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MAXIMIZING WATERMELON (*CITRULLUS LANATUS THUNB.*) GROWTH, YIELD AND QUALITY THROUGH SYNERGISTIC USE OF BIOFERTILIZERS AND INORGANIC NUTRIENTS

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ABSTRACT

India occupies the distinguished rank of the second-largest global contributor to horticultural yields. However, the pressing need for escalated productivity and heightened quality has surfaced in light of the surging populace. The attainment of these goals mandates the adoption of ecologically benign technologies that amplify production, thus safeguarding national food security and engendering sustainable production paradigms. In recent times, escalating concerns regarding the deleterious repercussions of synthetic fertilizers on soil vitality and the environment have spurred interest. Within this framework, biofertilizers have emerged as a viable panacea, proffering a protracted and economically judicious alternative to these predicaments. In accordance with the aforementioned imperatives, an orchestrated field experiment, titled "Impacts of Biofertilizers Augmented with Inorganic Nutrients on the Growth, Yield, and Quality Metrics of *Citrullus lanatus* Thunb. (Watermelon)," was executed at the New Vegetable Farm, housed within the precincts of the M. S. Swaminathan School of Agriculture, an esteemed entity within the rubric of Centurion University of Technology and Management, sited in R. Sitapur, Odisha. A Randomized Block Design (RBD), encompassing ten distinct treatments, was employed, with a thrice-iterated replication protocol. The experimental ensemble encompassed a solitary watermelon cultivar, interwoven with three biofertilizers - Azotobacter, Phosphate Solubilizing Bacteria (PSB), and Potassium Solubilizing Bacteria (KSB), realized through eight distinctive permutations of treatment combinations. This was juxtaposed with controls representing both 100% and 75% of the Recommended Dose of Fertilizer (RDF). The biofertilizers were introduced individually Azotobacter, PSB, and KSB in addition to a composite application. The culmination of the investigation unveiled compelling outcomes. Parameters encompassing growth metrics, yield indices, and attributes related to yield exhibited discernible optima. For instance, the apical treatment involving 75% NPK + Azotobacter + PSB + KSB yielded maximal sub-creeper density per plant (3.93), a zenithal count of fruits per plant (3.80), and an unparalleled yield quantum per hectare (71.66 t). Correspondingly, the nadir of node occurrence for the first female flower (5.33), the swiftest chronology of male flower emergence (30.53 days), and the truncated interlude between flower inception and fruit formation (41.27 days) were emblematic of this treatment. Concomitantly, the most elevated assemblage of total soluble solids (12.40 °Brix) and lycopene content (6.24 mg/100g) was realized through the medium of the 50% K, 100% N, P + KSB regimen.

***Keywords*:** Biofertilizers, Watermelon, Lycopene, Azotobacter

Introduction

In the intricate web of human progress, few sectors are as vital and impactful as agriculture. For millennia, agriculture has not only sustained civilizations but has also served as the cornerstone of economic development and societal well-being. This significance is especially pronounced in regions like R. Sitapur of Parlakhemundi in the Gajapati district of Odisha, where agriculture is not just an occupation, but a way of life ingrained in the cultural fabric. As we stand at the crossroads of the 21st century, the global agricultural landscape is undergoing a transformative shift. Climate change, evolving consumer demands, population growth, and technological advancements are ushering in a new era of agricultural practices. In this context, it becomes imperative to delve into the specific needs and challenges faced by local agricultural communities, such as those in R. Sitapur.

The Gajapati district is known for its rich agricultural heritage, with farmers contributing significantly to the regional economy. However, this sector is confronted with multifaceted challenges that threaten its sustainability and growth. Factors like unpredictable weather patterns due to climate change, inadequate access to modern farming techniques and technologies and limited awareness about sustainable agricultural practices have collectively cast a shadow on the future of farming in R. Sitapur.

The proposed research work aims to be a beacon of light in this scenario, illuminating a path towards a more resilient, efficient, and prosperous agricultural sector. By delving into the specific challenges faced by farmers in R. Sitapur, this research seeks to uncover tailored solutions that can uplift the local agricultural ecosystem. Whether it's through the adoption of precision agriculture techniques to empower the farmers of R. Sitapur to overcome their challenges and seize new opportunities.

