0.5	13.33±0.58 ns	20.17±0.76ns	27.17±1.04ns	34.17±1.04ns	38.00±1.73ns
		1	14.33±0.76ns	22.33±0.58ns	29.50±1.00ns	37.33±1.26ns	39.17±1.04*
Bio2		0.1	13.17±1.04ns	20.50±1.50ns	28.17±0.76ns	34.17±0.76ns	36.16±0.76*
		0.5	14.17±1.04ns	22.17±1.04ns	30.17±1.04ns	35.50±1.00ns	38.33±0.58*
		1	15.33±0.76ns	23.17±0.76ns	32.50±1.50ns	39.17±1.26ns	41.17±1.04*
Bio1+2		0.1	14.17±1.04ns	21.50±1.32ns	29.16±0.76ns	36.00±1.32ns	39.17±1.04ns
		0.5	15.17±1.26ns	23.17±0.76ns	13.00±1.32ns	36.17±0.76ns	40.50±1.50ns
		1	16.33±1.26ns	24.17±0.76ns	33.00±1.73ns	40.17±1.04ns	44.17±1.04ns
Bio1	100	0.1	11.33±0.58ns	17.83±0.76ns	24.50±1.32ns	31.67±1.26ns	33.17±1.04*
		0.5	12.17±1.26ns	19.17±1.04ns	26.33±0.76ns	32.50±1.50ns	34.33±1.26*
		1	13.67±0.58ns	21.17±1.04ns	27.33±1.04ns	35.17±0.76*	37.17±0.76*
Bio2		0.1	12.17±1.04ns	19.17±1.60ns	27.17±1.04ns	32.16±1.04*	34.50±1.32*
		0.5	13.33±0.76ns	21.50±1.32ns	28.50±0.87ns	34.33±0.76ns	37.17±0.76*
		1	14.33±1.04ns	22.17±1.04ns	31.17±1.04ns	37.33±1.26ns	38.17±0.76*
Bio1+2		0.1	13.00±1.73ns	20.17±1.04ns	28.17±1.04ns	34.66±1.15ns	37.33±1.04*
		0.5	13.33±1.04ns	22.17±0.76ns	29.33±1.26ns	34.83±0.76ns	38.17±1.04*
		1	15.17±0.76ns	22.50±1.32ns	32.33±0.76ns	39.17±0.76ns	41.17±0.76*
Bio1	200	0.1	10.17±1.04ns	16.50±0.87ns	23.50±0.87*	30.17±1.04*	31.17±0.76**
		0.5	11.17±0.76ns	18.50±0.50ns	24.17±1.04*	31.17±1.04*	32.16±1.04**
		1	12.33±1.04ns	19.50±1.32\	26.33±1.26ns	33.00±1.50*	34.50±1.32**
Bio2		0.1	10.17±0.76*	18.17±0.76ns	25.67±0.58*	31.17±0.76*	31.83±1.26**
		0.5	11.33±0.76*	20.17±1.04*	26.17±0.76*	32.17±1.04*	34.17±1.04**
		1	13.50±1.50ns	21.17±0.76*	29.33±1.26*	34.33±0.58*	35.33±1.53**
Bio1+2		0.1	11.17±0.76*	19.33±1.53ns	26.50±0.87*	33.17±0.76ns	34.17±1.04**
		0.5	12.66±1.15*	20.33±1.26*	27.17±0.76ns	33.83±0.29ns	35.17±0.76**
		1	13.66±1.60*	21.50±1.32*	30.50±1.00*	37.50±0.87ns	38.50±1.32**

Table 9. Effect of NaCl, Increasing Phosphate Doses, and Mycorrhizal Biofertilisers Application on Leaf Area in the Ibo Coco Variety. L. area: Leaf area; Bio: Biofertilisers; P: Phosphate; ns = $p > 0.05$; * = $p < 0.05$; ** = $p < 0.01$; and *** = $p < 0.001$.

