

DEMOCRATIC AND POPULAR ALGERIAN REPUBLIC
MINISTRY OF HIGHER EDUCATION AND RESEARCH SCIENTIFIC

UNIVERSITY OF BLIDA 1



FACULTY OF NATURAL SCIENCE AND LIFE

DEPARTEMENT OF BIOTECHNOLOGY AND AGRO-ECOLOGY



Specialty : Phyto pharmacy and plant protection

Dissertation for the academic Master's degree in natural and life sciences

Theme :

**Stimulatory effects of biological fertilizers on the
productivity of greenhouse vegetable crops**

Presented by :

REFSI Nada
KHELIFA Djihane

Defended Before the Jury :

Dr ZOUAOUI A.	MCA	U. BLIDA1	President
Dr BRAHIMI L.	MCA	U. BLIDA1	Promoter
Dr ABBED M.	MCA	U. BLIDA1	Examiner

2024-2025

DEMOCRATIC AND POPULAR ALGERIAN REPUBLIC
MINISTRY OF HIGHER EDUCATION AND RESEARCH SCIENTIFIC



UNIVERSITY OF BLIDA 1

FACULTY OF NATURAL SCIENCE AND LIFE

DEPARTEMENT OF BIOTECHNOLOGY AND AGRO-ECOLOGY



Specialty : Phyto pharmacy and plant protection

Dissertation for the academic Master's degree in natural and life sciences

Theme :

Stimulatory effects of biological fertilizers on the productivity of greenhouse vegetable crops

Presented by :

REFSI Nada

KHELIFA Djihane

Defended Before the Jury :

Dr ZOUAOUI A.	MCA	U. BLIDA1	President
Dr BRAHIMI L.	MCA	U. BLIDA1	Promoter
Dr ABBED M.	MCA	U. BLIDA1	Examiner

2024-2025

Acknowledgements

*First of all, I'd like to thank **Allah** for guiding me, supporting me and granting me patience and strength throughout this journey. Without His will and blessing, nothing would have been possible.*

*I would also like to express my gratitude and love to **my parents**, who have always believed in me, even in times of doubt. Their affection, silent sacrifice and unconditional support have been the source of my strength and perseverance.*

*My deepest thanks go to our promoter, **Mrs. Brahimi Latifa**, for her trust, her benevolence and her high-quality guidance. Her scientific rigor and wise advice have greatly contributed to the success of this work. Thank you for your patience, availability and support throughout this research.*

*I would also like to thank the members of the jury, **Mr. Zouaoui Ahmed** and **Mr. Abbad Mohammed**, for agreeing to assess this work and for the honor they have bestowed on me by taking part in this defense.*

*I would also like to thank **all the teachers** who have contributed specially **Mrs. Baba Aissa** , each in their own way, to my training throughout these years.*

*Finally, my heartfelt thanks go to **my family** and **friends**, near and far, for their support, presence and encouragement.*

Thank you all !

Dédicace

A moi-même Nada

À ma mère **Kaddour Nissa**, mon ange silencieux, dont les sacrifices invisibles et l'amour inconditionnel ont été ma force chaque jour.

À mon père **Abderezzak**, pilier discret, pour son soutien, ses sacrifices et la dignité.

À mon frère **Rahim**, qui a été pour moi une figure paternelle rassurante et forte, toujours là sans jamais faillir.

À ma sœur **Manel (Houria)**, que je porte dans mon cœur avec l'espoir sincère qu'elle connaîtra un avenir académique et professionnel à la hauteur de sa lumière.

À **TOI**, mon soutien, ma source d'énergie et de paix, qui a su être là dans les silences comme dans les tempêtes, Merci pour tout.

On dit que tout le monde profite de son nom, vous êtes aussi gentil que votre nom, merci pour tout, vous n'étiez pas seulement un professeur, vous étiez comme une grande sœur, merci d'avoir écouté, merci d'être venu, merci pour tout Madame **Brahimi Latifa**.

À Madame **Baba Aïssa Karima**, qui fut pour moi une seconde mère, une âme généreuse que je chérirai toujours avec reconnaissance et tendresse.

À **mes grands-parents**, merci pour votre tendresse et votre présence rassurante dans chaque étape de ma vie.

À **mes tantes** pour votre soutien constant, vos conseils et vos gestes de réconfort, tout particulièrement à ma tante **Ibtissem**, qui fut à la fois une sœur et une confidente.

À mon seul oncle **Abdenour** qu'il vit loin de nous, près à nos cœurs

À **Djihane**, mon binôme de cœur, ma sœur, celle qui a tout accepté, tout partagé, tout compris.

À mes amies-sœurs, **Ikram, Faten, Hadjer** et **Rawane**, aussi mes cousines **Hayam, Zaineb, Meriem** et **Noue el houda** celles avec qui j'ai grandi, ri, pleuré, et que je porte avec moi, toujours.

Et à mes amis garçons qui ont été pour moi des frères inattendus mais si précieux **Moncef, Rayan, Sami** et **Sohaib**.

Merci à vous tous. Ce travail est le fruit de votre amour.

Nada

Je dédie ce travail

À ma grand-mère,

Ton amour inconditionnel, ta tendresse infinie et ta force silencieuse ont toujours été une source d'inspiration pour moi. Tu as cru en moi même quand moi je doutais, et c'est avec une immense gratitude que je te dédie ce travail. Que ce modeste aboutissement soit un hommage à tout ce que tu représentes dans ma vie.

À ma chère maman,

Ton amour inépuisable, tes sacrifices silencieux et ta présence rassurante ont été le socle de ma réussite. Sans ton soutien, ta patience et tes prières, ce rêve n'aurait jamais vu le jour. Je te dédie ce travail avec tout mon amour, mon respect et une infinie gratitude

À ma chère tante Zineb,

Ta bienveillance, ton soutien constant et ton amour sincère ont été pour moi une lumière précieuse tout au long de ce parcours. Tu as su me réconforter, m'encourager et croire en moi quand j'en avais le plus besoin. Je te dédie ce travail avec tout mon amour et ma reconnaissance profonde.

À ma promotrice Latifa,

Votre bienveillance, votre disponibilité et votre accompagnement tout au long de ce parcours ont laissé une empreinte précieuse dans mon cœur et dans mon apprentissage. Merci pour votre écoute, vos conseils éclairés et votre encouragement constant. Ce travail vous est dédié avec tout mon respect et ma reconnaissance sincère

À ma binôme et amie Nada,

À toi qui as commencé ce voyage avec moi et l'as terminé à mes côtés. Merci pour ta présence, ton soutien, ta patience et tous ces moments partagés entre rires, stress et persévérance. Tu as été bien plus qu'un binôme : une véritable amie. Ce travail, je le partage avec toi de tout cœur.

Sans oublier mes frères Mohammed et Abd Elrahman et Anas et mes seours Khadidja et Maria et Enes et Anas

A Mes amis Hiba et Faten et Hadjer pour leur présence de tous les instants, leurs encouragements qu'ils m'ont apportés et pour les beaux souvenirs.

A tous ceux que j'aime.

Djihane

Table of content

Acknowledgements

Dedication

Abstract (English)

(French Abstract) résumé

ملخص (Arabic Abstract)

General Introduction

Chapter I - Literature Review.....3

1.Introduction.....	3
2.Global Importance of Tomatoes.....	3
3.Tomato Cultivation in Algeria.....	4
4.Biological and Agronomic Characteristics of Tomato (<i>Solanum lycopersicum</i> L.)....	5
5.Constraints Due to Improper Mineral Fertilization in Tomato Cultivation.....	9
6.Organic Fertilization as a Substitute for Inorganic Inputs in Tomato Cultivation.....	10
7.Organic Fertilization providing from Aquatic plants as a Sustainable Alternative to Mineral Fertilizers in Tomato Production.....	12
8.Aquatic biofertilizer.....	13
8.1. The bioactive components of marine species.....	14
a. Polysaccharides.....	14
b. Polyphenols.....	16
c. Pigments.....	17
d. Sterols.....	18
e. Terpene.....	19
f. Others.....	20

Chapter II - Materials and Methods.....22

1. Objectif.....	22
------------------	----

2. Description of the Experimental Site.....	22
3. Description of the Experimental Setup.....	23
4. Monitoring of the crop development under greenhouse conditions.....	23
4.1. Transplantation Method.....	23
4.2. Block Design and Plot Arrangement.....	24
5. Treatment preparation.....	25
5.1. Biomass reception and preparation.....	25
5.2. Preparation of the aqueous extract (crude).....	26
5.4. Formulation of the crude extract.....	27
6. Sample collection.....	29
6.1. Estimation of Morphological Parameters.....	30
6.2. Evaluation of Physiological Parameters.....	30
7. Harvest.....	31
8. Phytosanitary Status.....	31
9. Statistical Analysis.....	31

Chapter III – Results.....32

1. Effects of bioproducts on growth parameters.....	32
1.1. Growth parameter trends under the effect of bioproducts.....	32
1.2. Trend in growth parameters under the effect of bioproducts.....	34
1.3. Evaluation of variable representation on factorial space ($\cos^2$ on PC1 and PC2).....	37
2. Overall contribution of biofertilizers to tomato growth parameters.....	41
3. Comparative study of growth parameters under the effect of bioproducts.....	45
3.1 Comparative study of time effects on flowering and vegetative biomass.....	45
3.2. Comparative study of the effects of time on production parameters.....	48
3.3. Comparative study of the effects of time on physiological parameters.....	50
4. Comparative study of growth parameters under the effect of bioproducts.....	49
4.1 Comparative study of biofertilizer effects on flowering and vegetative biomass..	49
4.2. Comparative study of the effects of biofertilizers on production parameters.....	52

4.3. Comparative study of the effects of biofertilizers on physiological parameters53

Chapter IV – Discussion.....54

General Conclusion.....58

References.....59

List of figures :

Figure 1: The biggest tomato-producing countries in 2020.....	3
Figure 2: The main areas of tomato production in Algeria.....	4
Figure 3 : Demonstration of the five-growth stage of tomato, and the different levels of fruit ripeness.....	7
Figure 4 : Nutrients required in each tomato growth stage.....	8
Figure 5 : Contrasting influence of sole chemical fertilizer vs. integrated nutrient management on the nitrogen pools, mineralization, leaching and volatilization fluxes.....	9
Figure 6 : Classification of organic and inorganic fertilizer.....	11
Figure 7 : Aquatic fertilization effect on plants.....	12
Figure 8 : Possible effect of marine species.....	14
Figure 9 : Key mechanisms targeted by marines polysaccharides.....	15
Figure 10 : Classification of the main phenolic compounds in marines species....	16
Figure 11 : Basic chemical structures of the plant and marine pigments.....	17
Figure 12 : Role of phytosterols.....	18
Figure 13 : Role of terpenes in defense and stress response mechanisms.....	19
Figure 14 : Different bioactive components of marine species.....	21
Figure 15 : Location of the experimental greenhouse of the Plant Biotechnology laboratory.....	22
Figure 16 : Plant device.....	24
Figure 17 : Experimental layout plan.....	25
Figure 18 : Drying of aquatic biomass.....	26
Figure 19 : Crude extract.....	26
Figure 20 : Clarified aqueous extract process.....	27
Figure 21 : Bio fertilizer formulation.....	28
Figure 22 : pH adjustment.....	28
Figure 23 : The dilution of formulated solution.....	29
Figure 24 : Tomato with <i>Tuta absoluta</i> attack.....	31
Figure 25 : Principal Component Analysis (PCA) of growth parameters of tomatoes treated with different bioproducts over time.....	35
Figure 26 : Representation of growth and flowering variables on the principal axis (PC1) of the PCA, expressed by $\cos^2$ values.....	38

Figure 27 : Representation of aerial growth and dry matter variables on the principal axis (PC2) of the PCA, expressed by $\cos^2$ values.....	40
Figure 28 : Principal component analysis of physiological traits of tomato plants under the effect of biofertilizers.....	42
Figure 29 : Classification of biofertilizer treatments by CAH according to their physiological effects.....	44
Figure 30 : Estimating the effects of bioproducts on tomato length and weight....	45
Figure 31 : Estimation of the effects of bioproducts on leaf area and number of leaves.....	47
Figure 32 : Estimating the effects of bioproducts on tomato stealth.....	48
Figure 33 : Estimating the effects of bioproducts on tomato physiological.....	49
Figure 34 : Estimating the effects of bioproducts on tomato length and weight....	49
Figure 35 : Estimation of the effects of bioproducts on leaf area and number of leaves.....	51
Figure 36 : Estimating the effects of bioproducts on tomato stealth.....	52
Figure 37 : Estimating the effects of bioproducts on tomato physiological.....	
Figure 38 : Schematic representation of the effects of different bioproduct treatments on Tomato (<i>Solanum lycopersicum</i>) development.....	53
Figure 39 : A field illustration supports this observation: in the photo taken after the post-monitoring watering, we can clearly see the vegetative restart of plants under DF and M treatments.....	56

List of tables

Table 1 Analysis of relationships between vegetative and reproductive components

Table 2. Symbol-based summary of treatment effects on key plant traits in *Solanum lycopersicum*

List of abbreviations

Free-root : Fresh root weight

Dry-root : Dry root weight

Free air : Fresh aerial masses

Dry-air: Dry airmasses

Root-len :Root length

Stem-len :Stem length

Nbr leav : Number of leaves

Leav-S: Surface leaves

Total-le :Total surface

Chloroph : Chlorophylle

Nbr-bouq : Number of bouquets

Nbr-buds: Number of buds

Nbr-flow : Number of flowers

Nbr-frui : Number of fruits

Water-co : Water content

PCA / ACP : Principal Component Analysis / Analyse en Composantes Principales

ANOVA: Analysis of Variance

Stimulating effects of organic biofertilizers on *Solanum lycopersicum* L

Abstract :

Modern agriculture, although effective in increasing yields, relies heavily on the intensive use of chemical inputs, leading to progressive degradation of the environment and soil fertility. With this in mind, this study aims to assess the effect of biofertilizers derived from marine species on the growth of *Solanum lycopersicum* L. (tomato), a strategic crop in Algeria.

