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Growth Performance, Nutrient Uptake, and Biofortification Potential of Hydroponic Lettuce (*Lactuca sativa* L.) Under Calcium Supplementation

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ABSTRACT

Lettuce (*Lactuca sativa* L.), a fast-growing and commercially important leafy green, contains about 36 mg of calcium per 100 g. Its calcium content depends on water and nutrient uptake through the roots. This study aims to evaluate how varying calcium levels in hydroponics affect lettuce growth, nutrient absorption, and post-harvest nutrient content, providing insights into optimizing calcium enrichment in lettuce for improved human nutrition. In this study, growth performance, nutrient uptake, and biofortification potential of hydroponic lettuce under varying calcium supplementations of 90, 108, 126 and 144 mg/L were examined. As a result, lettuce fresh weights are significantly higher at 126 and 144 mg/L calcium supplementation. Highest calcium content was found in lettuce hydroponics grown with 108 mg/L calcium (2.35%), potassium and iron are the most abundant nutrients in lettuce hydroponics. Total flavonoid was significantly lowest in lettuce hydroponics cultured with 144 mg/L calcium. Nitrate is found exclusively in in lettuce hydroponics cultured with 144 mg/L calcium. Therefore, it can be deduced that lettuce hydroponics requires at least 126 mg/L calcium, but not more than 144 mg/L calcium for maximal growth, nutrient uptake and nutrient content, as well as safe for consumption.

Keywords: *Lactuca sativa* L., hydroponic, calcium, nutrient uptake, growth

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INTRODUCTION

Vegetables, like other valuable agricultural commodities like rice and fish (Jee et al., 2017; Lim et al., 2021) contributes greatly to the economy and are a primary dietary source of essential minerals such as calcium for the human body, they play roles in maintaining the gut microbiome balance and prevent dysbiosis. A balanced gut microbiota will help in preventing mental disorders and cancers (Lim et al., 2025a-b). It was recently discovered that calcium can aid in combating colorectal cancer (Papier et al., 2025), apart from its vital role in bone development and maintenance, blood clotting, and the regulation of hormones and enzymes. The recommended daily intake for most adults is around 1000 mg, while older individuals require a higher intake of approximately 1300–1700 mg per day (Yuan et al., 2018). Milk and dairy products are well-established sources of calcium; however, they may not be suitable for individuals with lactose intolerance. For such individuals, calcium requirements can be effectively met through alternative sources, such as specific leafy green vegetables, which offer a viable and nutritious substitute. Research has indicated that increasing the intake of calcium-rich vegetables can effectively enhance overall calcium consumption, potentially helping to prevent calcium deficiency. Leafy greens like celery, collard greens, Chinese cabbage, and soybean sprouts are particularly rich in calcium and serve as key mineral sources (Yuan et al., 2018). Boosting the calcium content in these vegetables could provide added nutritional value, especially since calcium deficiency is among the most common issues in modern diets.

Lettuce (*Lactuca sativa* L.) is a widely cultivated annual plant belonging to the Asteraceae family. It holds significant commercial value and is commonly used as the main ingredient in salads across the globe. One of its advantages is its short growing cycle, making it relatively easy to cultivate, especially via hydroponic (Cybulska et al., 2010; Petrazzini et al., 2014). Calcium is recognized as an essential nutrient in lettuce, 100 g of lettuce contains approximately 36 mg of calcium (USDA, 2025), and its concentration in the plant is influenced by calcium absorption, which is closely linked to root water uptake. This process ultimately determines how calcium is distributed throughout the plant, especially in the shoots (Yuan et al., 2018). Current studies often focus on calcium's impact in soil-based systems or its effects on a limited number of physiological parameters (Salama et al., 2024). There is a clear gap in integrative research that links calcium nutrition to lettuce biofortification potential (Salama et al., 2024). Thus, the aim of the present study is to determine the growth performance, nutrient uptake, and biofortification potential of hydroponic lettuce under varying calcium supplementations of 90, 108, 126 and 144 mg/L. This study provides insights into the optimal calcium concentration required to achieve the maximal calcium and other nutrient content in lettuce produce.

MATERIALS AND METHODS

Hydroponic system design and seedlings management

The experiment was conducted at the plant factory facility in Agriculture Research Centre (ARC) in Semenggoh, Sarawak, Malaysia from 16 December 2024 to 16 May 2025. The facility maintained a constant temperature of 28 °C and a continuous 24-hour photoperiod. While the lighting system did not include red or blue light sources, it utilized full-spectrum lamps with a 6500K rating, providing a consistent light intensity of approximately 50 $\mu mol/m^2/s$ throughout the entire day. Lettuce (LT40, Crop Power, MY) was grown using a hydroponic system based on the Nutrient Film Technique (NFT) (Fig. 1). The setup included growing channels about 6 meters long, made from food-grade PVC. Each channel was approximately 10 to 15 cm wide with a depth of at least 5 cm to support root growth and allow smooth nutrient flow. A submersible pump rated between 250–500 L per hour (50W) was used to maintain continuous circulation of the nutrient solution. The system's nutrient reservoir held at least 50 L, making it well-suited for small-scale hydroponic cultivation. Seeds were sown in moistened rockwool for germination. After germination, seedlings were transplanted to hydroponic racks. Fertilizer solution used contained 150 mg/L nitrogen, 31 mg/L phosphorus, 210 mg/L potassium, 24 mg/L magnesium, 2.5 mg/L iron, 0.25 mg/L manganese, 0.13 mg/L zinc, 0.44 mg/L boron, 0.023 mg/L copper, 0.024 mg/L molybdenum and four concentrations of calcium (90, 108, 126 and 144 mg/L) assigned for each treatment group. The pH was checked daily and maintained at pH 5.8 to 6.3.