Bio	NaCl mM	P	1	2	3	4	5 Weeks
Bio1	0	0.1	39.97±1.07	51.78±1.60	94.08±1.87	116.05±2.08	122.77±1.32
		0.5	56.40±0.92	73.70±1.57	96.93±1.79	120.55±1.89	125.64±1.19
		1	63.08±1.02	84.13±1.40	103.63±1.60	126.11±2.17	132.17±2.25
Bio2		0.1	43.38±1.28	77.12±1.64	97.33±0.99	118.33±0.58	124.72±2.03
		0.5	62.38±0.99	78.60±1.51	101.93±1.10	122.37±0.71	127.07±1.81

		1	68.65±1.58	96.63±1.35	109.63±1.30	128.53±0.80	135.86±0.80
Bio1+2		0.1	48.72±1.25	81.41±1.65	105.77±1.72	121.26±1.42	127.66±0.76
		0.5	64.74±1.2	97.63±1.30	108.83±1.89	125.29±0.96	130.20±2.10
		1	70.65±2.93	101.86±1.80	113.17±0.76	130.38±1.46	138.13±1.58
Bio1	50	0.1	28.43±1.29**	46.24±1.25*	89.10±1.85ns	112.13±1.02ns	116.27±1.05*
		0.5	54.60±1.22ns	65.70±1.67*	91.22±1.34	117.12±1.18ns	120.07±1.10*
		1	57.11±1.02*	78.10±1.55*	97.56±1.39*	122.20±1.31ns	125.23±1.17*
Bio2		0.1	19.44±0.77**	74.67±1.15ns	92.33±1.52*	114.60±1.68ns	118.50±1.80*
		0.5	56.06±1.00*	77.73±1.62ns	97.06±0.90ns	119.27±1.42ns	122.13±1.86ns
		1	57.30±1.30**	84.77±1.34**	105.50±180ns	126.47±1.50ns	127.13±0.86*
Bio1+2		0.1	33.14±1.39***	79.26±1.60ns	101.60±1.64ns	118.43±1.77ns	120.86±1.20*
		0.5	62.28±2.02ns	89.67±1.51*	104.83±1.89ns	121.53±1.28ns	124.20±1.31ns
		1	63.16±1.26*	94.40±1.64*	109.50±1.80ns	128.47±1.17ns	130.50±1.80*
Bio1	100	01	18.18±1.06***	41.37±1.68**	86.27±1.62*	105.71±1.84**	110.83±1.60**
		0.5	20.80±1.34***	54.46±1.55***	88.16±0.85*	111.16±2.25*	114.94±1.42**
		1	40.56±1.50***	73.73±1.42**	93.79±1.33*	115.60±1.97**	118.17±1.75**
Bio2		0.1	19.22±1.20***	61.82±1.57***	87.47±2.20*	107.50±1.80**	113.30±0.79**
		0.5	34.61±1.29***	73.16±1.67*	92.60±1.39*	113.88±0.20*	115.27±1.10**
		1	43.95±1.59***	83.16±1.60**	97.07±1.69**	117.40±2.11**	119.87±1.20***
Bio1+2		0.1	25.86±1.49***	63.08±2.00***	98.23±1.53*	110.83±1.76**	115.56±0.81**
		0.5	36.75±1.92***	86.10±1.15**	100.33±1.52*	116.53±129*	117.13±1.20**
		1	45.76±0.80**	87.43±1.50***	104.50±2.30*	121.16±0.76*	121.53±1.85***
Bio1	200	0.1	13.23±0.92***	40.83±1.69**	77.03±2.32***	94.8±1.79***	103.62±1.32***
		0.5	14.04±1.28***	51.24±1.88***	81.11±2.01***	99.49±1.65***	105.57±2.40***
		1	15.51±1.32***	71.57±1.53**	88.44±1.50***	103.80±1.93***	107.07±0.90***
Bio2		01	14.22±1.35***	57.67±1.66***	82.81±1.58***	95.76±1.66***	10570±1.15***
		0.5	21.78±1.34***	65.51±1.69**	85.39±1.51***	105.16±1.26***	107.17±1.04***
		1	22.04±1.12***	81.51±1.69***	91.03±1.34***	107.46±1.75***	108.08±1.59***
Bio1+2		0.1	18.46±1.33***	60.94±0.81***	86.77±1.16***	100.23±0.93***	106.76±1.36***
		0.5	22.00±1.46***	83.38±1.47***	89.05±1.07***	110.41±1.65***	112.13±1.02***
		1	32.65±1.41***	85.35±1.65***	98.23±1.36***	113.16±0.76***	114.56±1.72***

Table 10. Effect of NaCl on Chlorophyll Content in the Ibo Coco Variety Across Different NaCl Concentrations, Increasing Phosphate Doses, and Mycorrhizal. Bio: Biofertilisers; ns = $p > 0.05$; * = $p < 0.05$; ** = $p < 0.01$ and *** = $p < 0.001$.