The experimental work was carried out under semi-controlled conditions in a greenhouse, and involved the application of various marine extracts ‘in crude or formulated form. The effects of these bioproducts were analyzed on several morphological, physiological and reproductive parameters.

Results showed M and AV_F and D ‘extracts significantly stimulated vegetative growth, increased dry and fresh weight of roots and aerial parts, as well as floral and fruit induction. In addition, these treatments improved the chlorophyll content and water retention of plant tissues, reflecting improved stress tolerance, and extracts AV and D and SYN stimulated vegetative growth of tomato plants.

The study confirms the effectiveness of marine biofertilizers as sustainable alternatives to chemical fertilizers, boosting productivity while respecting ecological balances. These results encourage the adoption of these bio stimulants as part of a more environmentally-friendly agriculture.

Keywords: Tomato, biofertilizers, marine species, sensitive agriculture, bio stimulants

Effets stimulants des biofertilisants organiques sur *Solanum lycopersicum* L

Résumé :

L'agriculture moderne, bien qu'efficace pour augmenter les rendements, repose largement sur l'utilisation intensive d'intrants chimiques, ce qui entraîne une dégradation progressive de l'environnement et de la fertilité des sols. Dans cette optique, cette étude vise à évaluer l'effet de biofertilisants dérivés d'espèces marines sur la croissance du *Solanum lycopersicum* L. (tomate), une culture stratégique en Algérie.

Le travail expérimental a été réalisé en conditions semi-contrôlées dans une serre, et a porté sur l'application de différents extraits marins « sous forme brute ou formulée ». Les effets de ces bioproduits ont été analysés sur plusieurs paramètres morphologiques, physiologiques et reproductifs.

Les résultats ont montré que les extraits M et AV_F et D ont significativement stimulé la croissance végétative, l'augmentation du poids sec et frais des racines et parties aériennes, ainsi que l'induction florale et fructifère. De plus, ces traitements ont permis d'améliorer la teneur en chlorophylle et la rétention d'eau des tissus végétaux, traduisant une meilleure tolérance au stress et les extraits AV et D et SYN ont stimulé la croissance végétative des plantes de tomates.

L'étude confirme ainsi l'efficacité des biofertilisants marins comme alternatives durables aux engrais chimiques, en renforçant la productivité tout en respectant les équilibres écologiques. Ces résultats encouragent l'adoption de ces biostimulants dans le cadre d'une agriculture plus respectueuse de l'environnement.

Mots-clés : Tomate, biofertilisants, espèces marines, agriculture durable, biostimulants

التأثيرات المحفزة للأسمدة الحيوية العضوية على *Solanum lycopersicum* L

ملخص:

ورغم فعالية الزراعة الحديثة في زيادة الغلة، فإنها تعتمد اعتمادا كبيرا على الاستخدام المكثف للمدخلات الكيميائية، مما يؤدي إلى تدهور تدريجي للبيئة وخصوبة التربة. مع وضع ذلك في الاعتبار ، تهدف هذه الدراسة إلى تقييم تأثير الأسمدة الحيوية المشتقة من الأنواع البحرية على نمو *Solanum lycopersicum* L. (الطماطم) ، محصول استراتيجي في الجزائر.

تم تنفيذ العمل التجريبي في ظل ظروف شبه خاضعة للرقابة في دفيئة ، وشمل تطبيق مستخلصات بحرية مختلفة في شكل خام أو تركيبي. تم تحليل تأثيرات هذه المنتجات الحيوية على العديد من المعلمات المورفولوجية والفسيولوجية والتناسلية.

أظهرت النتائج أن المستخلصات M و AV_F و D ، حفزت بشكل كبير النمو الخضري ، وزادت من الوزن الجاف والطازج للجذور والأجزاء الهوائية ، وكذلك تحريض الأزهار والفاكهة. بالإضافة إلى ذلك ، حسنت هذه العلاجات محتوى الكلوروفيل واحتباس الماء للأنسجة النباتية ، مما يعكس تحملا أفضل للإجهاد ، وحفزت مستخلصات AV و D و SYN النمو الخضري لنباتات الطماطم.

وهكذا تؤكد الدراسة فعالية الأسمدة الحيوية البحرية كبديل مستدامة للأسمدة الكيماوية ، من خلال زيادة الإنتاجية مع احترام التوازنات البيئية. تشجع هذه النتائج على اعتماد هذه المحفزات الحيوية في سياق زراعة أكثر صداقة للبيئة.

الكلمات المفتاحية: الطماطم ، الأسمدة الحيوية ، الأنواع البحرية ، الزراعة المستدامة ، المحفزات الحيوية

General introduction

In the last decades, intensive agriculture has been founded on the massive use of chemicals, including fertilizers and pesticides, to satisfy the growing food needs of a constantly rising world population (FAO, 2012; Savci, 2012). Although this has greatly improved agricultural productivity, it has also played a vast role in environmental degradation and human health issues. One of the most tactical vegetable crops, tomato (*Solanum lycopersicum* L.) is in a dignified position due to its economic and nutritional value. Tomatoes are a staple source of vitamins, minerals and health-promoting antioxidant molecules (Bergougoux, 2014). Tomato production worldwide now exceeds 180 million tons a year, with particular importance in regions of the Mediterranean such as Algeria, where it is one of the major irrigated crops and has an important contribution to food security and national economy (Benalia and *al.*, 2020).

Chemical fertilization, or the act of delivering crops with minerals in a form that can be readily absorbed, has been made possible as a means of short-term intensification of agriculture (Zörb et *al.*, 2014). Repeated and excessive use of chemical fertilizers, however, can lead to slow soil fertility depletion, nitrate, disruption of the ecological balance and biodiversity and pollution of groundwater (Liu and *al.*, 2021). These major drawbacks have led the scientific community to look for different, sustainable alternatives that have fewer adverse effects on ecosystems and human health. Biofertilization and application of natural bio stimulants thus appear to be innovative and promising solutions to meet the challenges of modern farmers (du Jardin, 2015; Rouphael and *al.*, 2020). These approaches are based on the use of organic matter, micro-organisms or plant extracts which, in addition to their nutritional value, contain bioactive substances capable of stimulating plant growth, improving their tolerance to abiotic stress and strengthening their natural defenses.

Mineral fertilization, however, is marked by the precision of application and ready availability of the inputs that allow fast assimilation by plants, although it sometimes does not ensure better soil structure as well as richer microbial diversity (Zörb and *al.*, 2014). In contrast, organic fertilization progressively improves soil quality by adding organic matter and promoting biological activity, releasing nutrients gradually and sustainably (Calvo and *al.*, 2014). Thus, several studies have demonstrated the

benefits resulting from the use of extracts from marine species containing phytohormones, polysaccharides and minerals with a beneficial effect on the growth, physiology and stress resistance of crop plants (Goñi and *al.*, 2018).

This is the background to the present experimental work, which aims to assess the effect of extracts from marine species applied as biofertilizers on the growth of tomato seedlings. The aim is to contribute to the development of alternative solutions to conventional chemical fertilizers, and to provide scientific evidence for the use of these natural resources in sustainable agriculture

Chapter I: Literature Review

1. Introduction

Vegetable crops play a fundamental role in global food systems. Rich in vitamins, minerals, and fiber, fresh vegetables enhance the nutritional quality of diets and contribute to food security, especially in urban and peri-urban contexts (FAO, 2019). Among them, the tomato (*Solanum lycopersicum*) holds a prominent position as the most widely grown and consumed vegetable worldwide due to its high nutritional value, culinary versatility, and economic importance.

2. Global Importance of Tomatoes

Tomatoes are the leading vegetable crop in the world in terms of volume. According to FAOSTAT (2022), global production of fresh tomatoes reached 186.1 million tonnes, cultivated on approximately 5 million hectares, with an average yield of 37.2 t/ha. China is by far the largest producer, with nearly 68.2 million tonnes, accounting for 36.6% of the global total, followed by India (20.7 million tonnes) and Turkey (13 million tonnes) (FAOSTAT, 2022).

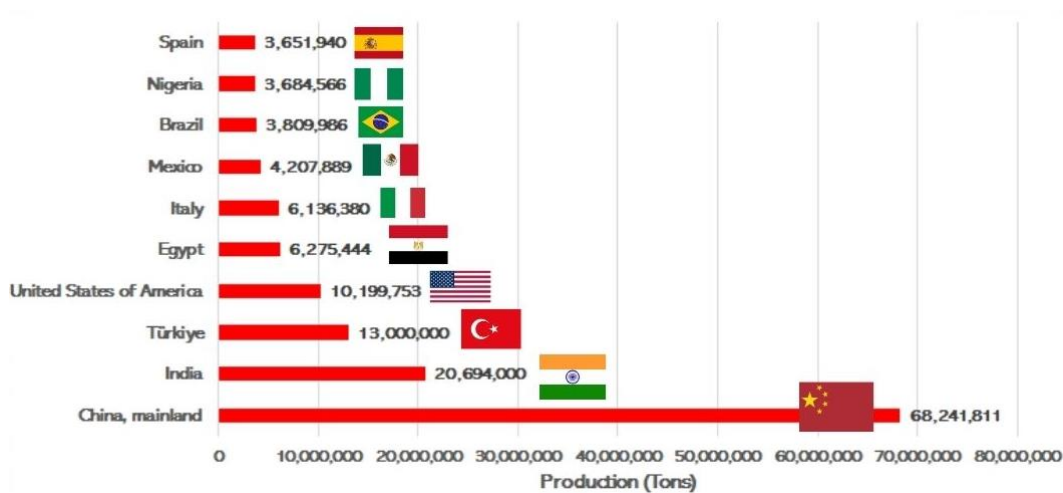


Figure 1: The biggest tomato-producing countries in 2022 (FAO, 2024)

Beyond its nutritional value, tomato cultivation contributes significantly to the economies of many countries by providing employment to millions of farmers and supporting dynamic processing chains (Pudup, 2022). The crop is also relatively adaptable to various climates and production technologies (open field, greenhouses,

hydroponics), making it a strategic component in the transition toward more sustainable agricultural systems.

3. Tomato Cultivation in Algeria

In Algeria, tomato production is one of the pillars of the vegetable sector. According to data from the Helgi Library and FAO (2022), national production reached 1,662,000 tonnes, placing Algeria 14th in the world. The cultivated area was about 25,000 hectares, and yields averaged 66 t/ha, an increase compared to the previous year (Helgi Library, 2023; FAOSTAT, 2022).

