GSC Advanced Research and Reviews

eISSN: 2582-4597 CODEN (USA): GARRC2

Cross Ref DOI: 10.30574/gscarr

Journal homepage: https://gsconlinepress.com/journals/gscarr/

(Research Article)

Use of marine minerals obtained through an innovative process with added silver for the cultivation and protection of *Solanum lycopersicum*

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GSC Advanced Research and Reviews, 2023, 16(03), 086–093

Publication history: Received on 29 July 2023; revised on 05 September 2023; accepted on 08 September 2023

Article DOI: https://doi.org/10.30574/gscarr.2023.16.3.0357

Abstract

Research objective: The aim of this research was to evaluate the stimulating potential of (FertilTomix: a product based on minerals and organic molecules from the sea) obtained from an innovative extraction process and its ability to increase plant defence capabilities following the addition of silver to seeded *Solanum lycopersicum* plants.

Materials and Methods: The experiments, which started in January 2023, were conducted in the CREA-OF greenhouses in Pescia (Pt), Tuscany, Italy (43°54′N 10°41′E) on *Solanum lycopersicum* cv "Siccagno". The plants were placed in ø 24 cm pots; 30 plants per thesis, divided into 3 replicas of 10 plants each. The experimentation was divided into two parallel trials, one concerning the growth and biostimulation of tomato plants. The second experiment, instead, concerned the use of sprayed FertilTomix in the protection from pathogenic fungi (*Phytophthora infestans, Leivellula taurica*). On August 28, 2023, plant height (measured at 70 days after transplanting), plant nodes (measured at 70 days after transplanting), leaf area index, total dry biomass, fruit fresh weight and total fruit number have been evaluated. In addition, plants affected by diseases were counted.

Results and Discussion: The experiment showed that the use of FertilTomix, irrespective of the extraction process, was able to significantly increase total plant growth, berry yield and weight, and reduce the mortality of *Solanum lycopersicum* plants. As found in the experiment in the treated theses, a significant increase in plant height and number of nodes per plant was noted, as well as a significant increase in total LAI. Differences were also noted between FertilTomix as such and FertilTomix enriched with silver; the former product worked better in the vegetative and root stimulation of the plants, while the product enriched with silver defended the plants better against attacks by *Phytipthora infestans* and *Leivellula taurica*. The use of this product is very interesting especially for those places where there is no water for irrigation and where fertilisers are scarce. The use of this product could obviate both problems. There are as yet no cost-effective technologies and processes in the world that can extract useful minerals from seawater for plant fertilisation and recycle the process water that can be used for irrigation.

Conclusions: The test demonstrated a significant effect on plant growth after the application of certain extracts obtained from an innovative process of extracting minerals from seawater. In addition, it emerged that the product could also be used for plant protection when enriched with silver. This product would be very useful especially in countries where water resources and fertilisers are scarce, with the possibility of producing them on site through innovative facilities.

Keywords: Seawater minerals; Microorganisms; Silver; Biofertilisers; Ormus

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1. Introduction

Fertilisation management is a particularly complex issue since, in addition to the dynamics and great variety of crops, soil and substrates come into play. These are extremely heterogeneous and complex systems, in which fertilisers undergo processes that may limit their availability or, on the contrary, favour synergic effects with the nutrients already present in the system [1]. The availability of nutrients is in fact regulated by the chemical, physical, mineralogical and biological properties that characterise the different types of soil and substrates. Recent years have seen a phenomenon of rising temperatures, increasingly hot and dry seasons with little rainfall, leading to an increase in desertification [2]. One of the most difficult challenges that farmers will face in the coming years will be water management, and companies producing technical means, particularly fertilisers, will play a key role in proposing highly efficient solutions. In soils today, one of the biggest issues is water capacity or better known as water retention, which in light soils tends to be low, favouring the leaching of nutrients and thus the loss of nutrients for the plant [3]. Water and nutrients are elements that need to be increasingly linked in order to go hand in hand to achieve the best performance from the current crop [4]. The fertilisers of the future will have to begin to have a twofold attitude: i) that of nourishing the plant; ii) that of having a greater impact on water retention. Only in this way will it be possible to have high and quality productions that can satisfy the continuous demand for food [5,6]. The fertilisers that will increase soil water retention will be those fertilisers that will allow cultivation even in arid areas as they will have to create a microclimate around the roots so that the plants absorb water and nutrients. Increasing soil water retention can better manage water over time, especially in years with low rainfall [7,8]. Furthermore, all nutrient leaching phenomena will be reduced as these are concentrated around the root system and fully available to the crop. The use of fertilisers that are able to act on soil water retention will bring a series of advantages: i) creation of an optimal zone for the root system; ii) greater availability of water in the initial phases; iii) less losses due to evaporation and percolation of water; iv) increase in water retention in sandy soils; v) maximisation of crop yields with less water use; vi) greater permeability of clay/heavy soils when dry; vii) protection of the environment and in particular of groundwater [9,10,11].