With the dual aims of curbing excessive inorganic fertilizer deployment and elevating produce quality while concurrently preserving soil health, the strategic integration of bio-fertilizers has garnered attention. These bio-fertilizers, characterized by their cost-effectiveness and environmentally harmonious nature, contribute to heightened soil sustainability and productivity. A cornerstone of their efficacy lies in the microorganisms they harbor, which facilitate the transformation of nutrient elements from latent to accessible forms through diverse biological processes. In a concerted effort to elucidate the ramifications of amalgamating bio-fertilizers with inorganic nutrients, a comprehensive study was undertaken.

Citrullus lanatus L. (Cucurbitaceae), commonly known as watermelon, holds substantial significance as a fruit vegetable within warmer global regions. Crops belonging to the Cucurbitaceae family exhibit favourable responses to nutrient supplementation. However, this often culminates in the excessive utilization of inorganic fertilizers to secure amplified yields and enhanced growth. Unfortunately, this indiscriminate reliance on chemical fertilizers precipitates an array of predicaments, including soil productivity degradation, environmental contamination, and the depletion of finite energy resources. To counteract these issues, the integrated plant nutrient approach has gained prominence, with the goal of achieving sustainable production while mitigating the adverse impacts of inorganic fertilizers on both soil vitality and the ecological milieu.

Watermelon, scientifically designated as *Citrullus lanatus* Thunb., stands as a diploid organism with a chromosomal count of 2n = 22. It finds its taxonomic place within the Cucurbitaceae family and originates from the fertile grounds of South Africa. The consumable portion of this botanical entity is the endocarp or placenta. Notably, watermelon thrives in warm climatic conditions, necessitating an elongated growing season for optimal development. Within the agricultural landscape of India, watermelon assumes a substantial role among the cucurbitaceous crops, encompassing a sprawling expanse spanning 1.19 million hectares, ultimately culminating in an annual yield of 3.25 million metric tons (NHB, 2022).

The watermelon's succulent pulp constitutes a remarkable 93% water content, albeit punctuated with modicum levels of vital nutrients. Within every hundred grams of watermelon flesh, a discernible nutritional profile unfolds. This includes energy contributions at 127 kJ/30 kcal, carbohydrate content at 7.55 g, sugars accounting for 6.2 g, a fractional fiber content of 0.4 g, nominal fat presence at 0.2 g, protein representation at 0.6 g, accompanied by 569 IU of vitamin A and 8.1 mg of vitamin C. In addition, this aqueous indulgence supplies 7 mg of calcium, 0.24 mg of iron, and a remarkable 4532 µg of lycopene. It is noteworthy that lycopene, a compound renowned for its anti-carcinogenic properties, is conspicuously present in red-fleshed watermelon cultivars (Choo and Sin, 2012). Pertinently, the lycopene content in the dark red watermelon variants surpasses those observed in tomatoes, grapefruit, and guava, as meticulously documented in the USDA nutrient database (Cooperstone, 2019).

Watermelon, characterized as a trailing vine, features a delicate, slender, and angular stem adorned with fine hairs, alongside tendrils branching out from each node. The flowers of watermelons, while small and yellow, exhibit a diameter of one centimeter and are less ostentatious in comparison to their cucurbitaceous counterparts (Paris *et al*, 2013). These blooms adhere to a monoecious pattern, wherein distinct male and female flowers coexist on a single plant. This floral arrangement transpires solitarily and adheres to a proportional distribution, typically encompassing a ratio of 5 to 7 male flowers for each female counterpart (Ranganna, 1986).

The realm of cucurbitaceous crops manifests a robust response to the infusion of nutrients. However, this often necessitates the overzealous application of inorganic fertilizers, an endeavor undertaken to attain amplified yields and foster augmented growth. Tragically, this indiscriminate reliance on chemical fertilizers ushers forth an array of predicaments, ranging from the degradation of soil productivity to environmental contamination, and even the depletion of non-renewable energy resources. To counteract these multifaceted concerns, the strategic integration of an all-encompassing plant nutrient paradigm comes into play. This approach, characterized as the integrated plant nutrient system, seeks to usher in sustainable production practices, while concomitantly curbing the deleterious repercussions stemming from the deployment of inorganic fertilizers on both soil health and the ecological milieu.