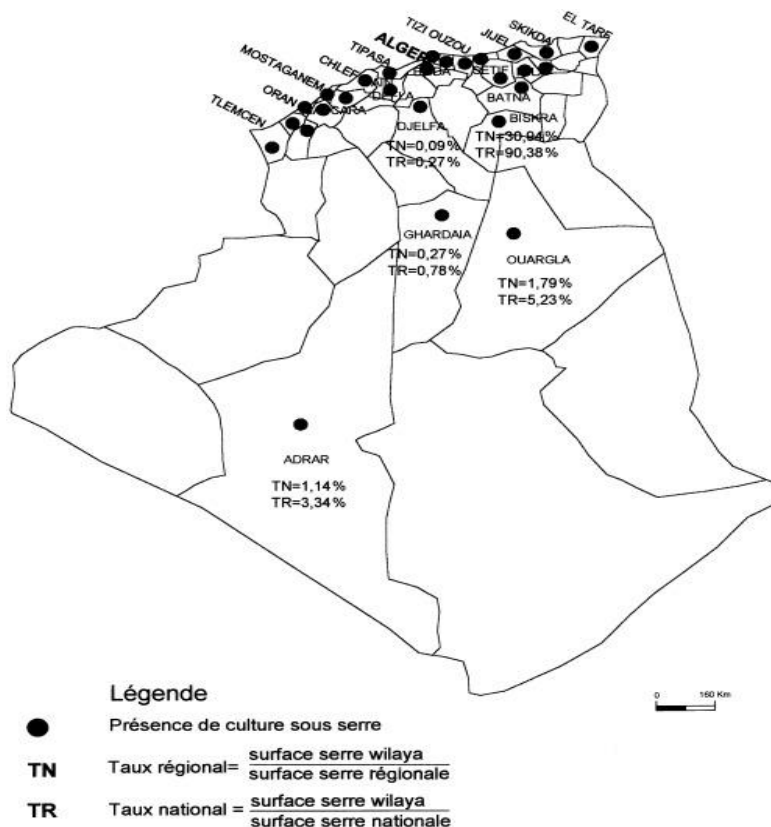


Figure 2 : The main areas of tomato production in Algeria (Boudhar and Chaou, 2016)

Cultivation takes place in various regions of the country, notably in the wilayas of Biskra, El Oued, Tipaza, Mostaganem, and Relizane. The development of greenhouse cultivation has extended the production period, ensuring an almost continuous supply of tomatoes in local markets. In Algeria, Tomato is a key crop cultivated over more than

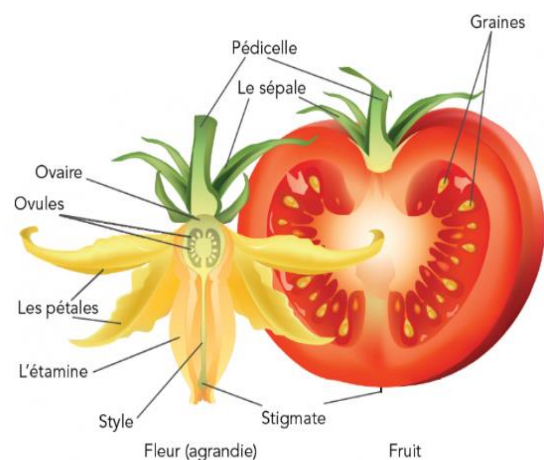
36000 ha, with production of 11 M IN 2022 (NADRP, 2023), the primary growing regions include Biskra and Adrar, where greenhouse farming enables off season production and better-quality control (Ait kaki and *al.*, 2023, Chahdi and Bessaoud, 2022).

4. Biological and Agronomic Characteristics of Tomato (*Solanum lycopersicum* L.)

Botanical classification situate Tomato (*Solanum lycopersicum* L.) belongs to the **Solanaceae** family, which includes other important crops such as potato, pepper, and eggplant. It is a dicotyledonous, herbaceous, usually determinate or indeterminate plant cultivated primarily for its fleshy fruit. The tomato is native to western South America and was domesticated in Mexico before spreading globally after the Columbian exchange (Peralta and *al.*, 2008).

From a taxonomic point of view, the tomato is classified as follows:

- **Kingdom:** Plantae
- **Order:** Solanales
- **Family:** Solanaceae
- **Genus:** *Solanum*
- **Species:** *Solanum lycopersicum* L.



Within the *Solanum* genus, tomato belongs to the ***Solanum* section Lycopersicon**, which comprises both cultivated and wild species. These wild relatives are essential for breeding due to their genetic diversity and resistance traits (Knapp and *al.*, 2004).

Varietal Classification of Tomato are generally classified based on fruit shape, size, color, growth habit (determinate vs. indeterminate), and use (fresh market, processing, cherry, etc.). The two main subspecies are:

- ***Solanum lycopersicum* var. *lycopersicum***: This is the cultivated type, characterized by larger fruit size and is widely grown worldwide.
- ***Solanum lycopersicum* var. *cerasiforme***: This subspecies includes cherry-type tomatoes, often used for breeding due to their resistance and adaptability (Blanca and *al.*, 2012).

Tomato cultivars are also distinguished by:

- **Growth habit**: Determinate types grow to a fixed height and are suitable for mechanized harvesting and processing. Indeterminate types continue to grow and bear fruit over a longer period, common in fresh market production (Jones, 2008).
- **Fruit characteristics**: Varieties may produce round, oblong, pear-shaped, or ribbed fruits, with colors ranging from red, yellow, orange to green and purple (Naika and *al.*, 2005).

Modern tomato breeding has led to the development of **hybrid varieties** that combine high yield potential, disease resistance, and shelf-life improvements, particularly for commercial farming (Tigchelaar, 1986).

The phenological development of tomato follows a well-defined sequence of stages that are crucial for optimizing agronomic practices and achieving high productivity. The tomato crop progresses through distinct phases, starting from seed germination, seedling establishment, vegetative growth, flowering, fruit set, fruit development, and finally maturation and senescence (Jones and *al.*, 2007). Under optimal conditions, seed germination occurs within 5–10 days at temperatures between 20–25°C (FAO, 2017). Vegetative growth typically lasts for 3 to 4 weeks, during which the plant develops its root system, stems, and leaves.

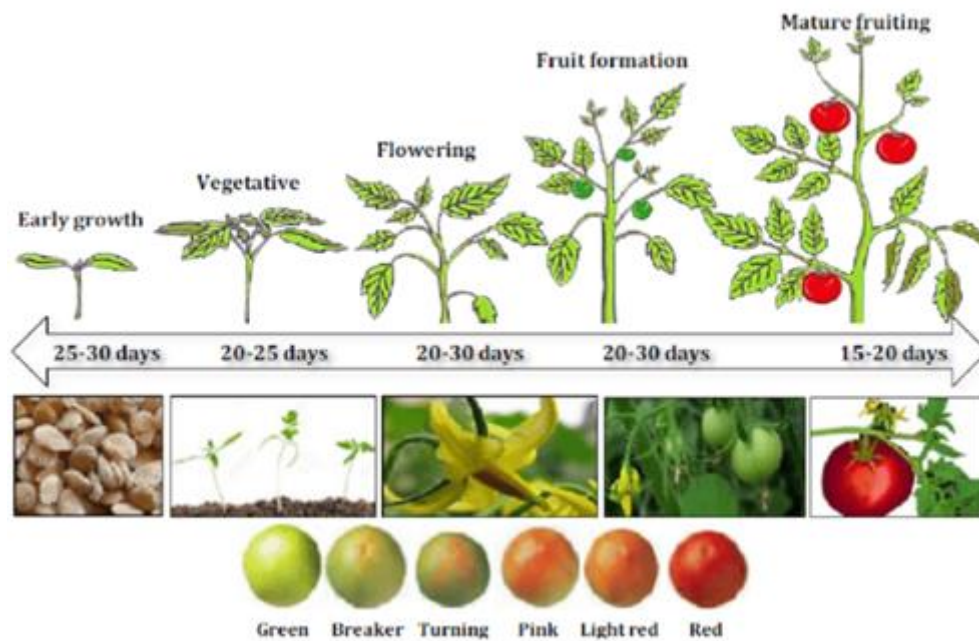


Figure 3: Demonstration of the five growth stages of tomato, and the different levels of fruit ripeness (Redmond et al., 2018)

The reproductive stage begins with flower initiation, generally around 20–30 days after transplanting, depending on the variety and environmental conditions (Adams and *al.*, 2001). Pollination and fruit set are highly sensitive to abiotic factors such as temperature and humidity. Fruit development and ripening take approximately 40–60 days, depending on cultivar and growing conditions (Peet & Welles, 2005). Throughout this cycle, appropriate irrigation, nutrient management, and pest control are essential to support each phenological phase and ensure successful fruit production stages (Meier, 2001).

Tomato plants (*Solanum lycopersicum* L.) exhibit stage-specific nutrient requirements, which must be met precisely to ensure optimal growth, fruit quality, and yield. During the **seedling stage**, nitrogen (N) is vital for early vegetative growth and chlorophyll production. Phosphorus (P) supports root development, while potassium (K) plays a role in osmotic regulation and early metabolic activities (Hochmuth & Hanlon, 2010).

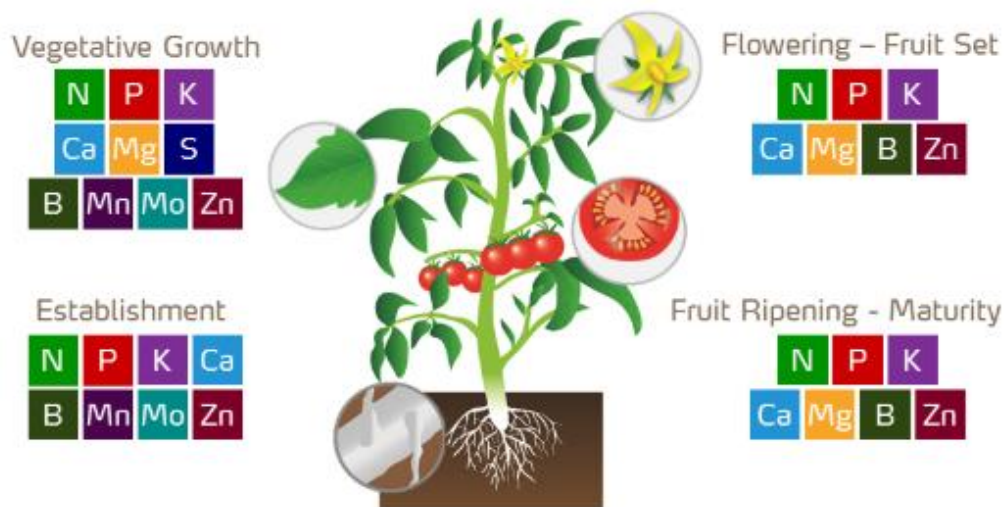


Figure 4: Nutrients required in each tomato growth stage (Anonym, 2024).

In the **vegetative stage**, the demand for nitrogen increases to support rapid biomass accumulation and leaf expansion. Adequate levels of calcium (Ca) and magnesium (Mg) are also necessary for cell wall development and photosynthetic efficiency (Dorais and *al.*, 2001). Micronutrients such as iron (Fe), manganese (Mn), and zinc (Zn) become increasingly important for enzymatic functions and hormone regulation.

As the crop transitions to the **flowering and fruit-setting stages**, a balanced supply of nutrients is essential. Excessive nitrogen at this point can delay flowering, whereas phosphorus becomes critical for energy transfer and fruit initiation. Potassium becomes dominant, enhancing pollen viability, flower retention, and resistance to stress (Sonneveld & Voogt, 2009). Calcium is crucial at this stage to prevent physiological disorders like blossom-end rot.

During the **fruit development and ripening stages**, potassium requirements peak, as it regulates sugar transport, fruit size, and color development. Magnesium supports chlorophyll in remaining leaves and influences sugar accumulation in fruits. Boron (B) and calcium continue to support cell integrity and fruit firmness (Hartz and *al.*, 1999). Tailoring fertilization according to these phenological stages improves both yield and fruit quality while reducing environmental impact.

5. Constraints Due to Improper Mineral Fertilization in Tomato Cultivation

Improper mineral fertilization in tomato cultivation can lead to a wide array of physiological disorders, reduced yield, and lower fruit quality. An **excess of nitrogen (N)** often stimulates excessive vegetative growth at the expense of flowering and fruiting, increasing susceptibility to pests and diseases such as powdery mildew and late blight (Zotarelli and *al.*, 2009). Conversely, **nitrogen deficiency** results in stunted growth and pale leaves due to insufficient chlorophyll synthesis.

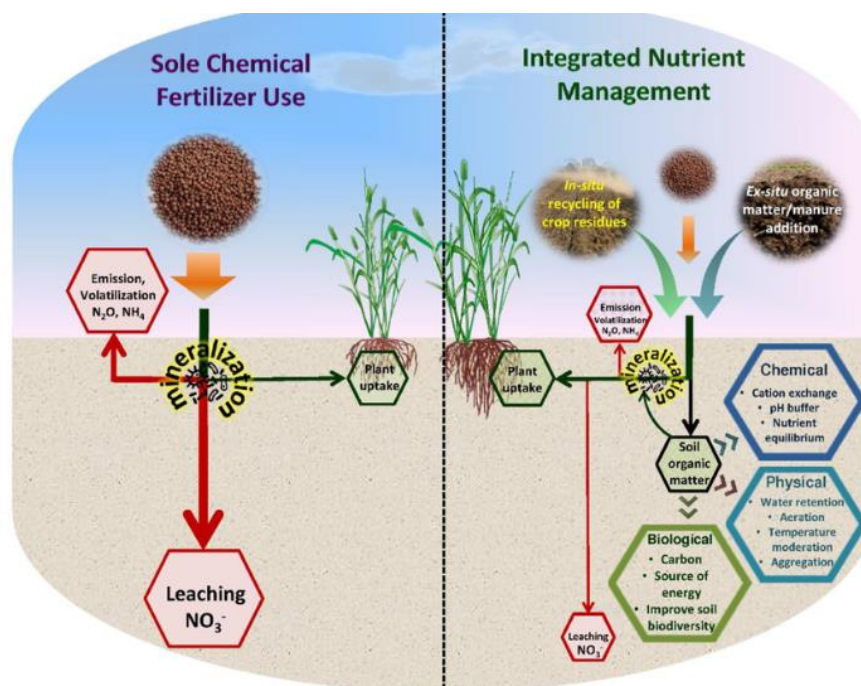


Figure 5: Contrasting influences of sole chemical fertilizer vs. integrated nutrient management on the nitrogen pools, mineralization, leaching, and volatilization fluxes (Bhardwaj, 2023).