1.1. Hypotheses on the effects of climate change

The various IPCC reports that have followed one another over time, and in particular the fourth and most recent one, have reported significant increases in global temperature for the period 1906-2005 and, above all, have shown that these changes are closely linked to increases in the concentration of greenhouse gases [12]. Various modelling applications on future climate trends agree on a reduction in summer precipitation ranging from 10 to 40 per cent, while winter precipitation is expected to increase in Alpine areas and decrease in southern regions [13]. A considerable increase in the interannual variability of rainfall and temperature is also predicted, with several summer seasons with no or very little rainfall, particularly in the South, which together with the increase in temperatures clearly indicates an increase in hot, dry summers [14]. Climate change will negatively affect crop productivity, particularly for spring and summer crops, for which increased water use for irrigation is generally expected. In general, studies have shown that climatic warming causes a contraction of the crop cycle, which leads to a reduction in the days available to the plant for biomass accumulation and results in a resulting decrease in the production level [15]. This effect is particularly evident in species with a determinate cycle, i.e. plants whose growth mode is based on the crossing of temperature thresholds that allow the transition from one phenological phase to the next [16]. For these species, an increase in temperature thus leads to an acceleration of the phenological cycle, with a contraction of the individual phases, to the detriment precisely of photosynthesis and thus of final production [17,18]. For these crops, new varieties will be needed if the longer seasons are to be exploited where possible. Genetic improvement, for obvious organisational and economic reasons, has oriented the new cultivars of what used to be non-determined species towards the first category, so that nowadays most of the cultivated species fall into the category of determinate-cycle plants, of the two, the grouping potentially most sensitive to climate change. For other plants, those with a non-determined cycle, whose cycle does not depend on exceeding any thermal threshold, the increase in temperature allows a greater accumulation of biomass, which will therefore have positive effects on production [19]. The overall picture is complex, because the growing season for spring-summer crops is expected to become longer and offer earlier sowing dates, but precisely because of the possible longer season, and in the presence of crops with a longer cycle than at present, higher water consumption is expected. It should also be noted that breeders have already successfully modified the cycle length and individual phenological phases, with particular reference to flowering and ripening dates to adapt crops to different environmental conditions [20].