Chlorophyll content (mg/l)		Concentration NaCl (mM)			
NaCl+P+Bio1	Phosphate (g)	0	50	100	200
Chl a	0.1	631±0.48	4.42±0.25ns	3.67±0.50ns	2.92±0.72*
	0.5	6.95±0.21	5.70±0.97ns	4.64±0.78ns	3.54±0.60*
	1	9.19±0.84	7.89±0.78ns	6.51±1.18ns	4.75±0.32**
	0.1	11.6±0.41	10.24±0.66ns	7.53±0.97**	5.34±0.92***

Chl b	0.5	13.83±1.22	11.22±0.82ns	9.64±1.00**	6.77±0.78**
	1	15.70±1.02	12.79±0.70ns	11.61±0.92**	9.58±0.89***
Chl a+b	0.1	17.90±0.89	14.39±0.84*	11.14±1.52**	8.26±1.52***
	0.5	20.79±1.36	16.93±0.63*	14.03±1.53**	9.72±0.70***
	1	24.53±1.07	20.7±1.33*	17.79±2.37**	14.08±0.83***
NaCl+P+Bio2					
Chl a	0.1	7.14±0.40	5.20±0.39ns	4.44±0.48ns	3.48±0.70*
	0.5	8.15±0.25	6.45±0.56ns	5.27±0.95ns	4.16±0.99**
	1	10.42±1.68	8.89±1.26ns	7.82±0.73ns	5.78±0.58**
Chl b	0.1	12.59±0.40	11.36±0.84ns	9.31±0.54*	7.30±0.49**
	0.5	14.24±0.53	13.36±0.40ns	11.57±0.60ns	8.97±0.90**
	1	17.46±1.30	14.64±0.39ns	13.96±1.00*	11.71±0.72**
Chl a+b	0.1	19.56±0.72	16.45±1.38*	13.52±0.60**	10.77±0.49***
	0.5	22.12±0.26	19.72±0.99*	16.97±1.22**	13.13±1.88***
	1	27.65±0.72	23.44±0.73*	21.77±1.67**	17.45±0.55***
NaCl+P+Bio1+2					
Chl a	0.1	8.74±0.38	6.84±0.55ns	5.39±0.62*	4.15±0.64**
	0.5	10.13±0.74	8.01±0.70ns	6.40±0.67*	4.47±0.60**
	1	12.92±0.60	10.75±0.47ns	8.95±0.40*	7.32±0.93**
Chl b	0.1	14.79±0.30	12.86±0.30ns	10.67±0.47*	8.50±0.58***
	0.5	16.63±0.45	15.07±0.62ns	13.18±0.32*	10.48±0.67***
	1	19.05±0.92	17.08±0.87ns	15.60±0.38*	13.04±0.19***
Chl a+b	0.1	21.07±0.74	19.33±0.67ns	15.98±1.08**	12.47±1.23***
	0.5	26.89±0.86	23.35±0.60*	19.23±0.89**	14.61±0.19***
	1	31.22±0.79	27.87±1.19*	24.52±0.70**	20.37±0.99***

4.0. Discussion

4.1. Impact of salinity on growth, physiological traits, and biochemical composition

• Inhibition of vegetative growth and biomass

Analysis of growth parameters reveals a global inhibition of *Colocasia esculenta* development under salt stress, particularly pronounced at concentrations of 100 and 200 mM. The reduction in dry biomass, which affects the root system more severely than the aerial parts, indicates an adaptive strategy aimed at limiting the absorption of toxic ions while preserving photosynthate production. These observations are supported by Choula [18] and subsequently by Zörb [20], who emphasise that root reduction is an immediate response to minimise Na⁺ entry into the plant.

Concurrently, the decrease in leaf number and leaf area is attributed to excessive salt accumulation within the cytoplasm, leading to premature senescence. This phenomenon corroborates the findings of Munns [21], who link leaf abscission to the vacuole's inability to compartmentalise salt beyond a critical threshold. This hindrance to foliar development is intrinsically linked to a decline in photosynthetic activity, resulting from membrane

dehydration and impaired chlorophyll synthesis, as demonstrated by Hussain [22] across various tropical crops. Furthermore, the inhibition of stem height and collar diameter from the second week of treatment reflects a disruption in ionic balance and a decrease in the turgor pressure required for cell elongation. These results align with the observations of Parihar [23], suggesting that NaCl-induced osmotic stress reduces hydraulic conductivity, thereby limiting tissue expansion. Suriya [24] also demonstrated in *Vigna* species that this initial constraint early disrupts hormonal homeostasis and blocks cellular expansion, confirming the sensitivity of tropical crops to the early stages of osmotic stress.