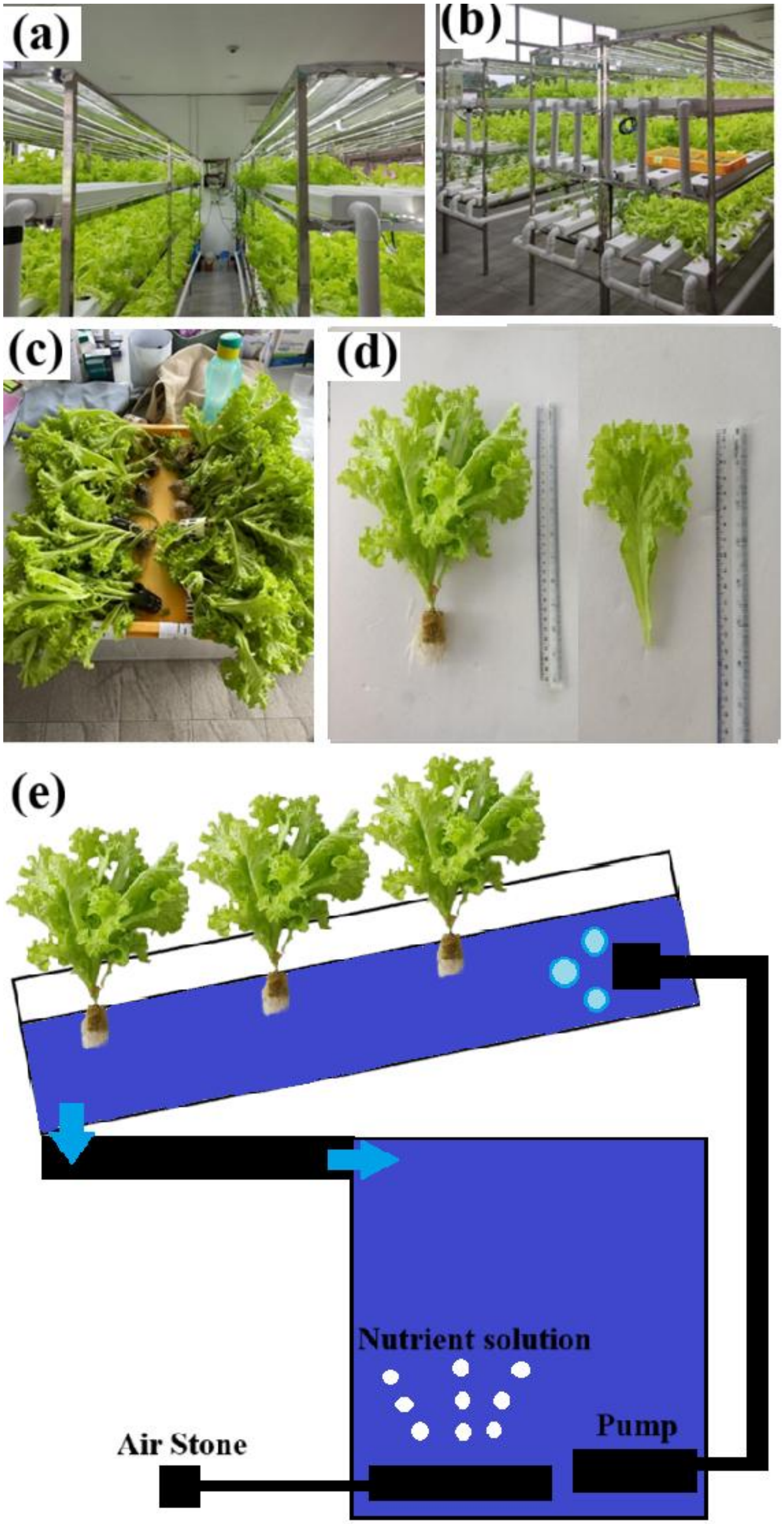

Fig. 1 Photo of (a,b) lettuce hydroponic site, (c) harvested lettuce, (d) measurement of lettuce height and leaf area, (e) overview of lettuce nutrient film technique (NFT) hydroponic system.

Measurement of lettuce biofortification potential

The nutrient water tank was flushed three days before harvesting the lettuce and the electrical conductivity before and after the flushing were measured. The lettuce was harvested after five weeks of cultivation (around 35 days). Mature leaves with bright color and a firm, crisp texture indicated the plants were ready for harvest. Harvesting took place in the early morning to take advantage of peak moisture levels in the plants. Clean, sterilized tools such as scissors or knives were used to cut the lettuce just above the root level. To avoid bruising, the harvested plants were not stacked. For better flavor, the lettuce was picked slightly before reaching full maturity. Fresh weight, plant height, leaf count and leaf area of lettuce were measured immediately after harvest.

