BIOSTIMULANT OBTAINED FROM SEAWATER IN THE CULTIVATION OF CHINESE VEGETABLE PLANTS

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ABSTRACT---

This study evaluated FertilTomix, a product derived from an innovative seawater extraction process, for its effects on the germination and growth of Pak choi, Tatsoi, and Mizuna. Additionally, its potential to enhance resistance against the fungal pathogens Pythium sp. and Fusarium sp. was assessed. Starting November 2024, experiments were conducted in Research Centre for Vegetable and Ornamental Crops greenhouses in Pescia (PT) with three treatment groups: (i) control without biofertilizer, (ii) biofertilizer, and (iii) FertilTomix. Plants were irrigated every six days and cultivated for six months. On 26 May 2025, data were collected on germination percentage, average germination time, plant height, leaf number, leaf area, vegetative and root biomass, root length, and total bacterial count in the substrate. Disease incidence caused by Pythium sp. and Fusarium sp. was also evaluated. FertilTomix significantly improved all agronomic parameters assessed. Seed germination rates increased, while average germination time decreased across Pak choi, Tatsoi, and Mizuna. Additionally, the incidence of seedling diseases caused by Pythium sp. and Fusarium sp. was reduced. Extracts obtained through an innovative mineral extraction process from seawater significantly enhanced plant growth and disease resistance. This approach offers a sustainable option for repurposing recycled seawater for irrigation, particularly in regions with limited freshwater resources. The mineral and organic components in seawater appear to promote plant development and strengthen defense mechanisms, potentially through both direct and indirect effects on soil microfauna.

KEY-WORDS: *Seawater minerals; Microorganisms; Sustainable agriculture; Biofertilizers; Rhizosphere*

INTRODUCTION

Life on Earth is widely believed to have originated in the sea, and even today, it would not be possible without the sea. It performs numerous life-supporting functions, including moderating extreme temperatures, acting as a vast heat reservoir and global thermostat [1]. The sea also serves as the most economical mode of transportation available to humans. Despite its vast potential, the ocean remains largely underexplored as a source of minerals. This is due to limited knowledge of marine mineral deposits, the absence of economically viable extraction technologies, and a lack of immediate economic or political demand [2]. Marine mineral resources are found in five key regions: beaches, seawater, the continental shelf, surface sediments, and the hard rock beneath these sediments [3]. Minerals have long been extracted from the first three of these regions [4], and as a result, there is extensive literature on the methods and materials being recovered. Many elements enter the ocean through biotic processes, in which both plants and animals play crucial roles [5]. For example, they extract calcium and silicon from seawater to form shells and skeletons. In addition to copper, animals can also concentrate other elements for metabolic functions [6]. Moreover, biota can absorb the organic components of complexes that help maintain certain elements in solution, such as manganese [7]. Once in the ocean, these elements either settle to the seafloor or precipitate into insoluble forms [8]. Due to diagenetic processes, the residues resulting from the dissolution of biogenic material may later be reclassified as inorganic [9].

The Mineral Content of Seawater

The Earth's surface is approximately 71% water, so it could be argued that it might have been more appropriately named after water rather than land. The sea contains around 330 million cubic miles of water, covering an area of 139 million square miles with an average depth of 2.46 miles. Seawater contains about 3.5% dissolved elements, meaning that each cubic mile of seawater estimated to weigh 4.7 billion tons holds approximately 166 million tons of dissolved solids. In total, the oceans store about 5×10^{16} tons of minerals. Advanced analytical techniques have enabled scientists to detect the concentrations of 60 elements in seawater [10]. With such sophisticated methods, it is likely that all naturally occurring elements can be found in seawater [11]. Table 1 presents these elements, along with their concentrations in seawater, their quantities in one cubic mile of seawater, and their total amounts in the world's oceans [12]. In addition to dissolved elements, seawater contains others such as ytterbium, beryllium, zirconium, and platinum—which are also found on the seafloor and in marine organisms [13]. Biological activity at the ocean surface can cause the concentration of various elements to vary over time and between locations [14]. Despite the general homogeneity of seawater, the less abundant elements are not always present in uniform concentrations. Numerous studies have shown that marine organisms can concentrate certain elements in their bodies to levels many times higher than those found in the surrounding seawater [15]. For example, the mucus of some tunicates can contain vanadium at concentrations up to 280,000 times that of seawater. The concentration of copper and zinc in marine organisms can also be influenced by other marine species—sometimes by factors of up to one million. Similarly, certain parts of fish skeletons can exhibit lead concentrations 20 times higher than background levels. For these organisms, such concentration is essential for biological functions. Understanding these natural processes could inform the development of artificial methods to extract and concentrate elements from dilute solutions, such as seawater [16].