Beyond the realm of natural climate variability, the relentless occurrence of frequent and intensified extreme events, instigated by human activity, stands as the chief impetus behind climate change. This shift catalyzes adverse repercussions, incurring losses and damages to both the natural world and humanity. Climate change, a phenomenon woven intricately into the tapestry of Earth's history, has recently surged to the forefront as a pivotal scientific concern, garnering attention over the past decade due to its escalating threat to food security. It exerts a discernible influence on soil fertility, orchestrated by alterations in soil moisture, surging soil temperatures, and elevated concentrations of CO_2. These factors collectively precipitate a cascade of land degradation, encapsulating shifts in the land's potential for productive human use.

Against the backdrop of these challenges, the canvas of land degradation unfolds as a pressing global predicament, amplifying notably in developing nations. This deterioration of land quality finds its causal roots in the sweeping embrace of climate change, in turn yielding substantial repercussions for agriculture. This juncture assumes a pivotal role, particularly as modern societies grapple with burgeoning populations and endeavor to meet the voracious global appetite for sustenance while grappling with finite soil resources. In this context, the concept of "land degradation neutrality" emerges as a compelling imperative, crystallizing as one of the Sustainable Development Goals. It encapsulates the collective resolve to halt the rampant erosion of land quality.

In pursuit of land degradation neutrality, a triad of concurrent actions is indispensable. Firstly, the avoidance of new land degradation is championed through the preservation of existing, robustly healthy land tracts. Secondly, the attenuation of extant land degradation necessitates the embrace of sustainable land management practices, entailing a concerted upscaling of efforts towards restoration. Lastly, the reclamation of degraded lands, culminating in their return to a natural or heightened productive state, occupies a significant facet of this endeavor. The attainment of land degradation neutrality entails a seismic shift in the ethos of land stewardship, pivoting from a course of "degrade-abandon-migrate" to a trajectory of "protect-sustain-restore." This paradigm shift emerges as the call of the hour, resonating as an integral component of the global strategy to safeguard our precious land resources.

In the aforementioned context, one of the pivotal concurrent actions necessary to attain land degradation neutrality is the incorporation of biofertilizers. These biofertilizers constitute a consortium of microorganisms that possess the remarkable ability to transform nutrients from their inert, non-utilizable state into a biologically accessible form, orchestrated through intricate biological processes. These microorganisms stand as a fiscally prudent and economical source of plant nourishment, devoid of the demand for non-renewable energy resources during their production. Their application fosters not only augmented crop growth but also an elevation in product quality, facilitated by the synthesis of plant hormones. Moreover, their role extends to nurturing sustainable crop production systems, thereby preserving the productivity of soil.

Biofertilizers, in their unique role as biocontrol agents, contribute to the management of numerous plant pathogens, amplifying their significance. These live formulations of beneficial microorganisms, when applied to seeds, roots, or soil, trigger a cascade of nutrient mobilization through their biological activities. This, in turn, engenders the restoration of a balanced microflora, enhancing soil health and overall productivity. Consequently, the adoption of biofertilizers is surging, driven by the escalating costs of chemical fertilizers, the positive impact on soil vitality, and the consequent surge in crop yields.

This realm of bio fertilization encompasses the utilization of biological microorganisms to enhance plant growth, whether by augmenting nutrient accessibility, releasing growth-promoting hormones, mitigating pathogen-induced damage, or bolstering resistance to environmental stresses. The utilization of nitrogen-fixing microorganisms like *Azotobacter* and phosphate-solubilizing bacteria holds well-documented promise as supplementary sources of plant nutrition in agricultural contexts (Gajbhiye *et al*., 2003).

The pivotal role of nutrients in shaping the quality and yield of horticultural crops cannot be overstated. Soil nutrient status serves as a linchpin, profoundly influencing crop productivity. While synthetic fertilizers and agrochemicals contribute substantially to production efficiency, excessive reliance on chemical fertilizers incurs collateral damages like soil degradation, groundwater pollution, and environmental harm. Such imbalanced use precipitates soil fertility loss and compromises soil health. In light of these challenges, the impetus for alternative, eco-friendly production systems that align harmoniously with the environment and judiciously manage soil health has grown more pronounced.