Total nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese, copper, zinc and boron measurement

The total nitrogen was calculated via Dumas combustion method using nitrogen analyzer. The amount of total phosphorus, potassium, calcium, magnesium, iron, manganese, copper, zinc and boron were determined by dry-ashing and Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) (Nascimento et al., 2025). The determination of P, K, Ca, Mg, Fe, Zn, Cu, and B was carried out on a dry-ashed extract of the plant sample. 1.0 g of the sample was accurately weighed into a crucible and was transferred to a muffle furnace. The temperature gradually rose to 300 °C and was maintained until smoking ceased. The temperature increased to 500 °C and ashing continued until white or greyish-white ash was obtained (approximately 5 hours). The crucible was allowed to cool. The ash was moistened with a few drops of water. 2 mL of concentrated hydrochloric acid (ACS reagent) was added, and the mixture was evaporated to dryness on a water bath for 1 hour. 10 mL of 5% nitric acid (ACS reagent) was added, and the solution was filtered into a 100 mL volumetric flask. The crucible and filter paper were washed several times with warm water, and the washings were transferred into the flask. The solution was mixed thoroughly. Readings for each element were obtained from a calibrated ICP-OES. The ICP-OES instrument was set up to monitor the responses of appropriate elements and standards. The instrument parameters were optimized as necessary to ensure system suitability.

Total phenolic measurement

The total phenolic content was enumerated using Folin-Cicocalteu method. 1.0 g of plant extract was weighed. 1.5 mL of diluted Folin-Ciocalteu reagent (50% v/v aqueous) and 7.5 mL of distilled water were added (Siddiqui et al., 2017). 1.0 mL of 20% Na_2CO_3 was added. The mixture was mixed well and was allowed to stand for 1 hour at room temperature. Absorbance was read at 760 nm using a UV-Vis spectrophotometer. The result was expressed as gallic acid equivalent (GAE) in g/100 g. The total flavonoid content was calculated using aluminium chloride colorimetric assay. A total of 0.5 g of plant extract was weighed. The extract was diluted with 4.0 mL of distilled water. 0.6 mL of 5% $NaNO_2$ solution was added. After 5 minutes, 0.3 mL of 10% $AlCl_3$ was added. At 6 minutes, 2.0 mL of 1.0 M NaOH was added. The volume was made up to 10 mL with distilled water. The mixture was mixed well, and the absorbance was read at 510 nm using a UV-Vis spectrophotometer. Results were expressed as gallic acid equivalent (GAE) in g/100 g. The preparation of the gallic acid standard solution was prepared.

Total anion measurement

The anion (chloride, fluoride, nitrate, nitrite, bromide, phosphate and sulphate) levels were determined using ion chromatography (Afanda et al., 2025). Crude fibre was determined as the combustible residue remaining after the removal of fat, carbohydrates, and proteins. This residue primarily consists of cellulose, with smaller amounts of hemicellulose and lignin, representing the portion of carbohydrates that is non-digestible and non-assimilable by humans. The sample was then sequentially treated with acid and alkali to eliminate carbohydrates and proteins. The remaining residue was dried and weighed, representing the combined weight of inorganic matter and crude fibre. After ashing the residue and determining the weight of the ash, the crude fibre content was calculated based on the weight loss. All plant materials were air-dried in an oven at 70 ± 5 °C prior to analysis. The drying time varied depending on the size and type of the sample. The dried material was then finely ground to ensure uniformity before analysis. The crucible containing Celite was heated at 105 °C for 3 hours. The crucible was placed onto the balance and was tared. 1 g of sample was weighed into the crucible. The exact sample weight (Ws) was recorded. The sample was boiled with 150 mL of 1.25% H_2SO_4. 2–4 drops of octanol were added to prevent bumping. The solution was boiled for 30 minutes. The H_2SO_4 was filtered off. The residue was washed with 30 mL of water. This step was repeated 3 times. The residue was boiled with 150 mL of 1.25% NaOH. 2–4 drops of octanol were added to prevent bumping. The solution was boiled for 30 minutes. The NaOH solution was filtered off. The residue was washed with 30 mL of water. This step was repeated 3 times. The residue was filtered with 25 mL of acetone. This step was repeated 3 times. The crucible was left at room temperature for 2–3 hours. The crucible was dried at 105 °C for at least 5 hours. The crucible was weighed (Wd). The crucible was ashed in a furnace at 525 °C for at least 3 hours. The crucible was cooled in a desiccator and was weighed (Wf).

Crude Protein/Fibre % was calculated as follows:
% Crude fiber = [(Wd – Wf)/Ws] x 100
Where,
Wd = Weight of dried crucible at 105°C
Wf = Weight of ashed crucible at 525°C
Ws = Sample weight (g) in crucible

There are 10 biological replicates for each treatment in this study and the research design used is completely randomized design. (CRD). One-way ANOVA was utilized to evaluate the differences between treatment groups, followed by Tukey's honestly significant difference post hoc test.

Table 1. The description of parameter measurement.