1.2. Experiments using minerals from the sea in agriculture

Hou Tian Zhen, head of the Department of Tree Physiology and Biochemistry at the Xinjiang Academy of Forestry Sciences in China, led a team of researchers who evaluated the use of sea minerals in three experiments [21]. First tested in 1989 at the A-ning Experiment Station, tomatoes treated with these minerals had nearly twice as many flowers per plant and 27% more fruit [22,23]. At the A-ning Experiment Station, a 1990 field experiment demonstrated that treated green beans increased yield by 81%, sweet beets by 67%, and soybeans by 29%. The A-ning Experiment Station conducted a large-scale experiment in 1991, where watermelon plots were 300 meters apart in a field [24]. The treated melons yielded 65% more than the control plots. The sea mineral extract was used by Harold Aungst, an alfalfa grower in Pennsylvania who achieved a 29% increase in protein with a significant increase in yield per acre and five cuts rather than three. In the first year, it produced 7.6 tons per acre, almost twice the average of 3.4 tons per acre in the state. In the second year, the production reached 10 tons per acre, three times the state average [25]. Milk production also increased by 30 percent due to treated hay. In Wisconsin, Wilson Mills has increased the fruit production on apple trees by using a marine extract since 1989. As a result of the studies, zinc absorption was 1200% increased, iron absorption was 400% increased, chromium absorption was 326% increased, and potassium absorption was 120% higher. The apples were giant and ripened two to three weeks earlier [26]. An Okinawa banana plantation experienced a 100% increase in yield and a 35% reduction in ripening time for the first eight years. The yield doubled every year, the fruit set tripled, and the sugar content increased significantly. The A-ning Experiment Station in 1990 found that treated green beans resulted in 81% more yield and treated sugar beets resulted in 67% more yield. While other neighboring farms experienced 80% empty pods due to environmental stress, treatment with marine mineral extracts increased coffee production by 50–100%, with better flavor, bigger beans, and 80% fancy and gourmet quality. There were fewer harvests needed because the young plants produced 1/3 earlier than expected [27,28]. In a trial carried out by Dr. Prisa in 2022 on Cichorium intybus and Carthamus tinctorius, it was shown that the use of Ormus (FertilTomix) increased seed germination, vegetative and root development and had significantly reduced plant mortality. Furthermore, a significant increase in beneficial microorganisms was observed in the theses treated with the product [29].

Research Objectives

The aim of this research was to evaluate the stimulating potential of (FertilTomix: a product based on minerals and organic molecules from the sea) obtained from an innovative extraction process and its ability to increase plant defence capabilities following the addition of silver to seeded *Solanum lycopersicum* plants.

Figure 1 Detail of treatment with FertilTomix on *Solanum lycopersicum*. Use of a pipette to provide 3 ml of product every week

2. Material and methods

The experiments, which started in January 2023, were conducted in the CREA-OF greenhouses in Pescia (Pt), Tuscany, Italy (43°54′N 10°41′E) on *Solanum lycopersicum cv "Siccagno* (Figure 1A,1B). The plants were placed in ø 24 cm pots; 30 plants per thesis, divided into 3 replicas of 10 plants each. The experimentation was divided into two parallel trials, one concerning the growth and biostimulation of tomato plants. The second experiment, instead, concerned the use of sprayed FertilTomix in the protection from pathogenic fungi (*Phytophthora infestans*, *Leivellula taurica*).

In the first test concerning the stimulant evaluation of the product FertilTomix on *Lycopersicon esculentum*, the experimental groups were:

- Control group (CTRL) (peat 80%+ pumice 20%), irrigated with water three times a week (5 ml per plant) and substrate fertilised once a week with Compo BIO (organic plant fertiliser; organic nitrogenous fertiliser; fluid borage), 5 ml of product in 1 L of water and then 3 ml per plant of this dilution;
- Biofertiliser (BIOAL) group (peat 80%+ pumice 20%), irrigated with water three times a week (5 ml per plant) and substrate fertilised once a week with Compo BIO (organic plant fertiliser; organic nitrogenous fertiliser fluid borer), 5 ml in 1 L water and then 3 ml per plant of this dilution; in addition, an algae-based biofertiliser

(Kelpak biostimulant, *Ecklonia maxima*, Kelp products International) was used, dilution 1 1000, 3 ml of this dilution once a week;