Azotobacters, as independent nitrogen-fixing bacteria, obviate the need for symbiosis and a specific host plant. Flourishing in well-drained, neutral soils, these bacteria can secure atmospheric nitrogen fixation in crops, yielding up to 30 kg N per hectare annually. Additionally, *Azotobacter* species produce antifungal compounds to counteract plant pathogens and enhance germination and vigour in young plants, thereby fostering improved crop establishment.

Phosphate-solubilizing bacteria play an instrumental role in the liberation of native phosphorus from recalcitrant sources like rock phosphate. They exude organic acids that facilitate phosphorus solubilization, mitigating the problems of phosphorus fixation and loss of applied fertilizers. In the same vein, potassium-solubilizing bacteria wield the ability to dissolve potassium-bearing minerals, converting insoluble forms into plant-accessible soluble forms through the secretion of organic and inorganic acids.

The epoch of eco-friendly farming champions the incorporation of biofertilizers as a conduit for fostering sustainability within agriculture. Thus, the integration of biofertilizers into the cultivation of horticultural crops emerges as an instrumental practice, safeguarding both soil health and the quality of agricultural output. This holistic approach not only elevates productivity but also aligns harmoniously with the imperatives of environmental stewardship.

The primary objective of this study is to examine and elucidate the impact of biofertilizers, in conjunction with inorganic nutrients, on the comprehensive spectrum of growth, yield, and quality attributes intrinsic to watermelon (*Citrullus lanatus* Thunb).

Material and Methods

The investigation, titled "Studies on the Influence of Biofertilizers in Combination with Inorganic Nutrients on Growth, Yield, and Quality Attributes of Watermelon (*Citrullus lanatus* Thunb)," has been initiated to unravel the intricate interplay between biofertilizers and conventional inorganic nutrients and their impact on the multifaceted aspects of watermelon performance. This study is being conducted at the New Vegetable Farm of the M.S. Swaminathan School of Agriculture, situated within the auspices of Centurion University of Technology and Management, located in Parlakhemundi, Odisha. The temporal scope of this research encapsulates the Rabi season of 2022-23.

The research site occupies a significant position within the North Eastern Ghat Agro Climatic Zone, characterized by an average annual rainfall of 1423.6 mm. The site's geographical coordinates are situated at a latitude of 18° 46' 41.8584" N and a longitude of 84° 5' 37.1436" E, encompassing an altitude of 1035 meters above mean sea level. The climatic milieu experienced at this location mirrors a hot, moist, and sub-humid climate, a factor that undoubtedly shapes the performance and behaviour of the watermelon crop under scrutiny.

Within this backdrop, the investigation strives to unveil the nuanced ramifications of coupling biofertilizers with inorganic nutrients on diverse aspects of watermelon growth, reproductive characteristics, yield metrics, and qualitative attributes. The holistic perspective of this research seeks to enhance our comprehension of modern agricultural practices and, in turn, refine strategies that harmonize ecological stewardship with enhanced productivity and quality standards for watermelon cultivation.

Experimental Material

The experimental setup encompassed a singular watermelon variety, which formed the foundational genetic material for the study. This variety was subjected to a diverse array of treatments, each comprising a distinct amalgamation of biofertilizers specifically *Azotobacter*, Phosphorous Solubilizing

Bacteria (PSB), and Potassium Solubilizing Bacteria (KSB) harmoniously coupled with varying concentrations of inorganic fertilizers falling within the realm of Nitrogen-Phosphorous-Potassium (NPK) nutrients.

The biofertilizers, pivotal components of the study, were sourced from the esteemed repository of Dr Y.S.R. Horticultural University, situated in Venkataramannagudem, West Godavari, Andhra Pradesh. These biofertilizers, revered for their biologically enriching attributes, served as the cornerstone of this experimental endeavor. They were selected with utmost care to ensure the utmost rigor and scientific validity in the exploration of their combined effects with inorganic fertilizers on the target watermelon variety.

This comprehensive approach, which embraces the selection of experimental material, seeks to unravel the intricate relationships and potential synergies that arise from the interplay of biofertilizers and inorganic nutrients. Through these deliberate and strategic interventions, the research aspires to contribute to the advancement of agronomic knowledge and the refinement of cultivation practices for watermelon, a key objective in the pursuit of sustainable and efficient agricultural systems (figure 1).