Phosphorus (P) deficiency during early growth limits root development and delays flowering, while excess phosphorus can interfere with micronutrient uptake, particularly zinc and iron (Alloway, 2008). **Potassium (K)**, essential for water regulation and enzyme activation, when deficient, causes poor fruit set, uneven ripening, and increased vulnerability to abiotic stresses such as drought and salinity (Sonneveld &

Voogt, 2009). Excessive potassium, on the other hand, may lead to imbalances with magnesium and calcium uptake.

Deficiencies in **calcium (Ca)**, particularly during fruit development, are closely associated with **blossom-end rot**, a common physiological disorder in tomatoes. This is often not due to a lack of calcium in the soil, but rather to impaired uptake caused by irregular irrigation or excessive ammonium or potassium fertilization (Ho & White, 2005). Similarly, **magnesium (Mg)** deficiency leads to interveinal chlorosis in older leaves, affecting photosynthetic activity.

The inappropriate use of mineral fertilizers not only compromises plant health but also results in nutrient leaching, environmental pollution, and increased production costs. Thus, a well-balanced and stage-specific nutrient management plan, based on soil and tissue analyses, is essential for sustainable tomato production (Hartz and *al.*, 1999).

6. Organic Fertilization as a Substitute for Inorganic Inputs in Tomato Cultivation

The excessive reliance on inorganic fertilizers in tomato production has raised concerns about soil degradation, environmental pollution, and reduced microbial biodiversity. In response, **organic fertilization** has gained increasing attention as a sustainable alternative (Diacono & Montemurro, 2010).

Several studies have shown that **organic fertilizers can meet the nutrient demands of tomato plants** (Kumar and *al.*, 2014).

Furthermore, combining organic amendments with **biofertilizers** (such as *Azospirillum*, *Bacillus*, or *Trichoderma*) can boost nutrient uptake efficiency and plant resistance to stress (Hashem and *al.*, 2019). However, the nutrient release from organic sources is often slower and less predictable than from synthetic fertilizers, making **timing and decomposition rate** crucial for synchronizing nutrient availability with crop demand.

While total substitution of mineral fertilizers may not always be feasible in intensive systems, **integrated nutrient management**, combining organic and inorganic sources

offers a balanced approach, enhancing sustainability while maintaining productivity (Agegnehu and *al.*, 2016).

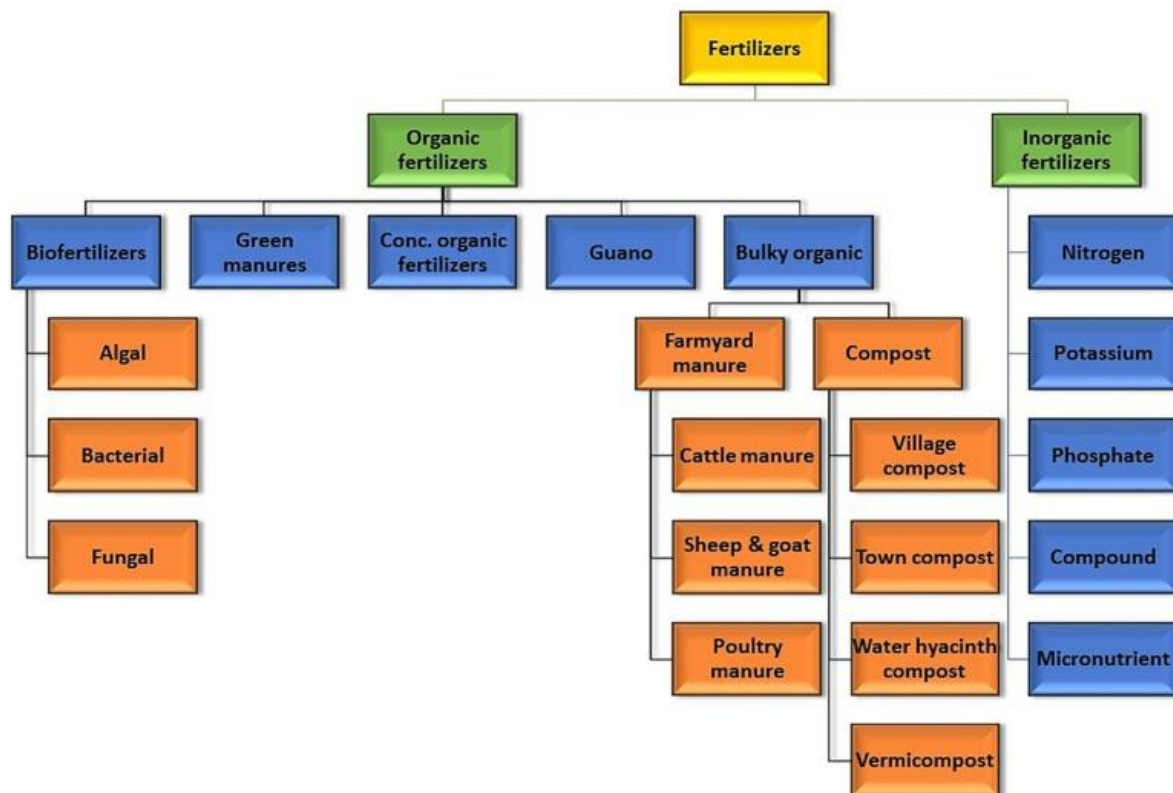


Figure 6: Classification of organic and inorganic fertilizers (Liu et al., 2010; Singh et al., 2020; Thakur, 2022; Vejan et al., 2021).

7. Organic Fertilization providing from Aquatic plants as a Sustainable Alternative to Mineral Fertilizers in Tomato Production

The substitution of inorganic fertilizers with organic fertilizers, particularly those derived from marine plants such as seaweeds, is increasingly recognized as a sustainable practice in tomato production. Organic fertilizers improve soil structure, microbial activity, and long-term fertility, while also reducing the risk of nutrient leaching and environmental contamination associated with synthetic fertilizers (Agegnehu and *al.*, 2016).

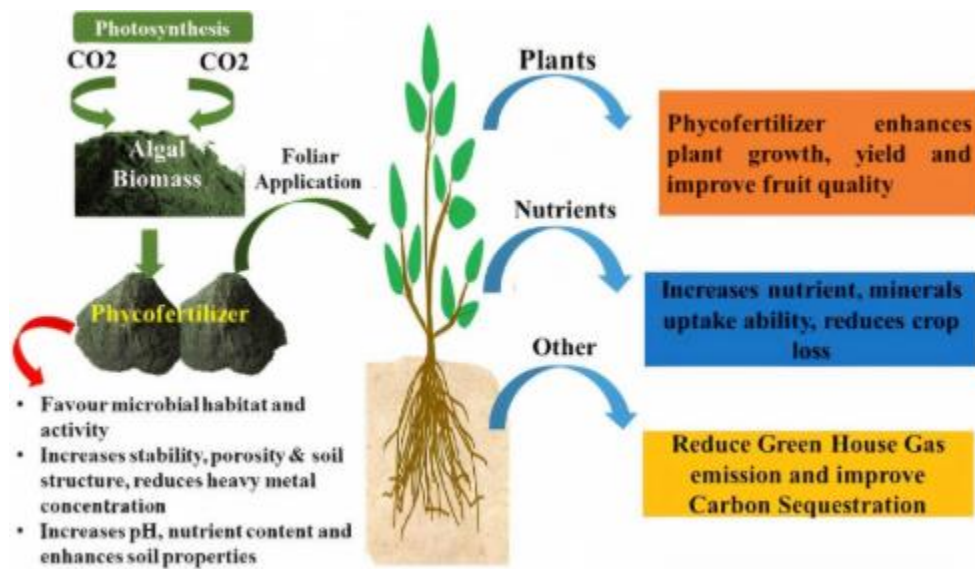


Figure 7: Aquatic fertilisation effect on plants (Abiddin, 2022)

Seaweed-based biostimulants, particularly extracts from *Ascophyllum nodosum*, *Ecklonia maxima*, and *Sargassum spp.*, are rich in macro- and micronutrients, phytohormones, amino acids, and polysaccharides that enhance nutrient uptake and improve plant resilience (Khan and *al.*, 2009). When applied as soil amendments or foliar sprays, these marine plant extracts have been shown to enhance root development, stimulate flowering and fruit set, and improve fruit quality parameters such as lycopene content and sugar accumulation (Sharma and *al.*, 2014).

Moreover, organic inputs help mitigate abiotic stresses such as drought, salinity, and temperature extremes by modulating antioxidant enzyme activity and osmoprotectant accumulation in tomato plants (Goñi and *al.*, 2016). The use of composted seaweed and algae-based biofertilizers also contributes to carbon sequestration and soil health restoration, particularly in degraded lands.

Although organic fertilizers generally release nutrients more slowly than mineral fertilizers, their synergistic effects on soil biology and plant physiology make them a key component of sustainable and integrated nutrient management in tomato farming systems (Calvo and *al.*, 2014).

8. Aquatic biofertilizer

The application of effective marine species to promote vegetative growth. Rapid decomposition in the growth substrate facilitated the release of macro- and micronutrients and other organic compounds, which had a dual effect on growth parameters. (Root and shoot length, surface area, fresh weight, dry weight, leaf mineral content and chlorophyll). (Priolo and *al.*, 2023).

The bioactive metabolites present in the biomass of marine species probably directly benefited plant metabolism and physiology during the vegetative period, the SP-amended substrate increased inorganic nutrient availability and substrate porosity, which enhanced root system development, nutrient uptake and assimilation and chlorophyll synthesis, and consequently benefited plant morphological attributes (Priolo and *al.*, 2023).

Exploited for agricultural applications since antiquity, they have considerably stimulated the use of bio remedies such as aquatic species extracts in agriculture. Liquid extracts of aquatic species are currently used for irrigation or foliar spraying (Godlowska and *al.*, 2016).

These extracts are easier and quicker to use as they limit the negative effects of decomposing and formed marine species, whereas applying fresh marine species to the soil usually requires a long decomposition wait. Liquid extracts of marine species have also been shown to stimulate early tomato seed emergence and germination rates, with a positive effect on vegetative growth, resulting in increased plant height, number of branches and leaf yield (Makhaye and *al.*, 2021).

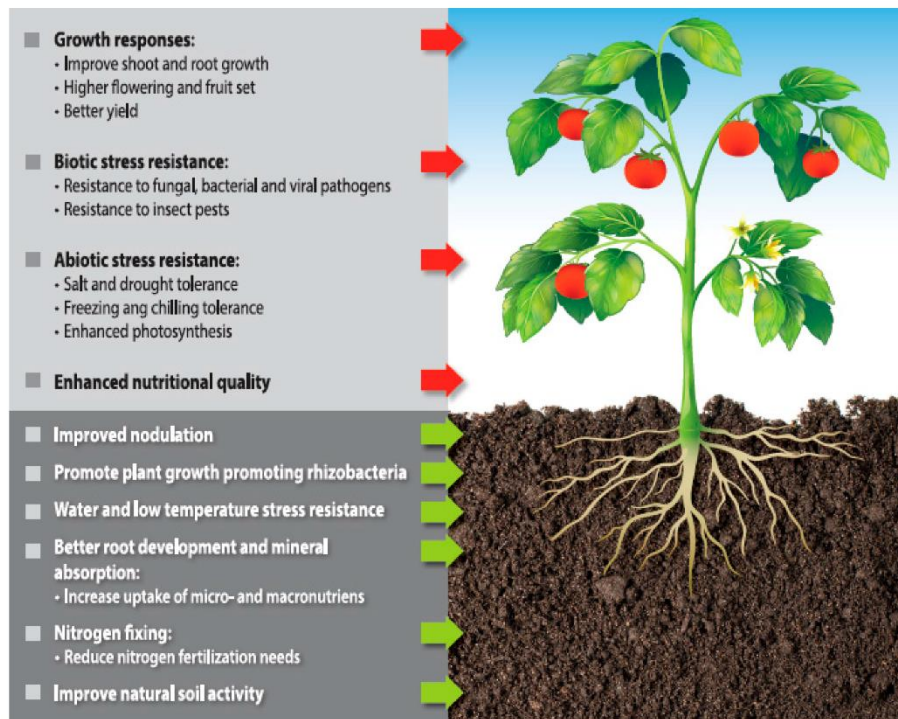


Figure 8: Possible effect of marine species (Izabela and *al.*, 2017)

8.1. The bioactive components of marine species

a. Polysaccharides :

Polysaccharides can be obtained from a number of sources, including aquatic spaces, plants, bacteria, fungi, insects, crustaceans and animals. They can be classified according to their structure, solubility, sources, applications and biological roles (CHOUANA, 2017).