• Physiological and mineral adjustments

Exposure of the Ibo coco variety to increasing doses of NaCl induces profound physiological restructuring, primarily characterised by a significant drop in chlorophyll content (a, b, and total). This pigment degradation, observed from 50 mM onwards, may be attributed to chlorophyllase activation or the destabilisation of the protein-lipid-pigment complex by toxic ions. These observations are supported by Hand [25] regarding three pepper cultivars and more recently by Arif [26], who demonstrate that salt stress triggers oxidative stress, causing chloroplast degradation and the inhibition of chlorophyll synthesis enzymes.

Regarding mineral distribution, a marked accumulation of Na⁺ is noted in all organs, particularly within the aerial parts. This efficient transfer to the leaves suggests that this variety adopts halophyte-like behaviour, utilizing sodium inclusion for osmotic adjustment. This is a phenomenon also highlighted by Flowers [27] and Nouck [28] as a tolerance strategy in certain tropical plants.

Simultaneously, the increase in potassium (K⁺) levels in both roots and leaves appears to be a crucial adaptive mechanism. As indicated by Assaha [29], maintaining a favourable K⁺/Na⁺ ratio is essential for cellular homeostasis and the regulation of osmotic potential, enabling the plant to mitigate the salt-induced water deficit. Finally, phosphorus (P) absorption is severely hindered by salinity, with a more pronounced reduction at the root level. This inhibition is explained by ionic antagonism between chloride ions (Cl⁻) and phosphates, as well as a decrease in the activity of phosphorus transporters in saline environments. This phenomenon corroborates the conclusions of Taffouo [30] and Machado [31], who specify that phosphorus availability decreases in the presence of high salt concentrations, thereby limiting energy metabolism and overall plant growth.

• Biochemical responses and cellular protection

The analysis of biochemical constituents in *Colocasia esculenta* var. Ibo coco reveals a vigorous activation of defence mechanisms against salinity. The significant increase in soluble proteins in the leaves, observed under increasing NaCl doses, indicates a major adaptive response. These results concur with those of Choula [18], showing that the accumulation of specific proteins plays a vital role in protecting cellular structures and facilitating osmotic adjustment. The work of Gupta [32] and Zhu [33] confirmed that specific protein accumulation is crucial for membrane stabilisation and the sequestration of toxic ions during periods of abiotic stress.

Parallel to this, the stimulation of total phenolic compound production from 50 mM NaCl underscores the importance of the secondary antioxidant system in this variety. Our results align with the findings of Sarker [34]

and Santos [35], who show that higher levels of total phenols improve free radical scavenging. This process limits lipid peroxidation and prevents cellular damage under abiotic stress.

4.2. Role of phosphate in growth, physiology, and biochemistry under saline conditions

• Restoration of growth and leaf development

Analysis of growth parameters demonstrates that exogenous phosphate (P) application acts as an effective mitigation lever against the deleterious effects of NaCl in *Colocasia esculenta* var. Ibo coco. Although dry biomass undergoes a global decline under high salinity (100 and 200 mM), increasing doses of P limit this collapse. Consistent with the observations of Giri [36], phosphate stimulates residual growth under saline conditions. Waqas [37] demonstrated that phosphate fertilisation improves water-use efficiency and cell division, thereby partially compensating for the biomass deficit induced by osmotic stress. The positive influence of phosphate is particularly evident in the foliar apparatus. A significant increase in both leaf number and leaf area, notably with the application of 1 g of P, aligns with earlier findings [38, 39, 40].

This accelerated organ development suggests that phosphate optimises energy metabolism (via ATP), enabling more robust leaf expansion despite ionic toxicity. These results are supported by Dissanayaka [41], who emphasise that P availability is crucial for membrane biosynthesis and photosynthetic regulation under abiotic stress, thereby promoting an increased light interception surface. Regarding structural parameters, the rise in collar diameter and stem height following P application reflects a restoration of turgidity and improved mineral distribution. As indicated by Balzergue [42], phosphate acts as a pivotal signal for plant architecture and facilitates osmotic adjustment. This finding is reinforced by Taffouo [12], who explain that nutrient balance is essential to stabilise leaf water potential under stress. Furthermore, according to Verma [43], phosphate promotes membrane stability and the accumulation of reserve substances, which are crucial for counteracting sodium toxicity. This resulted in an improved collar diameter, reflecting a more efficient allocation of resources towards storage and structural tissues.