Choice of Variety in The Experiment and Its Specifications

The investigation was conducted utilizing the Nirmal's Hybrid Watermelon, scientifically designated as NWMH-345 hailing from the esteemed Nirmal Seeds Private Limited, situated in Maharashtra, India. This particular hybrid variety took center stage as the subject of scrutiny, serving as the foundational genetic substrate through which the intricate interplay of biofertilizers and inorganic nutrients was meticulously studied. Characterized by its distinctive attributes, the Nirmal's Hybrid Watermelon (NWMH-345) embodies a medium-sized fruit, typically weighing between 6 to 8 kilograms. The fruit's physical morphology is distinguished by its rounded shape, accompanied by an outer rind boasting a lustrous, pure black hue. Within this elegant exterior lies a treasure trove of dark red-hued, crispy, and compact flesh, characterized by an elevated sugar content that contributes to its flavor profile. This delectable transformation is achieved over a span of 90 to 95 days from the initial sowing, culminating in the maturation of the fruit.

The NWMH-345 hybrid possesses a notable rind thickness that augments its resilience during transportation, rendering it highly suitable for shipping purposes. Additionally, the hybrid demonstrates commendable tolerance to the challenges posed by bud necrosis and fusarium wilt diseases, enhancing its robustness and viability in diverse agro-climatic settings.

The experimental design employed for this study adhered to a Randomized Block Design (RBD), a structured framework renowned for its statistical rigor. This design encompassed a total of ten distinct treatments, each meticulously tailored to explore specific interactions between biofertilizers and inorganic nutrients. To ensure robustness in the findings, each treatment was replicated three times, resulting in a total of three experimental units per treatment.

The cultivation protocols of each treatment involved the judicious application of biofertilizers. These biofertilizers were thoughtfully combined with farm yard manure, creating a synergistic union aimed at optimizing nutrient availability and fostering plant growth. The timing of this application was strategically planned, with the biofertilizers being introduced to the plant-soil system six days subsequent to the initial planting.

This experimental setup and methodology underscore the rigor with which the investigation was undertaken. By adhering to established experimental protocols, the study sought to minimize confounding variables and extract reliable insights into the complex interactions between biofertilizers, inorganic nutrients, and the growth dynamics of the targeted watermelon variety.

Table 1 : Treatment Details

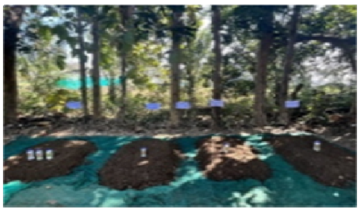
Treatment	Details
T_1	100 % RDF
T_2	75 % RDF
T_3	75 % N + 100 % P, K + *Azotobacter*
T_4	75 % P + 100 % N, K + PSB (Phosphate solubilising bacteria)
T_5	75 % K + 100 % N, P + KSB (Potassium solubilising bacteria)
T_6	75 % NPK + *Azotobacter* + PSB (Phosphate solubilising bacteria) + KSB (Potassium solubilising bacteria)

T_7	50 % N + 100 % P, K + *Azotobacter*
T_8	50 % P +100 % N, K+ PSB (Phosphate solubilising bacteria)
T_9	50 % K + 100 % N, P + KSB (Potassium solubilising bacteria)
T_{10}	50 % NPK + *Azotobacter* + PSB (Phosphate solubilising bacteria) + KSB (Potassium solubilising bacteria)

Table 2 : Sources of Biofertilizers and Inorganic Nutrients

Biofertilizers		
Biofertilizers	**Quantity (kg ha^{-1})**	**Preparation**
Azotobacter	5	Biofertilizers were incorporated into FYM remained under shade and kept moist for one week for the multiplication of biofertilizers
PSB (Phosphate Solubilising Bacteria)	5	
KSB (Potassium Solubilising Bacteria)	5	
Inorganic Fertilizers		
Dosage	**Nutrient**	**Quantity (kg ha^{-1})**
100% RDF	N	100 (217.39 kg)
	P_2O_5	60 (375 kg)
	K_2O	60 (100 kg)
75% RDF	N	75 (163.04 kg)
	P_2O_5	45 (281.25 kg)
	K_2O	45 (75 kg)
50% RDF	N	50 (108.695 kg)
	P_2O_5	30 (187.5 kg)
	K_2O	30 (50 kg)