Parameter	Measurement description
Fresh weight	Measured using a weight balance
Plant height	Measured using a ruler
Leaf count	Enumerated manually
Leaf area	Measured using a ruler

RESULTS AND DISCUSSION

Post-harvest plant height, leaf count, leaf area and fresh weight of lettuce hydroponics

The post-harvest plant height, leaf count, leaf area and fresh weight of lettuce hydroponics supplemented with varying calcium concentrations of 90, 108, 126 and 144 mg/L were depicted in Fig. 2. The highest plant height was observed in lettuce hydroponics supplemented with 90 mg/L calcium (13.62 cm), the lettuce supplemented with 126 mg/L calcium is significantly lower than the others (Fig. 2a). The most leaf count was observed in lettuce hydroponics cultivated with 144 mg/L calcium (16.27), despite no statistically significant differences enumerated across all other treatment groups (Fig. 2b). The leaf area of lettuce hydroponics was significantly lowest in 108 mg/L calcium supplemented lettuce, but the greatest leaf area was seen in lettuce hydroponics cultured with 144 mg/L calcium (146.73 cm^2) (Fig. 2c). The fresh weights of lettuce hydroponics gather interest as 126 and 144 mg/L calcium supplemented lettuce hydroponics resulted in significantly greater fresh weights as compared to the other two calcium supplementation lettuce hydroponics at $p<0.05$. Similar research outcomes have been deduced by Yuan et al. (2018) whereby 120 and 180 mg/L calcium supplemented lettuce yielded significantly greater fresh weight as compared to their 60 mg/L calcium supplemented counterparts. However, Yap et al. (2022) reported that the fresh weight of lettuce hydroponics supplemented with 350 mg/L calcium hydroxide was slightly lower than that supplied with 250 mg/L calcium hydroxide, though there is no significant difference detected. The same phenomenon was observed for calcium carbonate in the same study (Yap et al., 2022). They suggested that the calcium level should not be higher than 150 mg/L to avoid the occurrence of tip burn in lettuce (Yap et al., 2022). They postulated that the high calcium level can lead to high magnesium depressive uptake and further halt the lettuce growth (Yap et al., 2022). Calcium supplements contributed to higher fresh lettuce weight primarily by strengthening cell wall structures and improving water retention capacity. Calcium plays a crucial role in stabilizing cell membranes and promoting cell division and elongation, leading to more robust plant growth (Yuan et al., 2018). Additionally, adequate calcium enhances root development and nutrient uptake, which collectively support increased biomass and fresh weight accumulation in lettuce.

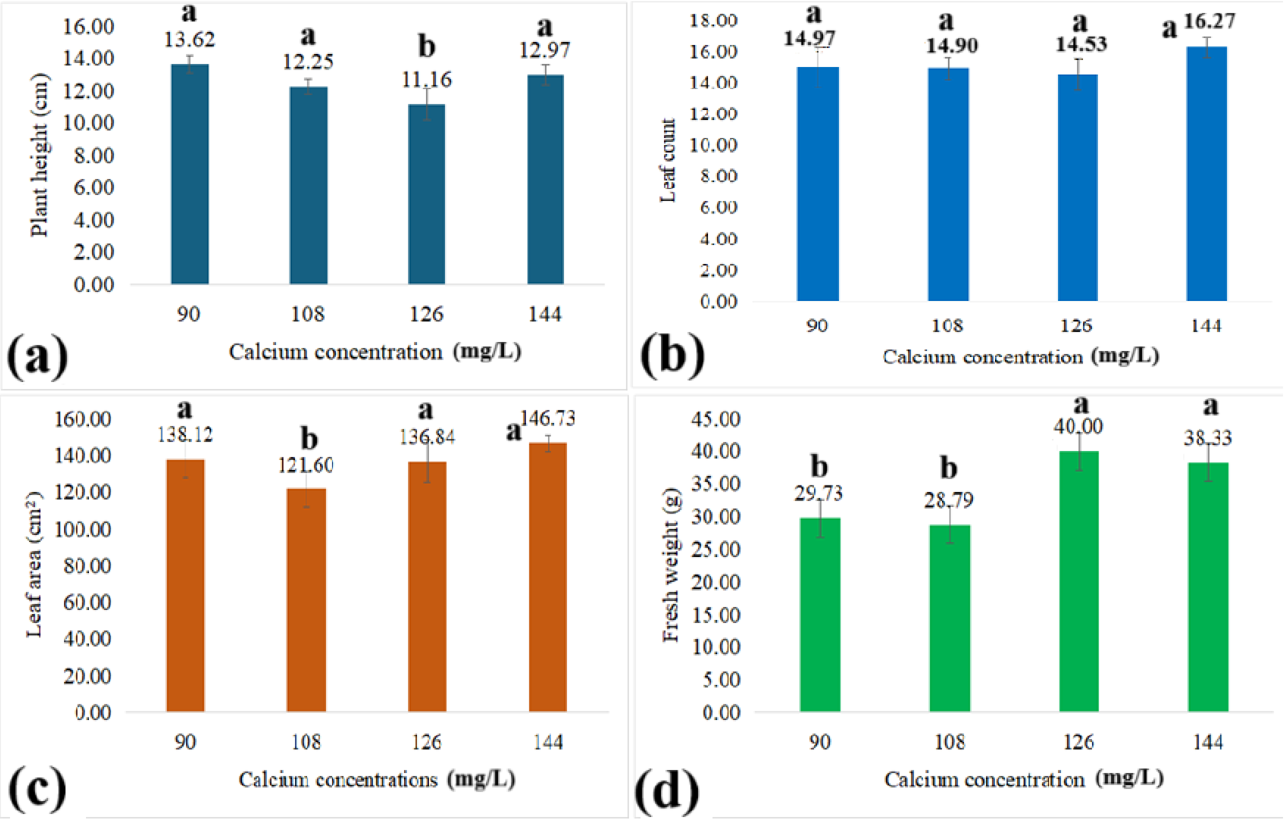

Fig. 2 The resultant lettuce hydroponic (a) plant height, (b) leaf count, (c) leaf area, and (d) fresh weight after harvesting, across different calcium supplementation. Different alphabets represent statistically significant group via ANOVA and Tukey post hoc at $p<0.05$.