• Nutritional balance and photosynthetic capacity

The interaction between salinity and phosphate application significantly influences the physiological state of *Colocasia esculenta*. Regarding chlorophyll content (a, b, and total), a continuous decline in pigments is observed under NaCl stress, even when phosphate is applied. Although chlorophyll levels remain lower than the control group, the application of Phosphorus (P) appears to support enough residual photosynthetic activity to allow for the elongation of the shoots. This observation aligns with the findings of Hnilickova [44], who noted that plants can maintain a minimum photosynthetic capacity for survival and growth despite salt-induced pigment loss. Crucially, this is in agreement with Ye [45], who emphasised that phosphorus availability facilitates nitrate translocation and stabilises the foliar metabolic activity essential for plant survival under saline conditions. Furthermore, Loudari [46] highlighted that phosphorus plays a protective role for the reaction centres of photosystem II (PSII). This protection helps limit the total degradation of chlorophyll and stabilises the photochemical apparatus despite the presence of ionic toxicity.

Regarding phosphorus distribution, the highest concentrations are located in the aerial parts, highlighting active translocation to the leaves to support metabolism. However, the inhibition of P absorption at 100 mM NaCl and

above confirms the existence of major ionic antagonism, given that salinity reduces phosphate availability in the soil solution and inhibits the activity of root transporters [31, 47].

• **Stimulation of biochemical defence mechanisms**

Analysis of biochemical constituents reveals that phosphate (P) application amplifies the intrinsic defence mechanisms of the Ibo coco variety against salinity. Regarding soluble proteins, their significant accumulation from 100 mM NaCl is strongly stimulated by the addition of phosphate, starting from a dose of 0.1 g. This synergy suggests that phosphorus provides the metabolic energy (ATP) required for the production of new stress proteins. This is fundamentally supported by Carstensen [48], who established that adequate phosphorus levels are essential for the stability of the photosynthetic electron transport chain, which directly dictates the availability of ATP for cellular defence and repair. Consequently, the accumulation of soluble proteins under saline conditions is highly dependent on the plant's phosphorus status, as observed by Razaq [49], who noted that phosphorus supplementation significantly boosts total protein content and physiological resilience in plants facing environmental stress. Furthermore, these findings are consistent with the work of Loudari [46], who demonstrated that phosphate nutrition optimises the synthesis of protective molecules, thereby ensuring the maintenance of cellular structural integrity despite osmotic adversity.

Similarly, the production of total phenolic compounds is significantly boosted by phosphate application in saline environments. While NaCl alone triggers an antioxidant response, the addition of P mitigates the harmful effects of salt by promoting a greater synthesis of these secondary metabolites. This observation aligns with the findings of Loudari [46], who demonstrated that optimised phosphate nutrition enhances the plant's biochemical resilience, specifically by increasing the concentration of protective secondary metabolites to counteract ionic toxicity. Furthermore, Tariq [50] established that phosphorus supplementation enhances the activity of enzymes involved in the shikimate pathway, a vital precursor to phenolic compounds.

4.3. Synergistic effects of mycorrhizal consortia and phosphate under stress

• **Enhanced biomass through fungal symbiosis**

The combined application of mycorrhizal biofertilisers (Bio 1, Bio 2, and the Bio 1+2 mixture) and phosphate represents an effective biotechnological strategy to mitigate salinity-induced growth inhibition in *Colocasia esculenta*. Results indicate a significant restoration of dry biomass, leaf number, leaf area, and stem dimensions, with the Bio 1+2 mixture proving particularly efficacious. This phenomenon is attributed to the capacity of mycorrhizal fungi to extend the root system via hyphae, thereby increasing the soil exploration surface for the uptake of phosphorus, a nutrient whose mobility is severely restricted in saline environments. As demonstrated by Balzergue [42] and Taffouo [51], this symbiosis facilitates osmotic adjustment, ensuring superior cellular turgidity. Furthermore, Cao [52] demonstrated that arbuscular mycorrhizal fungi actively modulate the plant's endogenous phytohormones under salt stress, which optimizes root system architecture and reinforces the plant's structural resilience. These hormonal adjustments work synergistically with mechanisms highlighted by Latef [53] regarding ionic homeostasis, restricting Na^+ transport to the shoots and maintaining a favourable K^+/Na^+ balance. The

symbiotic relationship ensures that the plant can effectively organise its biochemical defences, using the increased phosphate supply to fuel the energetic costs of ion exclusion and vacuolar sequestration.