(a)


(b)


(c)

a, b and c: Incorporation of biofertilizers with farm yard manures


(d) Application of biofertilizers


(e) Seed sowing


(f) Watermelon crop at stages (90 DAS)

Fig. 1 : Field Activities During Experimentation

Inoculation of Biofertilizers with Farm Yard Manure

The process of incorporating biofertilizers involves the utilization of well-decomposed farm yard manure as a carrier medium. A specified quantity of 200 kilograms of farm yard manure is employed for this purpose. Liquid formulations of the biofertilizers are mixed with the farm yard manure. This blending process is carried out in a sheltered environment beneath the canopy of a tree. The prepared heaps of farm yard manure are covered with gunny bags, providing a protective covering. To encourage the proliferation of microorganisms, periodic wetting is employed to sustain an optimal level of moisture. Following a duration of one week, the biofertilizer-enriched farm yard manure is systematically applied to the experimental plots, adhering to the prescribed treatment protocols.

The experimental timeline encompasses the sowing of watermelon seeds during the fourth week of December 2022, culminating in the final harvesting endeavors during the initial week of April 2022. Data collection entails a process wherein five plants are randomly selected and tagged within each individual experimental plot. This selection excludes the border plants, thereby ensuring a representative sample. The data collected are then subjected to a rigorous analysis using a methodology outlined by a specified reference (Panse and Sukhatme, (1967). The determination of statistical significance relies on the assessment of the 'F' value, employing a significance level of 5 percent.

Various parameters were assessed throughout the study. The number of sub creepers per plant was noted and the mean value is computed. The positioning of the first male and female flowers was determined in terms of the number of nodes along the main axis, with corresponding mean values calculated. The time interval from sowing to the appearance of the first male and female flowers was recorded and averaged. Additionally, the duration spanning flower to fruit formation is meticulously documented from pollination to the attainment of edible maturity. The number of fruits per plant is quantified during each harvest, with an average mean computed. The average weight of five randomly selected fruits from each treatment was measured, and subsequently used to calculate the average fruit weight per plant in kilograms. This cumulative insight was employed in the computation of yield per hectare, derived from the average yield obtained per plot for each distinct treatment.

Furthermore, the qualitative attributes of the watermelon were evaluated. The total soluble solids of fresh fruits were gauged using a digital refractometer at ambient room temperature, yielding readings expressed in ^{o}Brix. The refractometer was cleansed with distilled water after each measurement, adhering to recommended protocols. The lycopene content of the pulp was estimated using a spectrophotometry method, following a standardized procedure detailed by a specified reference (Davies, 1976).

This systematic and comprehensive approach underscores the scientific rigor and meticulousness with which the data were collected, analyzed, and interpreted throughout the course of this study.

Results and Discussion

The integration of biofertilizers with inorganic nutrients has exerted a discernible impact across a spectrum of growth, yield attributing, and yield characteristics, as evidenced by the comprehensive findings presented in Table 3 and Table 4. Noteworthy alterations in the growth parameters, including the count of sub-creepers per plant, have been observed due to the orchestrated application of these experimental inputs. Moreover, the key attributes associated with yield, encompassing the node number at which the first male and female flowers manifest, the temporal intervals taken for the emergence of the initial male and female flowers, and the span from flower initiation to fruit maturation, all showcase substantial variations under the influence of the combined biofertilizer and inorganic nutrient treatments.

The focal yield indicators, namely the number of fruits per plant and the yield per hectare, have exhibited discernible fluctuations as a result of this experimental amalgamation. These results underscore the intricate interplay between biofertilizers and inorganic nutrients, revealing their potential to influence both the qualitative and quantitative aspects of watermelon cultivation.

The tables encapsulate the nuanced alterations observed in response to these experimental interventions, serving as a repository of empirical evidence that substantiates the interdependence of biofertilizers and inorganic nutrients on the intricate dynamics governing watermelon growth, reproductive performance, and overall yield metrics.