Micronutrients and macronutrients uptake of lettuce hydroponics

The amount of micronutrients and macronutrients uptake of lettuce hydroponics were detected post-harvest and illustrated in Fig. 3. The most abundant macronutrients is the potassium (K), followed by calcium (Ca), phosphorus (P) and magnesium (Mg) for all treatment groups in this study. Phosphorus levels remained relatively stable across all calcium treatments, ranging from 0.90% to 0.94%, suggesting that calcium concentration had little influence on phosphorus uptake. Ding et. al. (2018) observed that leaf phosphorus concentrations remained stable across a wide range of calcium levels, indicating that calcium availability had minimal impact on phosphorus uptake in the plants capable of maintaining phosphorus homeostasis. Maintaining stable phosphorus is crucial, as phosphorus is central to ATP synthesis, nucleic acid formation, and root development, all fundamental to plant growth. Potassium is essential for stomatal regulation, enzyme activation, osmoregulation, photosynthesis, and stress resistance. Thus, the enhanced potassium uptake under moderate calcium suggests improved water-use efficiency, photosynthetic capacity, and resilience to abiotic stresses (Hasanuzzaman et. al., 2018). In contrast, potassium showed a pronounced response to calcium supplementation. Potassium content increased from 5.97% at 90 mg/L calcium to a peak of 6.77% at 126 mg/L, followed by a slight decrease to 6.62% at 144 mg/L. This suggests that moderate calcium levels improved potassium uptake, likely through enhanced membrane stability and transporter activity, while excessive calcium concentrations may have competitively inhibited potassium uptake at root absorption sites. Shaul (2002) reported similar trend that excessive calcium ion competitively inhibits potassium ion uptake at the plasma membrane transporters due to charge competition and transporter selectivity.

Magnesium levels decreased linearly from 0.70% to 0.57%, illustrating clear antagonism relation typical in hydroponic culture due to competition for root cation uptake (Vought et. al., 2024). Tissue calcium content increased from 2.09% (90 mg/L) to 2.35% (108 mg/L) but dropped to 1.48% at 144 mg/L, indicating physiological regulation to avoid ionic toxicity, a pattern observed in previous calcium biofortification trials. Calcium deficiency is globally linked to bone diseases (rickets, osteoporosis), hypertension, and colorectal cancer (Dayod et. al., 2010). Agronomic and foliar calcium fortification of staple crops (e.g., cereals, legumes, root crops) has proven effective, sometimes increasing edible calcium by up to 50% (Cheng et. al., 2024).

The most abundant micronutrients across all lettuce hydroponics are the iron, followed by zinc, boron, manganese and copper. The lettuce hydroponics supplied with 144 mg/L calcium has the most amount of iron (121 mg/L), they also contain the most amount of zinc (35 mg/L) and copper (3.33%) among all others. Interestingly, the concentration of manganese in 90 mg/L calcium grown lettuce hydroponics (30.33%) is significantly higher than all other treatment groups, they also encompass the most boron among all. Iron, zinc, boron, manganese, and copper are essential micronutrients that significantly influence lettuce growth and health (Ahmed et al., 2024). Iron is vital for chlorophyll synthesis and acts as a cofactor in many enzymatic reactions related to photosynthesis and respiration. Zinc supports auxin production, protein synthesis, and helps maintain membrane integrity, all of which are crucial for cell division and leaf expansion (Ahmed et al., 2024). Boron is important for cell wall formation, membrane stability, and the transport of sugars, making it essential for root and shoot development. Manganese plays a role in photosynthetic oxygen evolution and activates enzymes involved in nitrogen metabolism. Copper, though needed in very small amounts, is essential for lignin formation in cell walls and functions in redox reactions and photosynthetic electron transport (Ahmed et al., 2024). Together, these micronutrients ensure optimal metabolic function, structural development, and resistance to stress in lettuce plants. In short, increasing calcium concentration can lead to increase in potassium (up to 126 mg/L calcium) and iron levels, but has little or no effect on the levels of other micro- and macro-nutrients in lettuce hydroponics in this study. Interestingly, low calcium level (90 mg/L) promotes the highest level of manganese in lettuce hydroponics in this study.