Polysaccharides represent a potential bioresource for the valorization and protection of agricultural crops (Rachidi and *al.*, 2020).

The improvement in tomato growth after PS treatment was accompanied by an increase in its main components, such as nitrogen, enzymes, activities and protein content. Photosynthesis, nitrate assimilation and basic metabolism were enhanced by carboxylated or sulfated polysaccharides in similar studies (Castro and *al.*, 2012). In addition, basic metabolism and cycle-regulating cyclins were shown to be enhanced in plants treated with oligo-carrageenan, resulting in an increase in nitrate uptake (Zhu and *al.*, 2017).

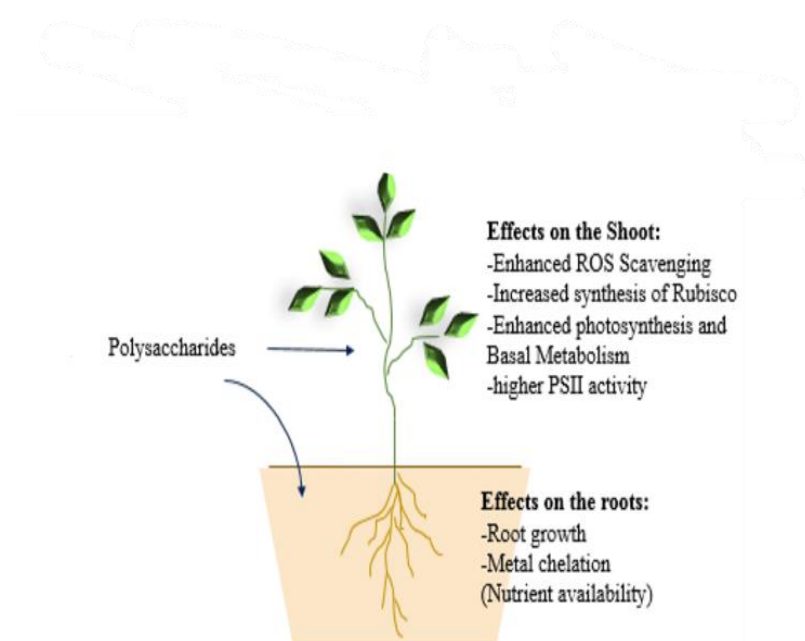


Figure 9: Key mechanisms targeted by marines' polysaccharides (Chanda and *al.*, 2019).

The main advantages of using polysaccharides or any other marine's species source biomolecule are: production takes place throughout the year, biomass harvest does not depend on climatic conditions or seasons, growth is fast, and cultivation is relatively simple compared to higher plants (Silvello, and *al.*, 2022)

Besides, marine species-based carbohydrates are easily saccharified and require less treatment than other sources, being highly competitive for many applications (Chen and *al.*, 2013). Marines' species polysaccharides have advantages over other polysaccharides sources (terrestrial plants, crustaceans, squid pens, or fungal cell walls), such as safety, stability, biocompatibility, and biodegradability (Morais and *al.*, 2021).

b. Polyphenols

Phenolics are among the most numerous and important bioactive compounds synthesized by marines species. They are produced for protection against various abiotic and biotic stress such as ultraviolet radiation, extreme temperature, salinity, pathogenic infection, and herbivory (Jimenez-Lopez and *al.*, 2021). The use of Polyphenols had an overall positive effect on plant growth, especially at the root level and in saline soils. It also increased the average content of photosynthetic pigments

(chlorophyll a and b and carotenoids), indicating an improvement in photosynthesis. Furthermore, Polyphenols appeared to partially inhibit the uptake of toxic ions, Na^+ and Cl^- , by roots and to some extent enhance the accumulation of K^+ and Ca^{2+} (Zuzunaga-Rosas and *al.*, 2022).

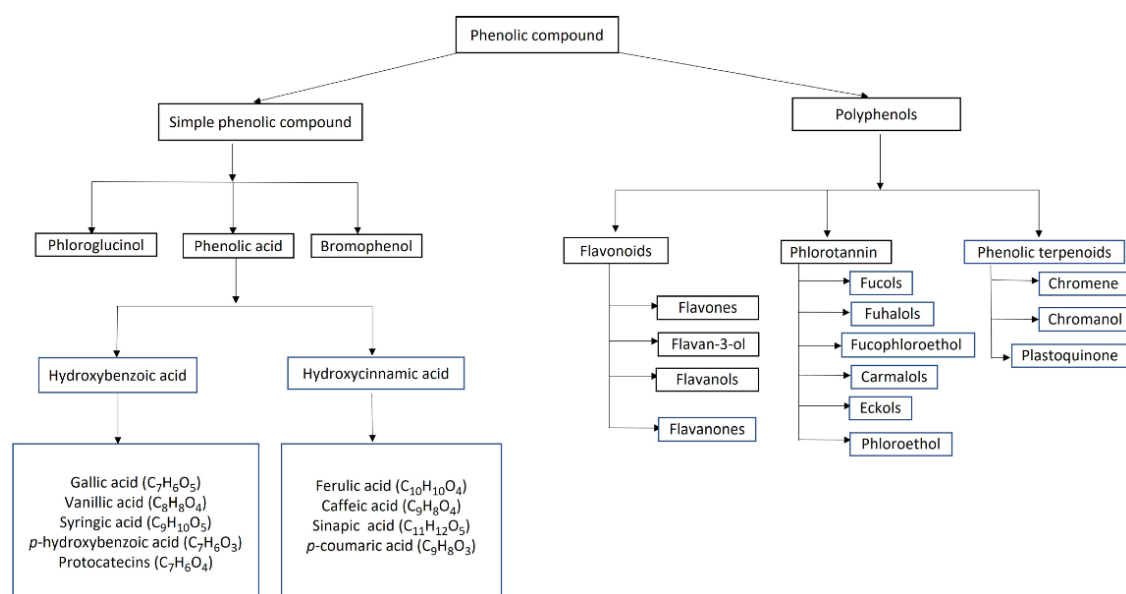


Figure 10 : Classification of the main phenolic compounds in marines species (Aina and *al.*, 2022)

Marines phenolics have a basic structure of a hydroxy group attached to an aromatic ring. They are categorized by the number of carbon atoms and benzene rings in a compound as well as their solubility. Phenolic compounds with a phenol ring, such as phenolic acids and phloroglucinol, are classified as simple phenolic compounds, whereas those with multiple phenols, such as phlorotannin, are classified as polyphenols (Cotas and *al.*, 2020). The different type of phenolic compounds in marines species are found are further illustrated in figure 9

c. Pigments

Plant pigments are substances that control different processes during development, growth, and metabolism (Sudhakar and *al.*, 2016). Pigments can be grouped into two main groups, lipid-soluble and water-soluble. The first can be divided into chlorophylls (Chls) and carotenoids and the second into flavonoids and betalins. (Solovchenko and *al.*, 2019; López-Cruz and *al.*, 2023; Rodríguez-Mena and *al.*, 2023).

Plant pigments are involved in many biological functions, such as plant development, growth and metabolism. As plants age, they acquire the necessary pigments in response to the environment and self-programming for reproductive success. They are what give plants their specific color (Barrera-Rojas and *al.*, 2025).

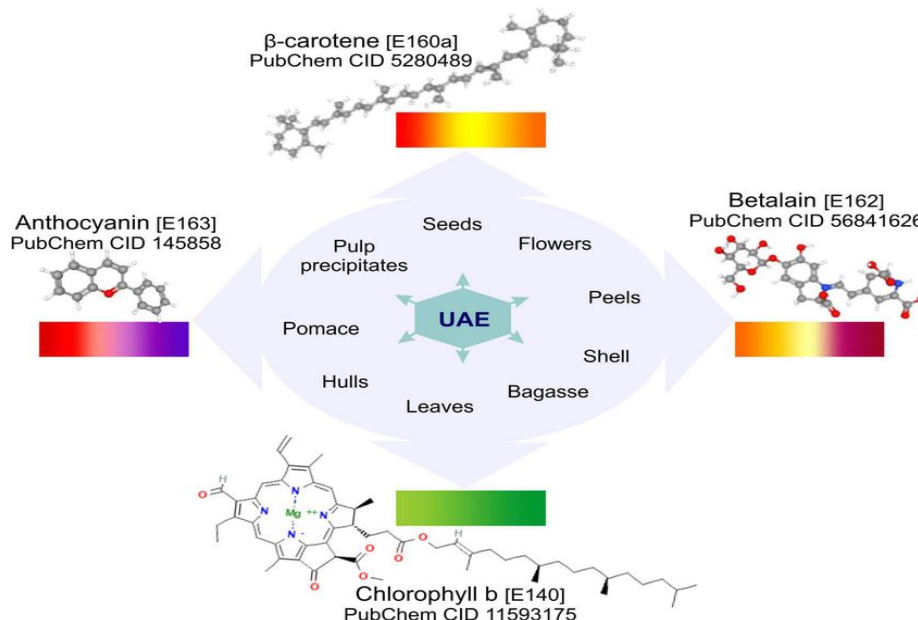


Figure 11: Basic chemical structures of plant and marine pigments (Linares and Rojas, 2022)

d. Sterols :

Phytosterols, or plant sterols, are lipid compounds found in plants. Phytosterols play an important role in plant cell membranes, where they contribute to structure and function in much the same way as cholesterol does in the human body (Dynveo, 2024). Researchers claim that “phytosterols and their esters may play a role in water stress tolerance by strengthening cell membranes (Sujith Kumar and *al.*, 2018). This is consistent with the observation that “one of the most important manifestations of stress in plants is the disintegration of the plasma membrane (Sujith Kumar and *al.*, 2018)

Sterols are necessary for the control of cell membranes (Pereira and *al.*, 2017). They are involved in membrane homeostasis maintenance in plant cells, in which they are expected to contribute to developing plant stress tolerances, particularly for abiotic stresses such as cold, heat, radiation of UV, drought and salinity (Rogowska & Szakiel, 2020). Sterols can influence the membrane physical status

during the stress conditions occur, by changing the total content of sterols and the profile variations, specifically the composition ratios of sterols molecular species such as stigmasterol and sitosterol (Rogowska & Szakiel, 2020).

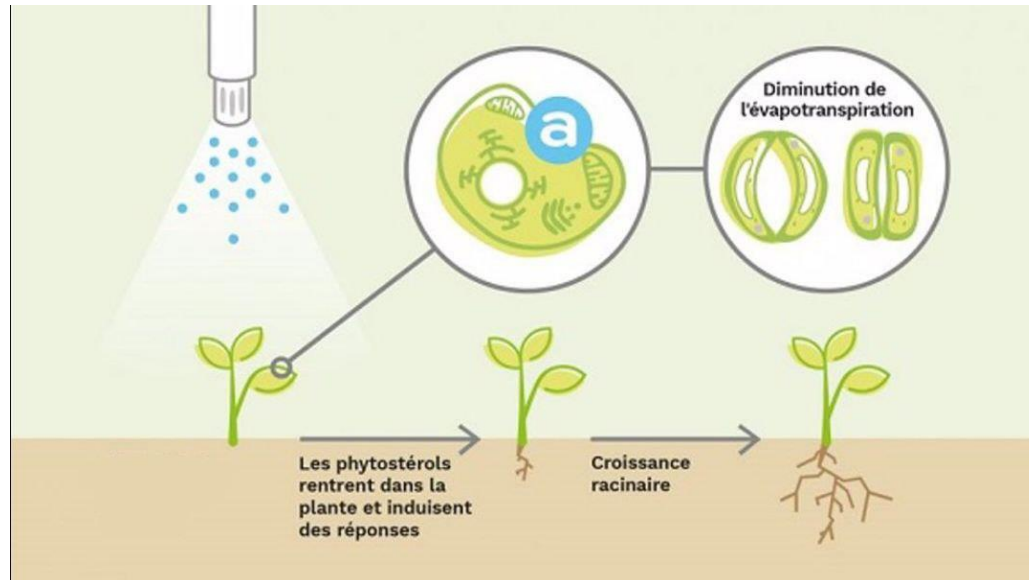


Figure 12 : Role of phytochemicals (Anonyme, 2023)

e. Terpene:

Terpenes are organic compounds naturally present in plants and fruit, responsible for their aroma. They are known not only for their pleasant aroma but also for helping plants defend themselves (Ramadoss and *al.*, 2023). Here are just a few of their benefits for plants:

Terpenoids have toxic and insect repellent effects and are also known to mediate interactions between plants and insects, such as pollinators and predators and parasitoids and herbivores, due to their odor. (Ramadoss and *al.*, 2023).