Table 1 - Seawater concentrations and amounts of 60 elements [17]

Element	**Concentration (mg/l)**	**Amount of element in seawater (tons/mile^3)**	**The total amount in the oceans (tons)**	**Element**	**Concentration (mg/l)**	**Amount of element in seawater (tons/mile^3)**	**The total amount in the oceans (tons)**
Chlorine	19.000	89.5 x 10^{6}	29.3 x 10^{15}	**Manganese**	0.002	9	3 x 10^{9}
Sodium	10.500	49.5 x 10^{6}	16.3 x 10^{15}	**Titanium**	0.001	5	1.5 x 10^{9}
Magnesium	1.350	6.4 x 10^{6}	2.1 x 10^{15}	**Antimony**	0.0005	2	0.8 x 10^{9}
Sulphur	885	4.2 x 10^{6}	1.4 x 10^{15}	**Cobalt**	0.0005	2	0.8 x 10^{9}
Calcium	400	1.9 x 10^{6}	0.6 x 10^{15}	**Caesium**	0.0005	2	0.8 x 10^{9}
Potassium	380	1.8 x 10^{6}	0.6 x 10^{15}	**Cerium**	0.0004	2	0.6 x 10^{9}
Bromine	65	306.000	0.1 x 10^{15}	**Yttrium**	0.0003	1	5 x 10^{8}
Carbon	28	132.000	0.04 x 10^{15}	**Silver**	0.0003	1	5 x 10^{8}
Strontium	8	38.000	12.000 x 10^{9}	**Lanthanum**	0.0003	1	5 x 10^{8}
Boron	4.6	23.000	7.100 x 10^{9}	**Krypton**	0.0003	1	5 x 10^{8}
Silicon	3	14.000	4.700 x 10^{9}	**Neon**	0.0001	0.5	150 x 10^{6}
Fluorine	1.3	6.100	2.000 x 10^{9}	**Cadmium**	0.0001	0.5	150 x 10^{6}
Argon	0.6	2.800	930 x 10^{9}	**Tungsten**	0.0001	0.5	150 x 10^{6}
Nitrogen	0.5	2.400	780 x 10^{9}	**Xenon**	0.0001	0.5	150 x 10^{6}
Lithium	0.17	800	260 x 10^{9}	**Germanium**	0.00007	0.3	110 x 10^{6}
Rubidium	0.12	570	190 x 10^{9}	**Chromium**	0.00005	0.2	78 x 10^{6}
Phosphorus	0.07	330	110 x 10^{9}	**Thorium**	0.00005	0.2	78 x 10^{6}
Iodine	0.06	280	93 x 10^{9}	**Scandium**	0.00004	0.2	62 x 10^{6}
Barium	0.03	140	47 x 10^{9}	**Lead**	0.00003	0.1	46 x 10^{6}
Indium	0.02	94	31 x 10^{9}	**Mercury**	0.00003	0.1	46 x 10^{6}
Zinc	0.01	47	16 x 10^{9}	**Gallium**	0.00003	0.1	46 x 10^{6}
Iron	0.01	47	16 x 10^{9}	**Bismuth**	0.00002	0.1	31 x 10^{6}
Aluminium	0.01	47	16 x 10^{9}	**Niobium**	0.00001	0.05	15 x 10^{6}
Molybdenum	0.01	47	16 x 10^{9}	**Thallium**	0.00001	0.05	15 x 10^{6}
Selenium	0.004	19	6 x 10^{9}	**Helium**	0.000005	0.03	8 x 10^{6}
Tin	0.003	14	5 x 10^{9}	**Gold**	0.000004	0.02	6 x 10^{6}
Copper	0.003	14	5 x 10^{9}	**Protactinium**	2 x 10^{-9}	1 x 10^{-5}	3,000
Arsenic	0.003	14	5 x 10^{9}	**Radium**	1 x 10^{-10}	5 x 10^{-7}	150
Uranium	0.003	14	5 x 10^{9}	**Rodon**	0.6 x 10^{-15}	3 x 10^{-12}	1 x 10^{-3}
Nickel	0.002	9	3 x 10^{9}				
Vanadium	0.002	9	3 x 10^{9}				