Crude protein, nitrogen, sulphur, total phenolics and flavonoids in lettuce hydroponics

The amount of crude protein, nitrogen and sulphur as well as total phenolics and flavonoids in lettuce hydroponics cultivated with varying calcium supplementation were displayed in Fig. 4. In this study, lettuce grown with the highest calcium concentration (144 mg/L) in hydroponics showed the highest levels of crude protein (29.40%), nitrogen (4.7%), and sulfur (0.55%). However, the total flavonoids was significantly the lowest (200.33 mg/100g GAE) in the same treatment group (Fig. 4d). Lettuce grown in hydroponics with 126 mg/L calcium exhibited the highest total phenolic content (237.03 mg/100g GAE) compared to all other treatments. Nitrogen and sulphur are critical macronutrients that influence both the growth of lettuce and its nutritional value. Nitrogen promotes vigorous vegetative growth, increases leaf biomass, and enhances chlorophyll and amino acid synthesis, directly contributing to higher crude protein levels in lettuce (Jang & Kuk, 2021). Sulphur is essential for synthesizing certain amino acids (like cysteine and methionine) and vitamins, and it also supports protein structure and enzyme activity. Calcium was found to have positive control in the key nitrogen-metabolizing enzymatic activities and further improve the nitrogen efficiency in green leafy crops like apple dwarf rootstock seedlings and lettuce (Xing et al., 2021). Weng et al. (2023) documented that the best growth response in poplar seedlings occurred at N-Ca of 2:1, which allows optimal nitrogen-related metabolic pathways and gene expression (in nitrate assimilation and photosynthesis). Recently, Kong et al. (2024) demonstrated that miniature amount of sulphur can significantly elevate leaf expansion, photosynthetic efficiency, shoot biomass as well as chlorophyll levels in lettuce. In this study, increasing calcium levels promotes the increment in nitrogen levels but the sulphur levels remained consistent.

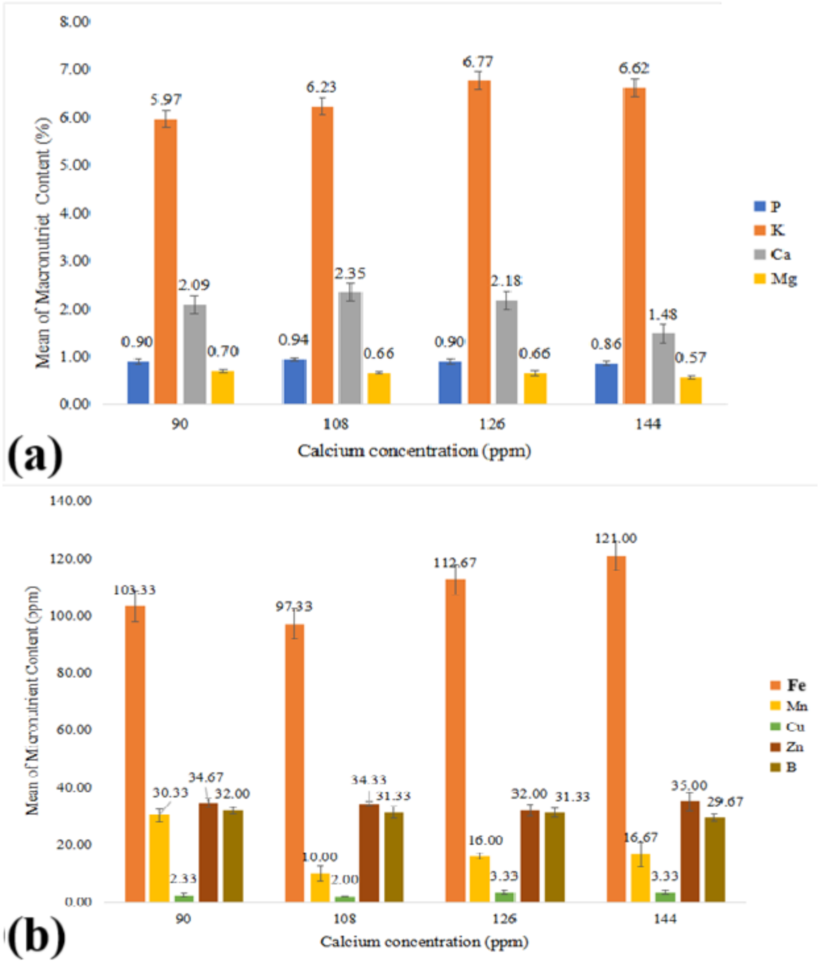

Fig. 3 The (a) macronutrient and (b) micronutrient uptake of lettuce hydroponic across different calcium supplementation.

Crude protein reflects the total nitrogen-based compounds in lettuce, offering essential amino acids to human diets. Phenolics and flavonoids are secondary metabolites that play protective roles in plants, helping lettuce resist pests, UV stress, and pathogens (Jang & Kuk, 2021). In humans, these compounds function as powerful antioxidants, reducing oxidative stress, lowering inflammation, and potentially decreasing the risk of chronic diseases like heart disease and cancer (Jang & Kuk, 2021). Calcium is one of the major contributors towards phenolic biosynthesis in plants (Naz et al., 2024), phenolic metabolism also necessitates the actions of calcium-dependant protein kinases via signalling pathways (Tian et al., 2022). Shabbir et al. (2022) have also reported that the antioxidant responses induced in plant was greatly enhanced by the presence of calcium, and this in turn spiked the phenolic synthesis in leafy vegetables. On the other hand, it was previously reported that high calcium levels can reduce flavonoid bioproduction significantly in plants (Khani et al., 2020), as this may interfere with the uptake of other essential minerals like potassium and magnesium (Ahmad et al., 2016). Thus, lettuce rich in nitrogen, sulphur, protein, phenolics, and flavonoids not only grows more robustly but also provides greater health benefits when consumed. In a nutshell, elevating calcium levels aid in the increment of crude protein, nitrogen, sulphur and phenolic content, but may cause the diminish in flavonoid amount in lettuce in this study. Calcium supplementation enhanced protein content, nutrient accumulation, and polyphenolic compounds in lettuce by improving metabolic and physiological processes. Calcium acts as a secondary messenger in signal transduction, which boosts enzyme activities involved in nitrogen assimilation, leading to higher protein synthesis (Tian et al., 2022). It also strengthens root systems, enhancing the uptake of essential nutrients like magnesium, potassium, and iron (Ahmad et al., 2016). Moreover, calcium helps mitigate oxidative stress, indirectly stimulating the biosynthesis of antioxidant polyphenolic compounds, contributing to improved nutritional quality and plant defense.