They also act as attractants for predators or parasites, making them an effective indirect defense against herbivores. Some terpenoids act as attractants for herbivores, and this property can be exploited in pest control strategies to deliberately lure herbivores into traps. Genetically modified plants. Overexpressed attractants can effectively lure herbivores into traps preventing them from escaping (Ramadoss and *al.*, 2023).

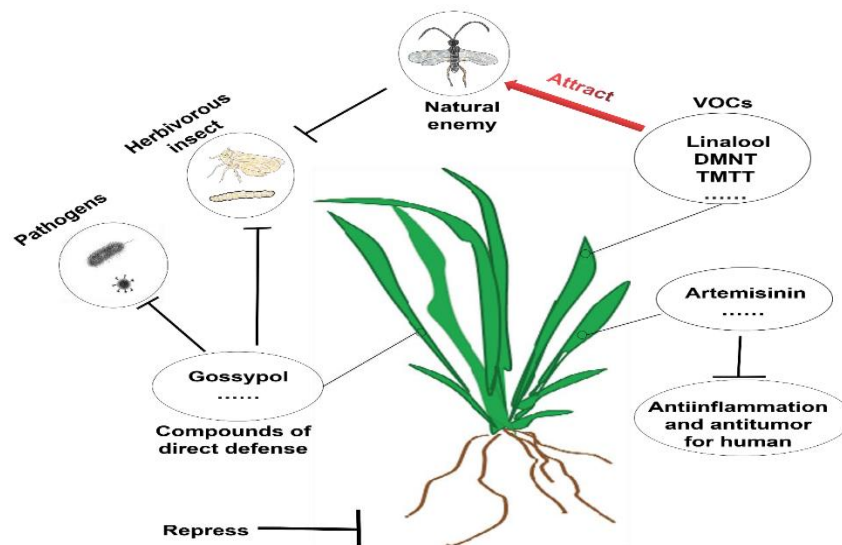


Figure 13: Role of Terpenes in Defense and Stress Response Mechanisms
(Anonyme, 2024.)

f. Others :

- Plant growth hormones:

Plant growth hormones, which can be found in marine species, are bioactive chemicals that control plant growth and production. Phytohormone activity determines the physiological effects of marine extracts on treated plants (Nedumaran and *al.*, 2015) . Some of the phytohormones detected in marine extract include auxins, cytokinins and gibberellins (Ali and *al.*, 2021)

Auxin is one of the plant growth-promoting hormones present in marine extract, playing a role in enhancing a plant's root system by improving root elongation and formation (Abbes and *al.*, 2020) . Auxin concentration in these species is different and highly dependent on the species. Auxins have been implicated in promoting initiation of lateral root primordium, development of formed lateral roots and elongation of primary roots (Wally and *al.*, 2013) . It has also been reported that auxin can help regulate plant defense (Islam and *al.*, 2020)

- **Minerals :**

Marines species are rich in minerals due to the bioaccumulation of metal ions found in the sea water and concentrates the accumulated components as carbonate salts (Azizi and *al.*, 2021). It has been shown to be a significant source of essential nutrients for plant development in previous studies (Sekar and *al.*, 2018).

- **Polyun-saturated Fetty Acides (PUFAs):**

Polyunsaturated Fetty acids are the other importance bioactive compounds in the marine's species. Due to their metabolic connections, PUFAs may be divided into two families: α -linolenic acid (n-3 fatty acid) and linoleic acid (n-6 fatty acid) (Holdt and Kraan, 2011). PUFAs are involved in developing environmental stress tolerance. They act as general de fenders for plants against various abiotic and biotic stresses including infection of pathogens, cold, drought and salinity stresses (He and Ding, 2020). For example, the accumulation of PUFAs is induced by the seaweed when a decrease in temperature occurs, as a reaction to develop cold stress tolerance. Hence, PUFAs content in the species that lives in cold areas is higher than the species that live in a high environmental temperature (Holdt and Kraan, 2011).

- **Betaines :**

Betaines are N-methylated compounds which act as nitrogen source for plants, when applied in low concentration and work as an osmolyte at higher temperature. They are also involved in protecting plants from drought stress, glycine betaine which is an osmo-protectant compound will accumulate in plants under the drought stress (Shemi and *al.*, 2021).

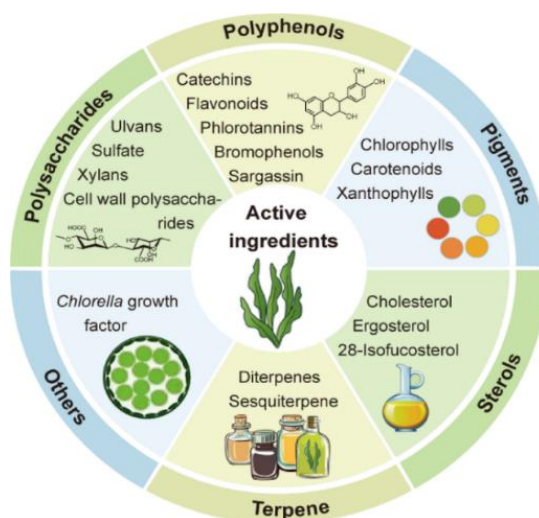


Figure 14 : Different bioactive components of marine species (Holdt and Kraan, 2011)

Furthermore, it has been observed that glycine betaine helps in the detoxification of reactive oxygen species (ROS), allowing photosynthesis to recover and reducing oxidative damage. Glycine betaine alleviates the oxidative stress damaging effects by the stabilization or activation of ROS-scavenging enzymes and/or the repression of ROS production by other mechanisms (Hasamuzzaman and *al.*, 2019).

This compound also helps in increasing the content of chlorophyll in leaves by reducing its degradation, hence results in the enhancement of plant yield (Chojnack, 2

Chapter II : Material and Method

1. Objectif

The objective of this study is to investigate the impact of marine-derived biofertilizers on the metabolic activity of *Solanum lycopersicum* L., a horticultural crop of significant economic and culinary value. The study further aims to evaluate their effects on vegetative growth stimulation, reproductive performance, and phytosanitary status under semi-controlled greenhouse conditions.

2. Description of the Experimental Site

Our work was carried out in the teaching greenhouse of the Biotechnology and Plant Production research laboratory, and also in the Applied Phyto pharmacy 109 laboratory of the Biotechnology and Agroecology Department, Faculty of Natural and Life Sciences, Saad Dahleb University, Blida, over a period of 5 months (March - July).



Figure 15: Location of the experimental greenhouse of the Plant Biotechnology Laboratory (Google Earth, 2025).

3. Description of the Experimental Setup

plant Material:

The plant material used consists of the following species:

✓ Variety: *Solanum lycopersicum* L., F1 hybrid (young tomato plants)

- Fruit Shape: Round to slightly oblong
- Color: Bright red when fully ripe
- Texture: Smooth and firm skin
- Flavor: Mildly sweet with balanced acidity
- Growth Habit: Vigorous plant with high productivity

These plants were provided from a nursery in Fouka-Tipaza, only vigorous, healthy seedlings of uniform size were retained for use in the experimental setup.

4. Monitoring of the crop development under greenhouse conditions

The experimental period was selected to encompass all phenological stages of the tomato plant, ensuring the development of the maximum number of floral clusters and the achievement of a sufficient fruit yield. The experiment was conducted over a four-month period, from March to June 2025.

4.1. Transplantation Method

Tomato seedlings were transplanted into plastic pots (3.5 kg). Each pot was prepared with two cups of fine gravel at the bottom to ensure good drainage, then filled with 2.5 kg of soil. We left them in the greenhouse for 10 days to adapt, then started applying the treatments.



Figure 16: Plant device (Original, 2025).

4.2. Block Design and Plot Arrangement

The system used was a block design with 35 replicates. The trial consisted of 8 blocks. Each block covered an area of 18 m² (dimensions: 6m× 3m). The distance between blocks was 90 cm, and the distance between plots within a block was 46 cm.

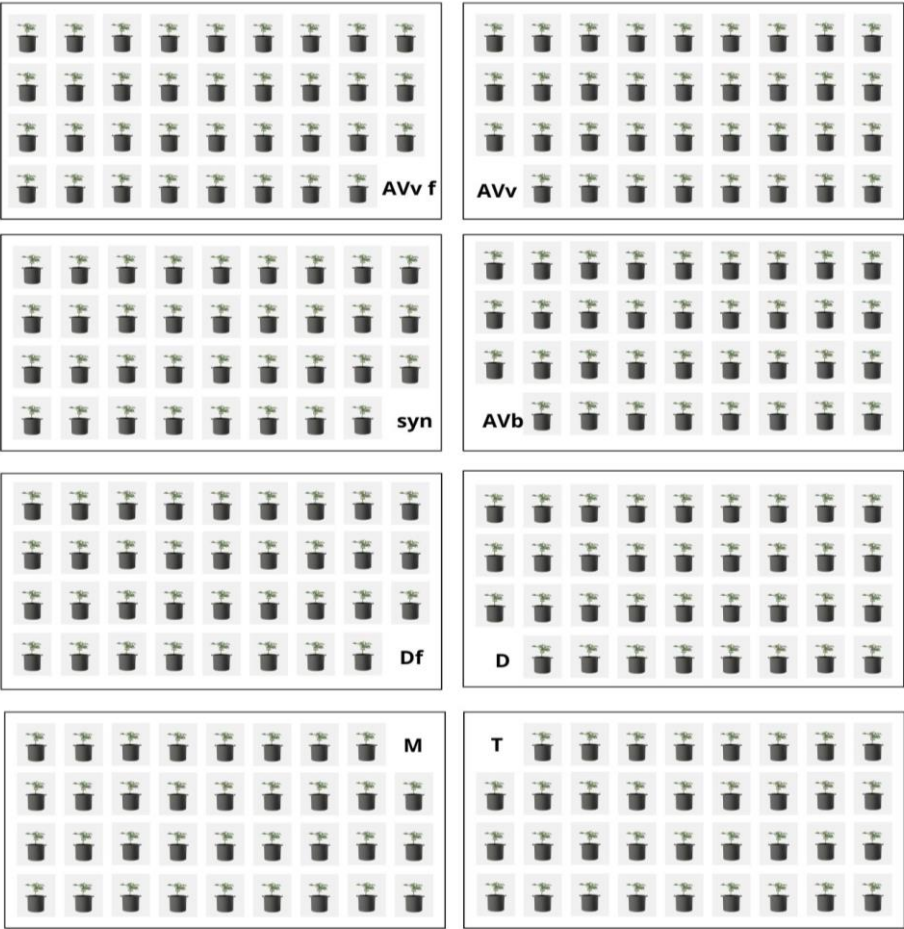


Figure 17 : Experimental layout plan (Original, 2025).

General Conclusion

This study was carried out to assess the effects of organic bioproducts based on marine species on the vegetative development, reproductive traits and physiological state of Tomato (*Solanum lycopersicum*), a crop known for its economic value and its importance in food security.

The experiment was carried out in the departmental teaching greenhouse over a period of around two and a half months, from mid-February to the end of June 2025, at the University of Blida.

The results showed that the different treatments had variable effects depending on the parameters observed.

The results showed variable effects depending on the parameters studied. The AVF, DF and M treatments stood out for their overall effectiveness, improving vegetative growth, flowering, productivity and physiological responses in tomato plants. SYN, AV and D, on the other hand, mainly promoted vegetative growth, with more limited effects on other developmental components.

From a physiological point of view, the bioproducts tested in this study showed the ability to enhance key functions such as photosynthesis. These effects probably result from the presence of bioactive compounds naturally present in marine species, including amino acids, phytohormones and enzymes.