- The group with fertiltomix with soda extraction procedure (FE0) (peat 80% + pumice 20%) and silver irrigated with water three times a week (5 ml per plant) and substrate fertilised once a week with Compo BIO (organic plant fertiliser; organic nitrogenous fertiliser; fluid borer), 5 ml of product in 1 L of water and then 3 ml per plant of this dilution; watering with fertiltomix (3 ml per plant) once a week;
- The group with pure fertiltomix (FE1) (peat 80% + pumice 20%) irrigated with water three times a week (5 ml per plant) and the substrate fertilised once a week with Compo BIO (organic plant fertiliser; organic nitrogenous fertiliser; fluid borage), 5 ml of product in 1 L of water and then 3 ml per plant of this dilution; wetting with fertiltomix (3 ml per plant) once a week;
- The group with 50% fertiltomix and 50% silver (FE2) (peat 80% + pumice 20%) irrigated with water three times a week (5 ml per plant) and substrate fertilised once a week with Compo BIO (organic plant fertiliser; organic nitrogenous fertiliser; fluid borage), 5 ml of product in 1 L of water and then 3 ml per plant of this dilution; wetting with fertiltomix (3 ml per plant) once a week.
- The group with 25% fertiltomix and 75% water (FE3) (peat 80% + pumice 20%) irrigated with water three times a week (5 ml per plant) and substrate fertilised once a week with Compo BIO (organic plant fertiliser; organic nitrogenous fertiliser; fluid borage), 5 ml of product in 1 L of water and then 3 ml per plant of this dilution; wetting with fertiltomix (3 ml per plant) once a week.

In the second plant protection test, the same experimental theses were used, but the product was also sprayed on the leaves.

On August 28, 2023, plant height (measured at 70 days after transplanting), plant nodes (measured at 70 days after transplanting), leaf area index, total dry biomass, fruit fresh weight and total fruit number have been evaluated. In addition, plants affected by diseases were counted.

2.1. Statistics

The experiment was carried out in a randomized complete block design. Collected data were analyzed by one-way ANOVA, using GLM univariate procedure, to assess significant ($P \le 0.05$, 0.01 and 0.001) differences among treatments. Mean values were then separated by LSD multiple-range tests ($P = 0.05$). Statistics and graphics were supported by the programs Costat (version 6.451) and Excel (Office 2010).

3. Results

Table 1 Evaluation of FertilTomix on agronomic characters on plants of *Solanum lycopersicum*

Groups	Plant height70 (cm/plant)	Plant nodes70 (n°/plant)	LAI tot (m^2 m^{-2})	DW Tot (g m^{-2})	FW (Kg m^{-2})	FN (n°)
CTRL	131.37 e	23.69 e	2.22 e	421.76 f	8.05 c	35.28 d
BIOAL	136.98 d	25.77 d	2.53 d	432.89 e	8.83 b	38.61 c
FE0	138.51 c	26.54 c	2.78 c	437.23 c	8.95 b	40.64 b
FE1	143.98 a	29.26 a	3,18 a	440.41 a	9.28 a	44.81 a
FE2	137.51 d	26.37 c	2.80 c	435.50 d	8.89 b	38.62 c
FE3	140.67 b	27.69 b	2.95 b	438.68 b	8.95 b	39.83 bc
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: (CTRL) control + COMPO BIO; (BIOAL) COMPO BIO + Ecklonia maxima ;(FE0) FertilTomix with soda extraction + silver; (FE1) FertilTomix pure; (FE2) 50% FertilTomix + 50% silver; (FE3) 25% FertilTomix + 75% water. Plant height and number of nodes measured at 70 days after transplanting; (LAI Tot) total plant defoliations; (DW Tot) plant dry weight; (FW) fruits fresh weight; (FN) fruits number

The experiment showed that the use of FertilTomix, irrespective of the extraction process, was able to significantly increase total plant growth (Figures 2-3), berry yield and weight (Figure 4), and reduce the mortality of *Solanum lycopersicum* plants (Tables 1). As found in the experiment in the treated theses, a significant increase in plant height and number of nodes per plant was noted, as well as a significant increase in total LAI. Differences were also noted between FertilTomix as such and FertilTomix enriched with silver; the former product worked better in the vegetative and root stimulation of the plants, while the product enriched with silver defended the plants better against attacks by *Phytopthora infestans* and *Leivellula taurica* (Table 2).