The superior efficacy of the Bio 1+2 mixture suggests a synergy between distinct mycorrhizal strains, promoting enhanced root colonisation and subsequent phosphate uptake, particularly at a dose of 1 g of phosphorus. This multi-strain interaction allows the host plant to exploit different functional advantages of each fungus, optimizing nutrient absorption pathways under stressful conditions. These observations corroborate findings by Wu [54] regarding mineral distribution and align with studies by Begum [55], which demonstrate that mycorrhizal inoculation stimulates the production of growth hormones (auxins, gibberellins) in plants subjected to abiotic stress. In summary, the synergy between mycorrhizae and phosphorus maintains robust morphological growth, establishing biofertilisers as an essential tool for taro cultivation in saline areas.

• **Preservation of chlorophyll and photosynthetic integrity**

Mycorrhizal inoculation, coupled with phosphate fertilisation, significantly attenuates the degradation of chlorophyll pigments induced by salt stress. Although pigment levels remain below those of the control, the strain mixture (Bio1+2) maximises the preservation of total chlorophyll (a+b), indicating improved photosynthetic efficiency. According to Balzergue [42], this mitigation relies on optimised mineral distribution and facilitated osmotic adjustment. This process is corroborated by Evelin [14] and Begum [55], who demonstrate that mycorrhizal symbiosis protects the photosynthetic apparatus by reducing oxidative stress and maintaining chloroplast integrity. Furthermore, Khaliq [56] and Chitarra [57] emphasise that this synergy promotes pigment synthesis through enhanced phosphorus availability and regulated mineral nutrition, thereby counteracting the inhibitory effect of NaCl. These results confirm that mycorrhizae provide a critical biotechnological lever for supporting the metabolic and photosynthetic activity of *Colocasia esculenta* under saline constraint.

5.0. Conclusion

In conclusion, this study demonstrates that salt stress significantly inhibits the growth, mineral homeostasis, and photosynthetic efficiency of *Colocasia esculenta* var. Ibo coco. Specifically, salinity disrupts nutrient uptake, reducing essential potassium (K^+) and phosphorus (P) levels while promoting toxic sodium (Na^+) accumulation, and degrades pigment content, leading to a significant reduction in biomass.

However, the application of phosphate fertiliser, in synergy with arbuscular mycorrhizal inoculation (particularly the Bio1+2 consortium), effectively mitigates these deleterious effects. This integrated approach preserves chloroplast integrity, enhances the synthesis of protective soluble proteins, and optimises mineral balance. Consequently, we recommend that farmers in salt-affected regions adopt a combined strategy of phosphate fertilisation and mycorrhizal bio-inoculation to improve taro resilience and sustain productivity under saline conditions. These findings confirm that this integrated biotechnological approach serves as a sustainable tool for managing salinity stress in tropical agriculture.

6.0. Suggestions

- 1) Evaluation of agronomic performance under real field conditions.

- 2) Detailed characterisation of physiological mechanisms and oxidative stress.
- 3) Study of endomycorrhizal persistence and colonisation rate.
- 4) Multi-varietal screening and extension to other local ecotypes.
- 5) Analysis of the long-term impact on soil microbiology and structure.

Declarations**Source of Funding**

This study did not receive grant from any funding agencies in the public, commercial, or not-for-profit sectors.

Competing Interests Statement

The authors declare no competing interests.

Consent for publication

All authors have given their consent for the publication of this manuscript.

Authors' contributions

O.S.W.F., L.M.T., S.E.S and V.D.T. designed the study; O.S.W.F., L.M.T., A.D.N., A.N.N. and A.V.T.I. performed the experiments and participated in the data analysis. O.S.W.F., L.M.T., S.E.S and A.D.N. wrote the manuscript; O.S.W.F., L.M.T., S.E.S., A.D.N., A.N.N., A.V.T.I. and V.D.T. reviewed the manuscript and provided with critical input and corrections. All the authors read and approved the submitted version of the manuscript.

Informed Consent

Not applicable.

Availability of data and material

Data supporting the results of the current study are available upon request from the corresponding author.

Institutional Review Board Statement

Not applicable

Ethical Approval

Not applicable.

Acknowledgement

The authors thank the Plant Biology Laboratory of the Faculty of Sciences at the University of Yaoundé I and the Plant Biology and Physiology Laboratory of the Faculty of Sciences at the University of Douala for their valuable technical assistance and for providing the essential facilities that made this research possible.

Declaration of Artificial Intelligence

Artificial intelligence was employed solely to assist in formatting and improving the language of the manuscript.

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