Experiments are conducted using sea minerals

The Xinjiang Academy of Forestry Sciences in the People's Republic of China conducted several experiments to evaluate the effects of sea minerals, under the leadership of Professor Hou Tian Zhen, head of the Department of Tree Physiology and Biochemistry [18]. A 1989 study showed that tomatoes treated with sea minerals produced 27% more fruit and nearly twice as many flowers compared to the untreated control. In 1990, field trials at the A-ning Experiment Station revealed substantial yield increases: green beans by 81%, sweet beets by 67%, and soybeans by 29%.

In a 1991 trial at the same station, watermelon plots treated with sea minerals planted 300 meters apart yielded 65% more fruit than the control plots [18]. Similarly, in the United States, Harold Aungst reported a significant improvement in alfalfa production. In the first year, his yield increased to 7.6 tonnes per acre nearly double the state average of 3.4 tonnes per acre and allowed five harvests instead of the usual three. By the second year, yields rose to 10 tonnes per acre, nearly three times the average [19]. Furthermore, feeding livestock with treated hay increased milk production by 30%. In Wisconsin, farmer Wilson Mills has observed remarkable improvements in apple production since 1989 after applying sea extracts. Over the first eight years, his apple yields doubled annually, fruit set tripled, and sugar content increased by 1,200%. Nutrient uptake also improved significantly: iron absorption increased by 400%, chromium by 326%, and potassium by 120%. Additionally, giant apples ripened two to three weeks earlier than usual [20]. In Okinawa, a 100% increase in banana yield and a 35% reduction in ripening time were recorded following the application of sea minerals. During the 1990 A-ning trials, treated green beans and sweet beets again showed yield increases of 81% and 67%, respectively [19].

After environmental stress devastated nearby farms leaving up to 80% of their coffee plants with empty pods plots treated with marine mineral extracts experienced a 50–100% increase in coffee yield. The quality of the coffee also improved, moving from "Fancy" to "Gourmet" grade. Young plants treated with the extracts produced one-third more yield than expected, matured more uniformly, and required fewer harvests due to synchronized ripening [18]. Additional trials conducted at Research Centre for Vegetable and Ornamental Crops in Pescia confirmed the growth-promoting effects of sea extracts on various species, including *Cichorium intybus*, *Carthamus tinctorius*, *Impatiens glandulifera*, *Helianthus annuus*, *Cucumis sativus*, *Solanum melongena*, and *Solanum lycopersicum* [18-20].

Objectives of the research

The aim of this research was to evaluate the stimulatory potential of FertilTomix, a product derived from an innovative seawater extraction process, on the germination and growth of Pak choi, Tatsoi, and Mizuna. In addition, the study assessed whether the product enhances resistance to fungal diseases such as *Pythium sp. and Fusarium sp.*

MATERIAL AND METHODS

The experiments, started in November 2024, were conducted in the greenhouses of CREA-OF in Pescia (PT), on Pak choi, Tatsoi and Mizuna.