References

1. Abbas, M., Anwar, J., Zafar-UI-Hye, M., Khan, R. I., Saleem, M., Rahi, A. A., Danish, S., & Data, R. (2020). Effect of seaweed extract on productivity and quality attributes of four onion cultivars. *Horticulturae*, 6(2), 28. <https://doi.org/10.3390/horticulturae6020028>
2. Adams, S. R., Cockshull, K. E., & Cave, C. R. J. (2001). Effect of temperature on the growth and development of tomato fruits. *Annals of Botany*, 88(5), 869–877. <https://doi.org/10.1006/anbo.2001.1524>
3. **Agegnehu, G., Nelson, P. N., & Bird, M. I.** (2016). The role of biochar and compost in improving soil quality, and crop performance: A review. *Soil Research*, 54(1), 1–16. <https://doi.org/10.1071/SR15070>
4. **Agegnehu, G., Nelson, P. N., & Bird, M. I.** (2016). The role of biochar and compost in improving soil quality, and crop performance: A review. *Soil Research*, 54(1), 1–16. <https://doi.org/10.1071/SR15070>
5. Aina, O., Bakare, O., Daniel, A., Gokul, A., Beukes, D. R., Adewale, O. F., Keyster, M., & Klein, A. (2022). Seaweed-derived phenolic compounds in growth promotion and stress alleviation in plants. *Life*, 12(10), 1548. <https://doi.org/10.3390/life12101548>
6. Ait Kaki, F., Kherbouche, A., & Saidi, M. (2023). Analysis of the determinants of greenhouse vegetable specialization in Biskra region, Algeria. *Sustainability*, 15(5), 4203. <https://doi.org/10.3390/su15054203>
7. Ali, O., Ramsubhag, A., & Jayaraman, J. (2021). Biostimulant properties of seaweed extracts in plants: Implications towards sustainable crop production. *Plants*, 10(3), 531. <https://doi.org/10.3390/plants10030531>
8. **Alloway, B. J.** (2008). *Micronutrients and crop production: An introduction*. International Fertilizer Industry Association (IFA).
9. Anonym, 2024: <https://www.yara.us/crop-nutrition/tomato/>
10. Azizi, M. N., Loh, T. C., Foo, H. L., Akit, H., Izuddin, W. I., Shazali, N., Teik Chung, E. L., & Samsudin, A. A. (2021). Chemical compositions of brown and green seaweed, and effects on nutrient digestibility in broiler chickens. *Animals*, 11(7), 2147. <https://doi.org/10.3390/ani11072147>

11. Barrera-Rojas, C. H., Nogueira, F. T. S., & van den Berg, C. (2025). Painting the plant body: Pigment biosynthetic pathways regulated by small RNAs. *New Phytologist*, 245(4), 1411–1420. <https://doi.org/10.1111/nph.19512>
12. Benalia, M., Bouzidi, N., & Maachou, A. (2020). Tomato production constraints and prospects in Algeria. *African Journal of Agricultural Research*, 15(7), 857–865. <https://doi.org/10.5897/AJAR2019.14585>
13. Bergougnoux, V. (2014). The history of tomato: From domestication to biopharming. *Biotechnology Advances*, 32(1), 170–189. <https://doi.org/10.1016/j.biotechadv.2013.11.003>
14. **Bhardwaj, A., Kumar, A., & Chandel, N.** (2023). Influences of sole chemical fertilizer vs. integrated nutrient management on nitrogen pools, mineralization, leaching, and volatilization fluxes [Illustration]. Dans *Organic farming vs. integrated nutrient management: A comparative review of agricultural productivity and sustainability*.
15. Blanca, J., Montero-Pau, J., Sauvage, C., Bauchet, G., Illa, E., Díez, M. J., & Causse, M. (2012). Genomic variation in tomato, from wild ancestors to contemporary breeding accessions. *BMC Genomics*, 13, Article 113. <https://doi.org/10.1186/1471-2164-13-113>
16. Boudhar, A., & Chaou, M. (2016). *Le contrôle et la certification en agriculture biologique: Version Tunisie* (1re éd.). Certification ABO. (Document PDF industriel, pas de DOI disponible)
17. Calvo, P., Nelson, L., & Kloepper, J. W. (2014). Agricultural uses of plant biostimulants. *Plant and Soil*, 383(1), 3–41. <https://doi.org/10.1007/s11104-014-2131-8>
18. Castro, J., Vera, J., González, A., & Moenne, A. (2012). Oligo-carrageenans stimulate growth by enhancing photosynthesis, basal metabolism, and cell cycle in tobacco plants (var. Burley). *Journal of Plant Growth Regulation*, 31(2), 173–185. <https://doi.org/10.1007/s00344-011-9222-y>
19. Chahdi, M. H., & Bessaoud, O. (2022). *Algeria's agriculture at a crossroads: Between dependence and food sovereignty* (Policy Paper No. 8). CIHEAM-IAMM. <https://www.iamm.ciheam.org/publications/pp8>
20. Chanda, M.-J., Merghoub, N., & El Arroussi, H. (2019). Microalgae polysaccharides: The new sustainable bioactive products for the development of

- plant bio-stimulants? *World Journal of Microbiology and Biotechnology*, 35(11), Article 177. <https://doi.org/10.1007/s11274-019-2745-3>
21. Chen, C. Y., Zhao, X. Q., Yen, H. W., Ho, S. H., Cheng, C. L., Lee, D. J., Bai, F. W., & Chang, J. S. (2013). Microalgae-based carbohydrates for biofuel production. *Biochemical Engineering Journal*, 78, 1–10. <https://doi.org/10.1016/j.bej.2013.04.006>
 22. Chojnacka, K. (2012). Biologically active compounds in seaweed extracts – the prospects for the application. *Open Conference Proceedings Journal*, 3, 20–28. <https://doi.org/10.2174/1876326x01203020020>
 23. **Chouana, T.** (2017). *Caractérisation structurale et activités biologiques des polysaccharides d’Astragalus gombo Bunge* (Thèse de doctorat, Université Clermont Auvergne & Université Kasdi Merbah – Ouargla). HAL. <https://tel.archives-ouvertes.fr/tel-02414068>
 24. Cotas, L., Leandro, A., Monteiro, P., Pacheco, D., Figueirinha, A., Gonçalves, A. M. M., da Silva, G. J., & Pereira, L. (2020). Seaweed phenolics: From extraction to applications. *Marine Drugs*, 18(8), 384. <https://doi.org/10.3390/md18080384>
 25. Craigie, J. S. (2011). Seaweed extract stimuli in plant science and agriculture. *Journal of Applied Phycology*, 23(3), 371–393.
 26. Crouch, I. J., & Van Staden, J. (1993). Evidence for the presence of plant growth regulators in commercial seaweed products. *Plant Growth Regulation*, 13(1), 21–29.
 27. **Diacono, M., & Montemurro, F.** (2010). Long-term effects of organic amendments on soil fertility: A review. *Agronomy for Sustainable Development*, 30(2), 401–422. <https://doi.org/10.1051/agro/2009040>
 28. Dorais, M., Papadopoulos, A. P., & Gosselin, A. (2001). Greenhouse tomato fruit quality. *Horticultural Reviews*, 26, 239–319.
 29. Du Jardin, P. (2015). Plant biostimulants: Definition, concept, main categories and regulation. *Scientia Horticulturae*, 196, 3–14. <https://doi.org/10.1016/j.scienta.2015.09.021>
 30. Dynveo. (2024, avril 20). Stérols végétaux : quelles plantes et quels aliments ? Dynveo. <https://www.dynveo.fr/blog/sterols-vegetaux-queelles-plantes-et-aliments--n286>

31. El Modafar, C., El Boustani, E., Filali-Maltouf, A., & El Hadrami, I. (2010). Use of seaweed extracts to enhance tomato tolerance to Fusarium wilt. *Plant Physiology and Biochemistry*, 48(9), 725–731.
32. FAO. (2021). Biofertilizers and biostimulants in sustainable agriculture.
33. FAOSTAT. (2022). *Crops and livestock products: Tomatoes, fresh*. <https://www.fao.org/faostat>
34. Food and Agriculture Organization of the United Nations (FAO). (2017). *Tomato production*. FAO.
35. Food and Agriculture Organization of the United Nations (FAO). (2019). *The state of food and agriculture*. FAO.
36. Food and Agriculture Organization of the United Nations (FAO). (2019). *Urban and peri-urban horticulture: Improving the livelihood and food security of urban populations*. <https://www.fao.org/urban-agriculture>
37. Food and Agriculture Organization of the United Nations (FAO). (2022). FAOSTAT. <http://faostat.fao.org/site/567/>
38. Food and Agriculture Organization of the United Nations (FAO). (2021). *The state of the world's land and water resources for food and agriculture 2021*. <https://www.fao.org/documents/card/en/c/cb7654en>
39. Godlewska, K., Michalak, I., Tuhy, Ł., & Chojnacka, K. (2016). Plant growth biostimulants based on different methods of seaweed extraction with water. *BioMed Research International*, 2016, Article 5973760. <https://doi.org/10.1155/2016/5973760>
40. Goñi, O., Fort, A., Quille, P., McKeown, P. C., Spillane, C., & O'Connell, S. (2018). Comparative transcriptome analysis of two plant species treated with a bioactive seaweed extract: A novel approach to understanding plant biostimulant mode of action. *Frontiers in Plant Science*, 9, Article 1199. <https://doi.org/10.3389/fpls.2018.01199>
41. Hartz, T. K., Miyao, E. M., & Valencia, J. G. (1999). Fertilizer requirements and management. In *Tomato production guide for California*. University of California, Davis.
42. Hasanuzzaman, M., Banerjee, A., Borhannuddin Bhuyan, M. H. M., Roychoudhury, A., Al Mahmud, J., & Fujita, M. (2019). Targeting glycinebetaine for abiotic stress tolerance in crop plants: Physiological mechanism, molecular

- interaction and signaling. *Phyton (Buenos Aires)*, 88, 185–221. <https://doi.org/10.32604/phyton.2019.07559>
43. Hashem, A., Tabassum, B., & Abd_Allah, E. F. (2019). Fungi–plant interaction: Role of arbuscular mycorrhizal fungi in improving plant tolerance to abiotic stress. *Frontiers in Microbiology*, 10, 1068. <https://doi.org/10.3389/fmicb.2019.01068>
 44. He, M., & Ding, N.-Z. (2020). Plant unsaturated fatty acids: Multiple roles in stress response. *Frontiers in Plant Science*, 11, 562785. <https://doi.org/10.3389/fpls.2020.562785>
 45. Helgi Library. (2023). *Tomato production in Algeria 2010–2022*. <https://www.helgilibrary.com>
 46. Ho, L. C., & White, P. J. (2005). A cellular hypothesis for the induction of blossom-end rot in tomato fruit. *Annals of Botany*, 95(4), 571–581. <https://doi.org/10.1093/aob/mci065>
 47. Hochmuth, G. J., & Hanlon, E. A. (2010). *Fertilizer management for greenhouse tomatoes: Florida greenhouse vegetable production handbook* (Vol. 3). University of Florida IFAS Extension.
 48. Holdt, S. L., & Kraan, S. (2011). Bioactive compounds in seaweed: Functional food applications and legislation. *Journal of Applied Phycology*, 23, 543–597. <https://doi.org/10.1007/s10811-010-9632-5>
 49. Islam, M. T., Gan, H. M., Ziemann, M., Hussain, H. I., Arioli, T., & Cahill, D. (2020). Phaeophyceae (brown algal) extracts activate plant defense systems in *Arabidopsis thaliana* challenged with *Phytophthora cinnamomi*. *Frontiers in Plant Science*, 11, 852. <https://doi.org/10.3389/fpls.2020.00852>
 50. Jimenez-Lopez, C., Pereira, A. G., Lourenço-Lopes, C., Garcia-Oliveira, P., Cassani, L., Fraga-Corral, M., Prieto, M., & Simal-Gandara, J. (2021). Main bioactive phenolic compounds in marine algae and their mechanisms of action supporting potential health benefits. *Food Chemistry*, 341, 128262. <https://doi.org/10.1016/j.foodchem.2020.128262>
 51. Jones, J. B. (2008). *Tomato plant culture: In the field, greenhouse, and home garden*. CRC Press.
 52. Jones, J. B., Jones, J. P., Stall, R. E., & Zitter, T. A. (2007). *Compendium of tomato diseases and pests*. APS Press.
 53. Khan, W., Rayirath, U. P., Subramanian, S., Jithesh, M. N., Rayorath, P., Hodges, D. M., Critchley, A. T., Craigie, J. S., Norrie, J., & Prithiviraj, B. (2009).