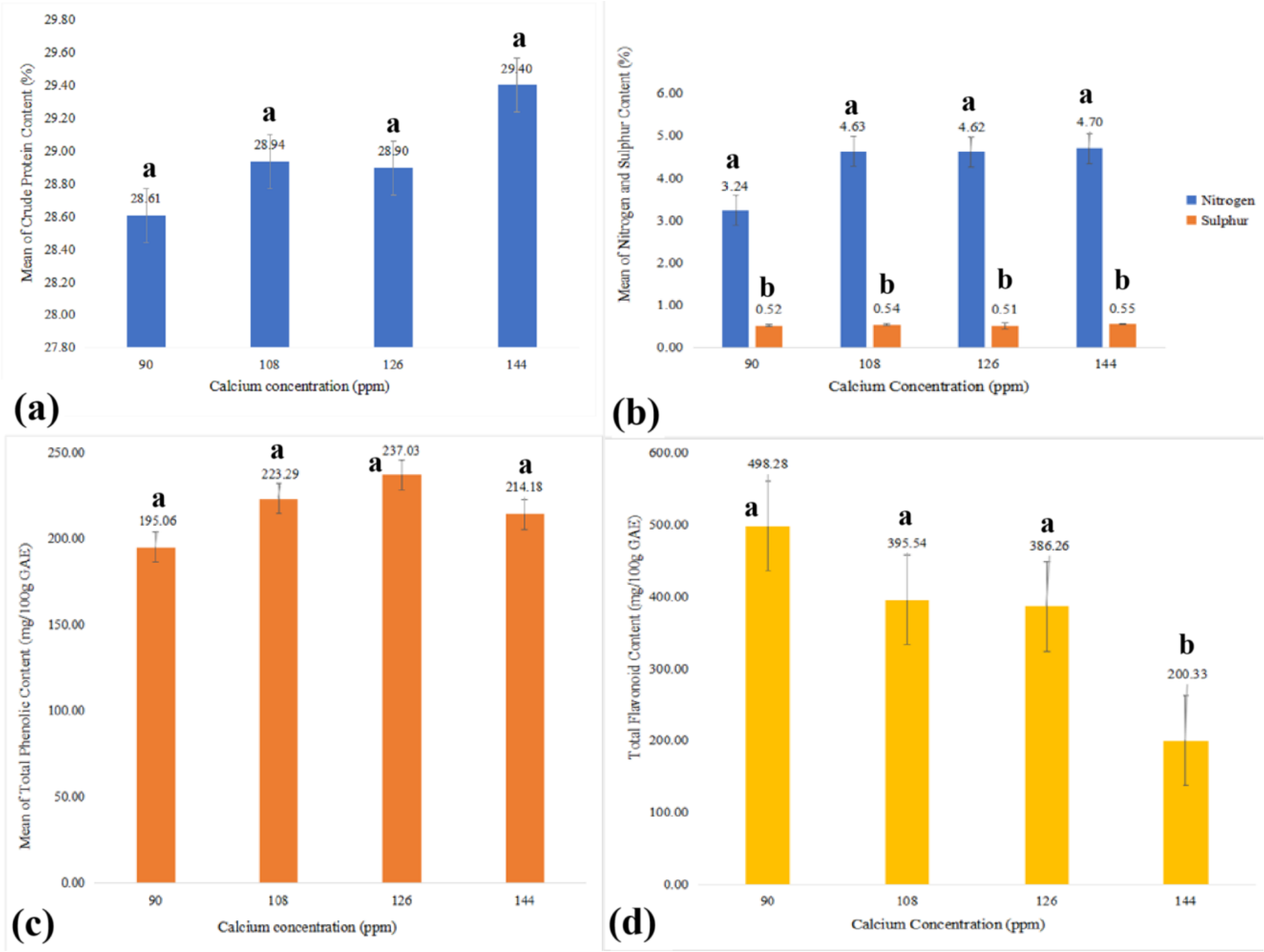

Fig. 4 The (a) crude protein content, (b) nitrogen and sulphur content, (c) total phenolic content and (d) total flavonoid content of lettuce hydroponic across different calcium supplementation. Different alphabets represent statistically significant group via ANOVA and Tukey post hoc at $p<0.05$.