Experimental Setup

Plants grown from seed were cultivated in pots under controlled greenhouse conditions. Sixty seeds were used per treatment (thesis), divided into three replicates of 20 seeds each, and sown in the growing medium at the beginning of November 2024. All seedlings obtained from germination were transplanted into 10 cm diameter pots and fertilized with a slow-release fertilizer (2 kg m^{-3} of Osmocote Pro®), which was incorporated into the growing medium at the beginning of January 2025.

Treatment Groups

The three experimental groups were:

- Group without biofertiliser (CTRL): (peat 80%+ pumice 20%), irrigated with water and substrate fertilized once a week with Compo BIO (organic vegetable fertiliser; organic nitrogenous fertiliser; fluid borer), 5 ml of product in 1 L of water and then 3 ml per plant of this dilution;
- Group with biofertilizer (BIOAL): (peat 80%+ pumice 20%), irrigated with water and substrate fertilized once a week with Compo BIO (organic vegetable fertiliser; organic nitrogenous fertiliser; fluid borer), 5 ml of product in 1 L of water and then 3 ml per plant of this dilution; in addition, an algae-based biofertilizer (Kelpak biostimulant, *Ecklonia maxima*, Kelp products International) was used, dilution 1:1000, 3 ml of this dilution once a week;
- Group with FertilTomix (FE0): (peat 80% + pumice 20%), irrigated with water, 3 ml per plant once a week.

Cultivation Practices

The plants were drip-irrigated every six days and cultivated for a period of six months. Irrigation was controlled by a timer, which was adjusted weekly based on weather conditions and the leaching fraction. Climate conditions were continuously monitored at five-minute intervals using an on-site meteorological station (Decagon Devices, Pullman, WA 99163, USA), which recorded solar radiation, relative humidity, and air temperature. The minimum, mean, and maximum daily average values of photosynthetic photon flux density (PPFD) were 88.2, 122.3, and 187.5 µmol m^{-2} s^{-1}, respectively. Mean daily global radiation was 15.4 MJ m^{-2} d^{-1}. The minimum, mean, and maximum daily average air temperatures were 4.3, 9.5, and 13.3 °C, respectively. The mean daily relative humidity was 38.2%.

Data Collection

On 26 May 2025, data were collected on germination percentage, average germination time, plant height, number of leaves, leaf surface area, vegetative and root biomass, root length, and total bacterial count in the substrate. Additionally, plant mortality caused by *Pythium* sp. and *Fusarium* sp. infections was assessed.

Microbial Count

The total microbial count was determined directly by microscopy using a Thoma counting chamber. The slide surface was etched with a grid of known square areas to facilitate accurate cell counting in a defined sample volume. Viable microbial load was assessed through serial decimal dilutions, followed by surface plating (1 mL) and colony counting after incubation.

Statistics

The experiment was conducted using a randomized complete block design (RCBD). Data were analyzed using one-way ANOVA through the General Linear Model (GLM) univariate procedure to assess significant differences among treatments at $P \leq 0.05$, 0.01, and 0.001. Mean values were separated using the Least Significant Difference (LSD) multiple range test at $P = 0.05$. Statistical analyses and graphical representations were performed using CoStat (version 6.451) and Microsoft Excel (Office 2010). During the analysis, assumptions of normality and homoscedasticity were verified for both the distribution and variance of residuals.

RESULTS

The experiment demonstrated that treatment with the product FertilTomix (FE0) significantly improved all assessed agronomic parameters, reduced the incidence of seedling diseases caused by *Pythium* sp. and *Fusarium* sp., enhanced seed germination, and shortened average germination time in Pak choi, Tatsoi, and Mizuna (Tables 1, 3, and 5). While treatment with a commercial algae-based product also promoted plant growth, the effects observed with FertilTomix were notably more pronounced.