Also in this experiment, for optimal application of the product FertilTomix, it was also observed that when the substrate is slightly moist, the product is absorbed more easily than when the substrate is dry, when the product remains on the surface and colours the soil white (Figure 1).

There was also a significant increase in soil microbiology (data not shown) in the pure FertilTomix theses, compared to the algae and control theses. The microbiology in pure FertilTomix was also superior to that enriched with silver.

Table 2 Number of *Solanum lycopersicum* plants affected by *Phytophthora infestans* and *Leivellula taurica* after treatment with FertilTomix

Groups	***Phytophthora infestans* (n°)**	***Leivellula taurica* (n°)**
CTRL	6.1 a	6.4 a
BIOAL	4.4 a	4.2 b
FE0	1.2 d	1.4 d
FE1	3.2 c	3.2 c
FE2	1.2 d	1 d
FE3	3.6 c	3.6 bc
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: (CTRL) control + COMPO BIO; (BIOAL) COMPO BIO + Ecklonia maxima ;(FE0) FertilTomix with soda extraction + silver; (FE1) FertilTomix pure; (FE2) 50% FertilTomix + 50% silver; (FE3) 25% FertilTomix + 75% water

Figure 2 Comparison of the control thesis (CTRL), the thesis with algal biofertiliser (BIOAL) and the theses treated with FertilTomix (FE0; FE1; FE2;FE3) on vegetative growth of *Solanum lycopersicum*

Figure 3 Effect of the FertilTomix treatment (FE1) on root growth of *Solanum lycopersicum* compared to the fertilising algae treatment (BIOAL)

Figure 4 Effect of the FertilTomix treatment (FE1) on fruits size of *Solanum lycopersicum* compared to the fertilising algae treatment (BIOAL) and control (CTRL)

4. Discussion

The use of marine extracts in these experiments significantly influenced plant development and fruit production and size in *Solanum lycopersicum* cv Siccagno. Furthermore, it resulted in a significant increase in microfauna in the substrates treated without silver, an effect probably influenced by all the mineral and organic substances present in the seawater. Also of interest was the increase in leaf LAI and root development, an effect probably influenced by the microbial activity in the soil, which not only increased root development, but also led to increased nutrient uptake, as found in previous trials by the same author [30]. The presence of molecules such as silver significantly reduced the mortality of the treated seedlings, probably acting on the intrinsic stimulation of the plant's defences and not directly on biotic stresses (in the treated theses, in fact, the soil microbial biomass increased) [31,32,33]. The use of this product is very interesting especially for those places where there is no water for irrigation and where fertilisers are scarce. The use of this product could obviate both problems. There are as yet no cost-effective technologies and processes in the world that can extract useful minerals from seawater for plant fertilisation and recycle the process water that can be used for irrigation [34,35,36,37]. The technology of the Aquatomix company and the FertilTomix product itself can be considered innovations in this sense, which deserve great consideration and further study.

The results obtained, however, already lay the foundations for further studies and field and surface applications of this technology.

5. Conclusion

The test demonstrated a significant effect on plant growth after the application of certain extracts obtained from an innovative process of extracting minerals from seawater. In addition, it emerged that the product could also be used for plant protection when enriched with silver. This product would be very useful especially in countries where water resources and fertilisers are scarce, with the possibility of producing them on site through innovative facilities.In general, the experimentation showed how the mineral and organic substances in seawater can have a significantly positive influence on soil microfauna, with direct and indirect effects on plant growth and defence. The results obtained are particularly interesting for those who have to cultivate in arid environments or those without drinking water, as well as for those who want to start reducing the use of industrial fertilisers and use an inexhaustible source such as seawater. Further experiments will be carried out on the use of FertilTomix in the presence of water stress.

Compliance with ethical standards

Acknowledgments

The research is part of the FERTILPOM project: Use of a biostimulant based on minerals extracted from seawater for the cultivation and defence of tomato plants. We thank the company AQUATOMIX LLC of San Diego, California, and in particular, Mr Nicola Ghelardi, for funding the project.

Disclosure of conflict of interest

The author declares no conflict of interest.

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