Anion concentration in lettuce hydroponics

The amount of anion concentration in lettuce hydroponics cultivated with varying calcium supplementation were displayed in Fig. 5. The most abundant anion found across all lettuce hydroponics is the nitrite ion, with the lettuce hydroponics grown with 126 mg/L calcium dominating the chart (3316.33 mg/L). Surprisingly, the nitrate is only detected exclusively (1792.05 mg/L) in lettuce hydroponics cultivated with 144 mg/L calcium. The lettuce hydroponics grown with 108 mg/L calcium contains the most chloride (103.43 mg/L) and bromide (0.90 mg/L) whereas the lettuce hydroponics grown with 126 mg/L calcium topped the phosphate (219.53 mg/L), sulphate (65.46 mg/L) and fluoride (26.56 mg/L) charts. Chloride is essential in small amounts for photosynthesis and osmotic balance in lettuce, helping with stomatal function. However, excess can cause leaf burn (Seyrek et al., 2024). It is important for fluid balance and digestion as part of human stomach acid. Bromide has no known essential role in plant growth and is generally considered non-beneficial in high amounts. It has sedative effects for human at high levels and is tightly regulated in food and water. Phosphate is crucial for energy transfer (ATP), nucleic acid formation, and root development in lettuce (Seyrek et al., 2024). For humans, it supports bone health, energy metabolism, and cellular repair. Sulphate is a key source of sulfur in plants, vital for amino acid and enzyme production. It aids in human body detoxification and is part of important structural proteins. Fluoride is not essential for plants and can be toxic at high concentrations. In humans, small amounts strengthen tooth enamel and help prevent cavities, but excess can cause fluorosis.

Nitrate is a primary nitrogen source for lettuce, promoting leafy growth and protein synthesis (Martínez-Moreno, et al., 2024). In humans, dietary nitrates from vegetables may support cardiovascular health, but excessive intake (more than 700 mg/L, according to EU food regulations) can pose health risks. Nitrite is usually a byproduct of nitrate metabolism. In plants, it's quickly converted to useful forms, but accumulation can be toxic (Martínez-Moreno, et al., 2024). Nitrites in high amounts (more than 5000 mg/L) can affect oxygen transport in blood, though from vegetables, they are generally safe and can form beneficial nitric oxide. The accumulation of high nitrate is an indication of impaired nitrate metabolism, possibly induced by the high calcium level (Santamaria, 2005). In this study, increasing calcium level to the highest (144 mg/L) leads to reduction in levels of anion such as chloride, nitrite, bromide, phosphate, sulphate and fluoride, and the high level of nitrate found poses concern over long-term dietary exposure. Thus 126 mg/L calcium level showed the most preferred treatment as it produced highest fresh weight, retain sufficient essential nutrients and safe for consumption.

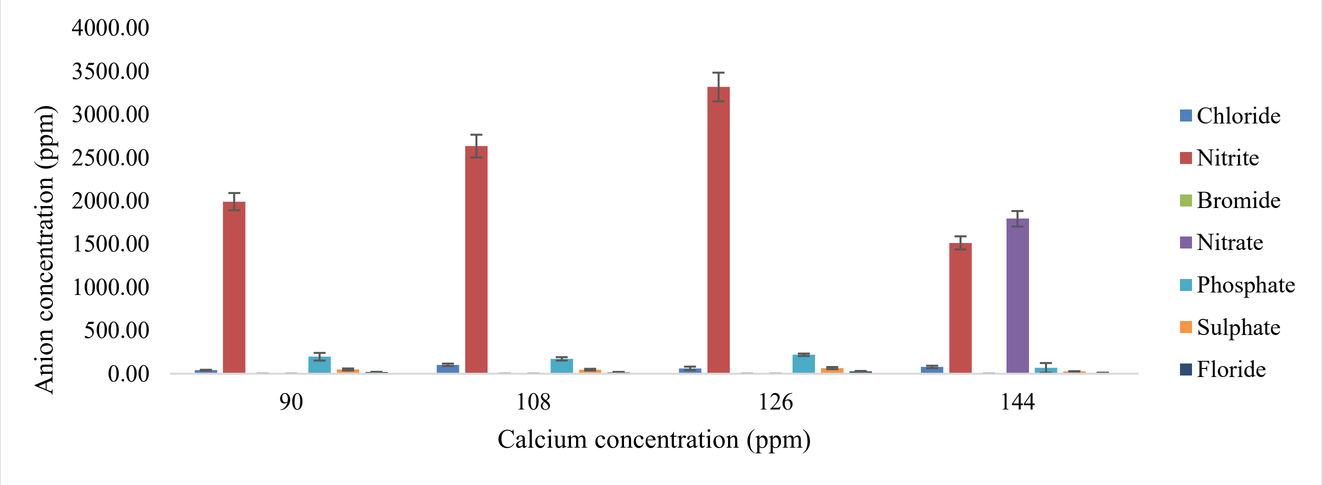

Fig. 5 The anion concentrations in lettuce hydroponic across different calcium supplementation.

CONCLUSION

In short, the effects of different calcium supplementation concentrations in lettuce hydroponics were explored in this study in terms of growth, nutrient uptake, and nutrient content. Lettuce fresh weights were significantly higher at 126 and 144 mg/L calcium supplementation. Potassium and iron were the most abundant nutrients in lettuce hydroponics. Total flavonoid content was significantly lowest in lettuce hydroponics cultured with 144 mg/L calcium. Nitrate was found exclusively in lettuce hydroponics cultured with 144 mg/L calcium. Therefore, it was deduced that lettuce hydroponics required at least 126 mg/L calcium, but not more than 144 mg/L, for optimal growth, nutrient uptake, and nutrient content, while remaining safe for consumption.

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