Application of FertilTomix resulted in substantial improvements in plant height, number of leaves, leaf area, vegetative and root biomass, root hair length, and microbial biomass in the substrate. Furthermore, the treatment effectively suppressed phytopathogens, as evidenced by the significantly reduced number of diseased seedlings (Tables 2, 4, and 6). In Pak choi, vegetative growth increased by 29%, and root growth by 35.7% compared to the control. Tatsoi exhibited a 20.7% increase in vegetative growth and a 41.2% increase in root growth (Figure 1), while Mizuna showed respective increases of 19.7% and 12.2% (Figure 2). Disease incidence was markedly reduced with FE0 treatment: in Pak choi, *Pythium* sp. and *Fusarium* sp. incidence decreased by 83.7% and 78.6%, respectively; in Tatsoi, reductions were 82.2% and 87.0%; and in Mizuna, 94.4% and 88.6%, respectively. Although the algae treatment also yielded beneficial effects, its impact was consistently less significant than that of FertilTomix. Regarding seed germination and mean germination time, FertilTomix (FE0) produced the most favorable results. In Pak choi, seed germination increased by 20.6%, accompanied by a 20.5% reduction in average germination time (Figure 3). A similar trend was observed in Tatsoi, where germination improved by 19.7% and mean germination time decreased by 23.0%. In Mizuna, seed germination increased by 15.2%, while average germination time was reduced by 34.7%. These results indicate that FertilTomix not only enhances seedling vigor and growth but also accelerates early developmental stages across all tested *Brassicaceae* species.

Table 1 - Evaluation of the use of FertilTomix on the agronomic growth of Pak choi

Pak choi	PH (cm)	LN (n°)	LSA (cm^2)	VW (g)	RW (g)	RL (cm)
CTRL	8.24 ^{c}	6.84 ^{c}	5.34 ^{c}	15.24 ^{c}	8.34 ^{c}	2.77 ^{c}
BIOAL	11.13 ^{b}	8.22 ^{b}	8.56 ^{b}	17.33 ^{b}	9.99 ^{b}	3.88 ^{b}
FE0	13.66 ^{a}	10.12 ^{a}	11.13 ^{a}	19.66 ^{a}	11.32 ^{a}	4.55 ^{a}
ANOVA	***	***	***	***	***	***

One-way ANOVA; n.s. – non-significant; *,**,*** – significant at $P \leq 0.05$, 0.01 and 0.001, respectively; different letters for the same element indicate significant differences according to Tukey's (HSD) multiple-range test ($P = 0.05$). Parameters: PH = plant height (cm); LN = leaves number (n°); LSA= leaves surface area (cm^2); VW = vegetative weight (g); RW = roots weight (g); RL = roots length (cm); Treatments: CTRL=Control; BIOAL=Biofertiliser; FE0= FertilTomix.

Table 2 - Evaluation of the use of FertilTomix on microbial substrate colonisation, seed germination and pathogen protection of Pak choi seedbeds

Pak choi	STB (Log CFU/g soil)	Py attack (n°)	Fu attack (n°)	SG (n°)	AGT (days)
CTRL	2.22^{c}	3.44^{a}	4.11^{a}	15.44^{c}	9.22^{c}
BIOAL	3.44^{b}	1.88^{b}	1.04^{b}	16.88^{b}	8.11^{b}
FE0	4.66^{a}	0.56^{c}	0.88^{c}	19.44^{a}	7.33^{a}
ANOVA	***	**	**	***	***

One-way ANOVA; n.s. – non-significant; *,**,*** – significant at P ≤ 0.05, 0.01 and 0.001, respectively; different letters for the same element indicate significant differences according to Tukey's (HSD) multiple-range test (P = 0.05). Legend Thesis: (CTRL) control + COMPO BIO; (BIOAL) COMPO BIO + *Ecklonia maxima* ;(FE0) FertilTomix with lye extraction. Parameters: STB = Substrate total bacteria (Log CFU/g soil); PY = Plants dead number for *Pythium* sp. (n°) ; FU= Plants dead number for *Fusarium* sp. (n°); SG = Seeds germination (n°); AGT = Average germination time (days).