- Seaweed extracts as biostimulants of plant growth and development. *Journal of Plant Growth Regulation*, 28(4), 386–399. <https://doi.org/10.1007/s00344-009-9103-x>
54. Khan, W., Rayirath, U. P., Subramanian, S., Jithesh, M. N., Rayorath, P., Hodges, D. M., ... & Prithiviraj, B. (2009). Seaweed extracts as biostimulants of plant growth and development. *Journal of Plant Growth Regulation*, 28(4), 386–399.
 55. Knapp, S., Bohs, L., Nee, M., & Spooner, D. M. (2004). Solanaceae – a model for linking genomics with biodiversity. *Comparative and Functional Genomics*, 5(3), 285–291. <https://doi.org/10.1002/cfg.428>
 56. Kumar, A., & Sharma, R. (2023). Role of inorganic fertilizers in modern agriculture: Nourishing plants with minerals. *International Scholars Journals*.
 57. Kumar, A., Singh, R. J., & Kumar, R. (2014). Effect of organic and inorganic sources of nutrients on yield and quality of tomato (*Solanum lycopersicum* L.). *Journal of Horticultural Research*, 22(1), 135–139
 58. Linares, G., & Rojas, M. (2022). Ultrasound-assisted extraction of natural pigments from food processing by-products: A review. *Frontiers in Nutrition*, 9, 891462. <https://doi.org/10.3389/fnut.2022.891462>
 59. Liu, S., Wang, Z. Y., Niu, J. F., Dang, K. K., Zhang, S. K., & Wang, S. Q. (2021). Changes in physicochemical properties, enzymatic activities, and the microbial community of soil significantly influence the continuous cropping of *Panax quinquefolius* L. (American ginseng). *Plant and Soil*, 463, 427–446. <https://doi.org/10.1007/s11104-021-04911-2>
 60. Liu, W., Zhang, Y., Jiang, S., Deng, Y., Christie, P., Murray, P. J., Li, X., & Zhang, J. (2021). Spatiotemporal changes in microbial community structure and enzyme activity in an acidified soil fertilized long-term with chemical fertilizer. *Science of the Total Environment*, 753, 142250. <https://doi.org/10.1016/j.scitotenv.2020.142250>
 61. Liu, Y., Lv, Z., Hou, H., Lan, X., Ji, J., & Liu, X. (2021). Long-term effects of combination of organic and inorganic fertilizer on soil properties and microorganisms in a Quaternary Red Clay. *PLOS ONE*, 16(12), e0261387. <https://doi.org/10.1371/journal.pone.0261387>
 62. López-Cruz, R., Sandoval-Contreras, T., & Iniguez-Moreno, M. (2023). Plant pigments: Classification, extraction, and challenge of their application in the food

- industry. *Food and Bioprocess Technology*, 16, 2725–2741.
<https://doi.org/10.1007/s11947-023-03099-3>
63. Makhaye, G., Mofokeng, M., Tesfay, S., Aremu, A., van Staden, J., & Amoo, S. (2021). Influence of plant biostimulant application on seed germination.
64. Meier, U. (2001). *Growth stages of mono- and dicotyledonous plants* (BBCH Monograph). Federal Biological Research Centre for Agriculture and Forestry.
65. Michalak, I., Chojnacka, K., & Saeid, A. (2017). Plant growth biostimulants, dietary feed supplements and cosmetics formulated with supercritical CO₂ algal extracts. *Molecules*, 22(1), 66. <https://doi.org/10.3390/molecules22010066>
66. Ministère de l'Agriculture et du Développement Rural (MADR). (2022). *Rapport sur la filière maraîchère en Algérie*.
67. Ministère de l'Agriculture et du Développement Rural (NADRP). (2023). *Rapport annuel sur la production maraîchère : Filière tomate en Algérie*. Alger : NADRP.
68. Mišurcová, L. (2011). Chemical composition of seaweeds. In S.-K. Kim (Ed.), *Handbook of marine macroalgae: Biotechnology and applied phycology* (pp. 171–192). John Wiley & Sons. <https://doi.org/10.1002/9781119977087.ch10>
69. Morais, M. G., Rosa, G. M., Moraes, L., Alvarenga, A. G. P., Silva, J. L. V., & Costa, J. A. V. (2021). Microalgae polysaccharides with potential biomedical application. In *Polysaccharides of microbial origin* (pp. 363–380). Springer International Publishing. https://doi.org/10.1007/978-3-030-68697-4_14
70. Naika, S., Jeude, J. V. L., de Goffau, M., Hilmi, M., & Van Dam, B. (2005). *Cultivation of tomato: Production, processing and marketing*. Agromisa Foundation and CTA.
71. Nedumaran, T., & Arulbalachandran, D. (2015). Les algues : Une source prometteuse pour le développement durable. In P. Thangavel & G. Sridevi (Eds.), *Environmental sustainability: Rôle des technologies vertes* (pp. 65–88). Springer India. https://doi.org/10.1007/978-81-322-2056-5_5
72. Peet, M. M., & Welles, G. (2005). Greenhouse tomato production. In *Crop Production Science in Horticulture* (Vol. 13).
73. Peralta, I. E., Spooner, D. M., & Knapp, S. (2008). *Taxonomy of wild tomatoes and their relatives (Solanum sect. Lycopersicoides, sect. Juglandifolia, sect. Lycopersicon; Solanaceae)*. *Systematic Botany Monographs*, 84, 1–186.
74. Pereira, C. M. P., Nunes, C. F. P., Zambotti-Villela, L., Streit, N. M., Dias, D., Pinto, E., Gomes, C. B., & Colepicolo, P. (2017). Extraction of sterols in brown

- macroalgae from Antarctica and their identification by liquid chromatography coupled with tandem mass spectrometry. *Journal of Applied Phycology*, 29, 751–757. <https://doi.org/10.1007/s10811-016-0905-5>
75. Priolo, D., Tolisano, C., Brienza, M., & Del Buono, D. (2023). Application of seaweed generates changes in the substrate and stimulates the growth of tomato plants. *Plants*, 12(7), 1520. <https://doi.org/10.3390/plants12071520>
76. Priolo, D., Tolisano, C., Brienza, M., & Del Buono, D. (2023). L'application d'algues génère des modifications du substrat et stimule la croissance des plants de tomates. *Plants*, 12(7), 1520. <https://doi.org/10.3390/plants12071520>
77. Pudup, M. B. (2022). The resilience of home and community gardening during COVID-19: Evidence from the United States and Europe. *Journal of Agriculture, Food Systems, and Community Development*, 11(2), 65–78. <https://doi.org/10.5304/jafscd.2022.112.004>
78. Rachidi, F., Touraev, A., & Camprubi, A. (2020). Microalgae polysaccharides bio-stimulating effect on tomato plants: Growth and metabolic distribution. *Biotechnology Reports*, 26, e00509. <https://doi.org/10.1016/j.btre.2020.e00509>
79. Ramadoss, R., Muthusamy, S., & Manickam, M. (2023). Plant secondary metabolites: The weapons for biotic stress. *Metabolites*, 13(1), 122. <https://doi.org/10.3390/metabo13010122>
80. Rodriguez-Mena, A., Ochoa-Martínez, L. A., Gonzalez-Herrera, S. M., Rutiaga-Quinones, O. M., Gonzalez-Laredo, R. F., & Olmedilla-Alonso, B. (2023). Natural pigments of plant origin: Classification, extraction and application in foods. *Food Chemistry*, 398, 133908. <https://doi.org/10.1016/j.foodchem.2022.133908>
81. Rogowska, A., & Szakiel, A. (2020). The role of sterols in plant response to abiotic stress. *Phytochemistry Reviews*, 19, 1525–1538. <https://doi.org/10.1007/s11101-020-09708-2>
82. Roupael, Y., Colla, G., Trevisan, M., Cocetta, G., Del Follo-Martinez, A., Cardarelli, M., & Bonini, P. (2020). Toward a sustainable agriculture through plant biostimulants: From experimental data to practical applications. *Frontiers in Plant Science*, 11, 40. <https://doi.org/10.3389/fpls.2020.00040>
83. Sanye, M., et al. (2021). Agroecology and climate-smart practices in Mediterranean horticulture. *Mediterranean Journal of Agriculture*, 34(2), 45–59.

84. Savci, S. (2012). An agricultural pollutant: Chemical fertilizer. *International Journal of Environmental Science and Development*, 3(1), 73–80. <https://doi.org/10.7763/IJESD.2012.V3.191>
85. Sekar, P. R., Manimaran, P., Lakshmi, J., & Rajasekar, P. (2018). Influence of foliar application of seaweed extract and plant growth regulators on growth and physiological attributes of *Jasminum sambac*. *Environment and Ecology*, 36, 262–264.
86. Sharma, H. S. S., Fleming, C., Selby, C., Rao, J. R., & Martin, T. (2014). Plant biostimulants: A review on the processing of macroalgae and use of extracts for crop management to reduce abiotic and biotic stresses. *Journal of Applied Phycology*, 26, 465–490. <https://doi.org/10.1007/s10811-013-0101-9>
87. Shemi, R., Wang, R., Gheith, E.-S. M. S., Hussain, H. A., Hussain, S., Irfan, M., Cholidah, L., Zhang, K., Zhang, S., & Wang, L. (2021). Effects of salicylic acid, zinc and glycine betaine on morpho-physiological growth and yield of maize under drought stress. *Scientific Reports*, 11, 3195. <https://doi.org/10.1038/s41598-021-82264-7>
88. Shi, T. S., Collins, S. L., Yu, K., et al. (2024). A global meta-analysis on the effects of organic and inorganic fertilization on grasslands and croplands. *Nature Communications*, 15, 3411. <https://doi.org/10.1038/s41467-024-47829-w>
89. Silvello, M. A. D. C., Gonçalves, I. S., Azambuja, S. P. H., Costa, S. S., Silva, P. G. P., Santos, L. O., & Goldbeck, R. (2022). Microalgae-based carbohydrates: A green innovative source of bioenergy. *Bioresource Technology*, 344, 126304. <https://doi.org/10.1016/j.biortech.2021.126304>
90. Solovchenko, A., Yahia, E. M., & Chen, C. (2019). Pigments. In E. M. Yahia (Ed.), *Postharvest physiology and biochemistry of fruits and vegetables* (pp. 225–252). Woodhead Publishing. <https://doi.org/10.1016/B978-0-12-813278-4.00011-9>
91. Sonneveld, C., & Voogt, W. (2009). *Plant nutrition of greenhouse crops*. Springer Science & Business Media.
92. Sudhakar, P., Latha, P., & Reddy, P. V. (2016). Plant pigments. In P. Sudhakar, P. Latha, & P. V. Reddy (Eds.), *Phenotyping crop plants for physiological and biochemical traits* (pp. 121–127). Academic Press. <https://doi.org/10.1016/B978-0-12-803196-4.00015-6>

93. Sujith Kumar, M. S., Mawlong, I., Ali, K., & Tyagi, A. (2018). Regulation of phytosterols biosynthetic pathway during drought stress in rice. *Plant Physiology and Biochemistry*, 129, 11–20. <https://doi.org/10.1016/j.plaphy.2018.05.006>
94. Thakur, S., Bisen, R. K., Verma, S. K., Agrawal, H. P., Chaure, N. K., & Shrivastava, R. (2022). Study on effect of plant growth regulators on growth and yield of tomato (*Lycopersicon esculentum* Mill.). *Journal of Pharmacognosy and Phytochemistry*, 11(4), 309–310.
95. Tigchelaar, E. C. (1986). Tomato breeding. In T. K. Bose & M. G. Som (Eds.), *Vegetable crops in India* (pp. 428–447). Naya Prokash.
96. Wally, O. S. D., Critchley, A. T., Hiltz, D., Craigie, J. S., Han, X., Zaharia, L. I., Abrams, S. R., & Prithiviraj, B. (2013). Regulation of phytohormone biosynthesis and accumulation in *Arabidopsis* following treatment with commercial extract from the marine macroalga *Ascophyllum nodosum*. *Journal of Plant Growth Regulation*, 32, 324–339. <https://doi.org/10.1007/s00344-012-9301-9>
97. Wang, J., Liu, X., Zhang, X., Song, X., Guo, L., & Xu, J. (2019). Effects of long-term application of organic fertilizer on improving organic matter content and retarding acidity in red soil from China. *Soil and Tillage Research*, 195, 104382. <https://doi.org/10.1016/j.still.2019.104382>
98. Wang, Z., Yu, Y., Sun, Y., Liu, L., Zhang, Q., & Fan, J. (2022). Overfertilization reduces tomato yield under long-term continuous cropping system via regulation of soil microbial community composition. *Frontiers in Microbiology*, 13, Article 952021. <https://doi.org/10.3389/fmicb.2022.952021>
99. Zhou, R. R., Wang, Y., Tian, M. M., Jahan, M. S., Shu, S., & Sun, J. (2021). Mixing of biochar, vinegar and mushroom residues regulates soil microbial community and increases cucumber yield under continuous cropping regime. *Applied Soil Ecology*, 161, 103883. <https://doi.org/10.1016/j.apsoil.2021.103883>
100. Zhu, K., Zhang, Y., Nie, S., Xu, F., He, S., Gong, D., Wu, G., & Tan, L. (2017). Physicochemical properties and in vitro antioxidant activities of polysaccharide from *Artocarpus heterophyllus* Lam. pulp. *Carbohydrate Polymers*, 155, 354–361. <https://doi.org/10.1016/j.carbpol.2016.08.091>
101. Zörb, C., Senbayram, M., & Peiter, E. (2014). Potassium in agriculture—Status and perspectives. *Journal of Plant Physiology*, 171(9), 656–669. <https://doi.org/10.1016/j.jplph.2013.08.008>

102. **Zotarelli, L., Hochmuth, G. J., Hanlon, E. A., Olson, S. M., Simonne, E. H., & Santos, B. M.** (2009). *Nitrogen recommendations for tomatoes in Florida using IFAS standard nutrient recommendation and component approaches*. University of Florida, IFAS Extension.
103. Zuzunaga-Rosas, J., González-Orenga, S., Tofei, A. M., Boscaiu, M., Moreno-Ramón, H., Ibáñez-Asensio, S., & Vicente, O. (2022). Effect of a biostimulant based on polyphenols and glycine betaine on tomato plants' responses to salt stress. *Agronomy*, 12(9), 2142. <https://doi.org/10.3390/agronomy12092142>