Table 3 - Evaluation of the use of FertilTomix on the agronomic growth of Tatsoi

Tatsoi	PH (cm)	LN (n°)	LSA (cm^{2})	VW (g)	RW (g)	RL (cm)
CTRL	7.23^{c}	5.84^{c}	4.32^{c}	13.44^{c}	7.31^{c}	2.61^{c}
BIOAL	8.44^{b}	8.42^{b}	5.66^{b}	14.86^{b}	8.45^{b}	4.92^{b}
FE0	10.88^{a}	9.22^{a}	7.42^{a}	16.22^{a}	10.32^{a}	5.89^{a}
ANOVA	***	***	***	***	***	***

One-way ANOVA; n.s. – non-significant; *,**,*** – significant at P ≤ 0.05, 0.01 and 0.001, respectively; different letters for the same element indicate significant differences according to Tukey's (HSD) multiple-range test (P = 0.05). Parameters: PH = plant height (cm); LN = leaves number (n°); LSA= leaves surface area (cm^{2}); VW = vegetative weight (g); RW = roots weight (g); RL = roots length (cm); Treatments: CTRL=Control; BIOAL=Biofertiliser; FE0= FertilTomix.

Table 4 - Evaluation of the use of FertilTomix on microbial substrate colonisation, seed germination and pathogen protection of Tatsoi seedbeds

Tatsoi	STB (Log CFU/g soil)	Py attack (n°)	Fu attack (n°)	SG (n°)	AGT (days)
CTRL	2.56^{c}	2.21^{a}	3.68^{c}	14.55^{c}	8.24^{c}
BIOAL	3.57^{b}	1.18^{b}	2.18^{b}	15.33^{b}	7.11^{b}
FE0	4.73^{a}	0.26^{a}	0.48^{a}	18.12^{a}	6.34^{a}
ANOVA	***	**	**	***	***

One-way ANOVA; n.s. – non-significant; *,**,*** – significant at P ≤ 0.05, 0.01 and 0.001, respectively; different letters for the same element indicate significant differences according to Tukey's (HSD) multiple-range test (P = 0.05). Legend Thesis: (CTRL) control + COMPO BIO; (BIOAL) COMPO BIO + Ecklonia maxima ;(FE0) FertilTomix with lye extraction. Parameters: STB = Substrate total bacteria (Log CFU/g soil); PY = Plants dead number for Pythium sp. (n°) ; FU= Plants dead number for Fusarium sp. (n°); SG = Seeds germination (n°); AGT = Average germination time (days).

Table 5 - Evaluation of the use of FertilTomix on the agronomic growth of Mizuna

Mizuna	PH (cm)	LN (n°)	LSA (cm^{2})	VW (g)	RW (g)	RL (cm)
CTRL	10.23^{c}	5.86^{d}	1.33^{d}	35.64^{d}	24.33^{d}	2.64^{d}
BIOAL	13.44^{a}	8.44^{a}	2.36^{b}	44.88^{a}	29.84^{a}	4.98^{a}
FE0	11.88^{b}	7.22^{b}	2.42^{b}	42.66^{b}	27.31^{b}	3.89^{b}
ANOVA	**	***	**	***	***	***

One-way ANOVA; n.s. – non-significant; *,**,*** – significant at P ≤ 0.05, 0.01 and 0.001, respectively; different letters for the same element indicate significant differences according to Tukey's (HSD) multiple-range test (P = 0.05). Parameters: PH = plant height (cm); LN = leaves number (n°); LSA= leaves surface area (cm^{2}); VW =

vegetative weight (g); RW = roots weight (g); RL = roots length (cm); Treatments: CTRL=Control; BIOAL=Biofertiliser; FE0= FertilTomix.

Table 6 - Evaluation of the use of FertilTomix on microbial substrate colonisation, seed germination and pathogen protection of Mizuna seedbeds

Mizuna	STB (Log CFU/g soil)	Py attack (n°)	Fu attack (n°)	SG (n°)	AGT (days)
CTRL	2.33 ^{c}	1.96 ^{a}	2.46 ^{a}	16.33 ^{c}	11.24 ^{c}
BIOAL	3.26 ^{b}	0.88 ^{b}	1.04 ^{b}	17.94 ^{b}	9.66 ^{b}
FE0	4.68 ^{a}	0.11 ^{c}	0.28 ^{c}	19.26 ^{a}	7.34 ^{a}
ANOVA	***	**	**	***	***

One-way ANOVA; n.s. – non-significant; *,**,*** – significant at $P \leq 0.05$, 0.01 and 0.001, respectively; different letters for the same element indicate significant differences according to Tukey's (HSD) multiple-range test ($P = 0.05$). Legend Thesis: (CTRL) control + COMPO BIO; (BIOAL) COMPO BIO + Ecklonia maxima ;(FE0) FertilTomix with lye extraction. Parameters: STB = Substrate total bacteria (Log CFU/g soil); PY = Plants dead number for Pythium sp. (n°) ; FU= Plants dead number for Fusarium sp. (n°); SG = Seeds germination (n°); AGT = Average germination time (days).

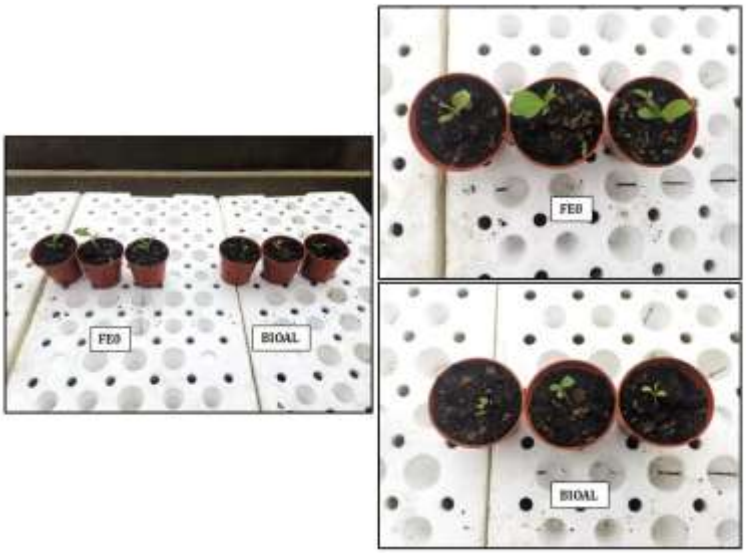

Figure 1 - Comparison of the thesis with biostimulant (BIOAL) and with Fertiltomix (FE0) in the germination and vegetative growth of Tatsoi plants

Figure 2 - Comparison of the thesis with biostimulant (BIOAL) and with Fertiltomix (FE0) in the germination and vegetative growth of Mizuna plants

Figure 3 - Comparison of the thesis with biostimulant (BIOAL) and with FertilTomix (FE0) in Pakchoi germination

DISCUSSION

Surface and underground water, though renewable, are finite resources estimated to total approximately 1.4 billion cubic kilometers globally [21]. Of this, about 97% is seawater, nearly 2% is locked in ice, leaving less than 1% as accessible freshwater [22]. The agricultural sector is the predominant consumer, accounting for roughly 70% of global freshwater use, with usage reaching up to 90% in the Middle East and North Africa (MENA) region [23]. This pressure is expected to intensify due to population growth and increasing food demands, further straining natural water resources [24]. Alarmingly, freshwater is being depleted at a rate exceeding its natural replenishment, making urgent conservation measures necessary [25]. One promising strategy involves the use of alternative water sources to reduce reliance on already overexploited freshwater systems. In this context, seawater whether desalinated or blended with freshwater has emerged as a viable alternative for agricultural use [26]. The use of sea minerals as an alternative to synthetic fertilizers has also demonstrated positive effects on plant growth in species such as aubergine, cucumber, *Impatiens glandulifera*, *Helianthus annuus*, and tomato, as confirmed by the findings of this study [18-20]. The observed improvements in plant growth and enhanced root development appear linked to a significant increase in microbial biomass within the substrate following application of the stimulating treatment. Dry organic fertilizers, such as fishery waste and guano, can serve as nutrient sources; however, their availability is limited, and their nitrogen (N) mineralization process typically requires several weeks [27]. In organic systems, plant-available nitrogen is primarily supplied through the incorporation of cover crops and manure-based composts [28]. Additionally, marine-derived minerals extracted from sea salt have been utilized in both soil and foliar applications to enhance nutrient availability and plant growth [29-31]. A resource such as FertilTomix, derived from seawater, represents a readily available and sustainable input, especially valuable in regions like many African countries where both water and conventional fertilizers are limited. The application of this product has also proven effective in other contexts, notably in enhancing the growth of *Lemna minor*, *Cichorium intybus*, and *Carthamus tinctorius* [18,32]. In these cases, treatment not only reduced disease incidence but also significantly improved seed germination rates and notably decreased average germination time. At present, there is no widely adopted, cost-effective method for extracting minerals from seawater for use in plant fertilization or for recycling process water in irrigation [33,34]. Generally, biostimulants derived from seawater have been shown to accelerate plant growth, enhance root development, and increase vegetative biomass including leaves, stems, and fruits while also contributing to a shortened growth cycle [35,36]. Moreover, studies report larger and more abundant fruits, increased flowering, improved resistance to fungal diseases and pests, and greater tolerance to environmental stresses such as drought, salinity, and temperature fluctuations [12]. Some research further highlights enhancements in the taste and nutritional value of agricultural products following treatment with seawater-derived biostimulants [23]. However, critical challenges remain. There is limited scientific literature specifically addressing the effects of seawater-derived biostimulants on plant development [39]. Additionally, chemical analyses often lack the precision required to fully characterize complex marine-derived mineral solutions [32]. The variability of biostimulant efficacy frequently influenced by soil type and crop species also complicates their application [19]. These issues underscore the need for more detailed and standardized research to better understand and optimize seawater-based biostimulants in agriculture [8]. In this context, FertilTomix and the technological innovations developed by Waterdust represent promising advances. These approaches merit further evaluation to assess their broader potential for sustainable agriculture and water management. Planned future research will focus on: (i) evaluating FertilTomix's effectiveness under biotic and abiotic stresses, including water scarcity, salinity, and temperature extremes; (ii) conducting comprehensive analyses of FertilTomix's mineral and organic composition, as well as the associated wash water, which remains only partially characterized due to its complexity and the high cost and technical demands of advanced analytical methods; (iii) assessing FertilTomix's impact on the mineral and nutraceutical profiles of fruits and vegetables; (iv) expanding experimentation across a wider range of plant species and application protocols to validate and generalize observed effects; and (v) investigating the combined use of wash water with other fertilizers, biostimulants, and growing media. Despite the need for further research, current results provide a solid foundation for future studies and potential applications of this technology in both open-field and soilless cultivation systems.

CONCLUSIONS

Extracts derived from an innovative mineral extraction process using seawater demonstrated significant positive effects on plant growth in experimental trials. Additionally, the recycled seawater produced through this process shows promising potential for reuse in irrigation, particularly in regions facing freshwater scarcity. The findings suggest that the mineral and organic components of seawater positively influence soil microfauna, which in turn supports plant growth and enhances plant defense mechanisms via both direct and indirect pathways. This study is especially relevant for agricultural practices in arid and semi-arid environments or areas with limited access to potable water. It also offers a sustainable alternative for stakeholders aiming to reduce dependence on synthetic fertilizers by harnessing seawater as a virtually inexhaustible resource. Current ongoing trials are investigating whether FertilTomix can further improve the quality of fruits and vegetables when applied in both soil-based and soilless cultivation systems.

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