Growth characteristics: The findings of the study distinctly illustrate that the application of treatment T_6 (comprising 75% NPK + *Azotobacter* + PSB + KSB) yielded the highest count of sub creepers per plant, with an impressive value of 3.93. In contrast, the treatment denoted as T_2 (75% RDF) exhibited the lowest number of sub creepers per plant, registering values of 2.13, while the T_1 treatment (100% RDF) displayed a slightly higher count at 2.43. These outcomes underscore the discernible impact of the experimental treatments on the sub-creeper count, further emphasizing the role of different nutrient combinations in influencing this particular growth attribute.

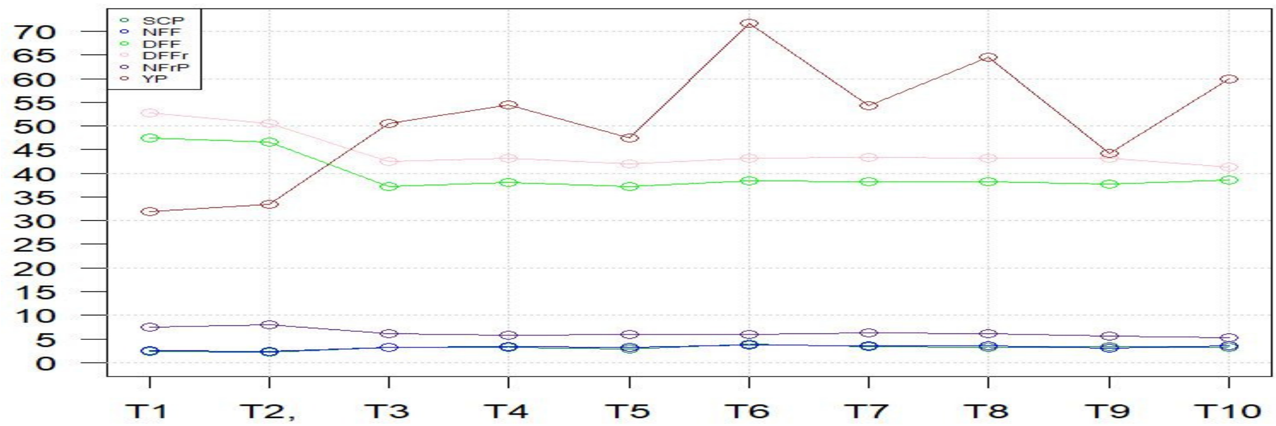
Yield attributing characteristics: The outcomes of the study have unveiled intriguing trends. Specifically, the application of 100% RDF (Recommended Dose of Fertilizer) yielded the highest node number (3.47) at which the first male flower materialized. In contrast, the treatment involving 50% NPK + *Azotobacter* + PSB + KSB (T_{10}) yielded the lowest node number (5.33) at which the initial female flower emerged. This same treatment (T_{10}) exhibited the minimum time span for the first appearance of a male flower (30.53 days), the shortest duration from flower initiation to fruit formation (41.27 days), and the speediest interval for the first female flower's manifestation (37.20 days). Intriguingly, the application of 75% K + 100% N, P + KSB (T_5) led to similar noteworthy results in these temporal attributes.

On a different note, the treatment characterized by 75% P + 100% N, K + PSB (T_4) displayed the lowest node number (2.33) for the emergence of the first male flower. Conversely, the treatment involving 75% RDF (T_2) resulted in the highest node number (8.07) at which the initial female flower appeared. Furthermore, the application of 100% RDF corresponded to the longest intervals: 41.20 days for the appearance of the first male flower, 47.67 days for the first female flower, and 52.73 days for the transition from flower to fruit formation.

These detailed findings illuminate the intricate interplay of treatments and their nuanced effects on critical growth and reproductive milestones within the watermelon cultivation process. The study's results emphasize the significance of carefully tailored nutrient combinations in steering the progression of these developmental stages.

Yield attributes: The findings of the study elucidate intriguing patterns in relation to fruit yield. Specifically, the application of 75% NPK + *Azotobacter* + PSB + KSB (T_6) emerged as the most promising treatment, yielding the highest count of fruits per plant (3.80) and an impressive yield per hectare of 71.66 tons. In contrast, the application of 75% RDF (T_2) resulted in the lowest number of fruits per plant (2.33), indicative of its comparatively limited yield potential. Notably, the treatment involving 100% RDF (T_1) showcased the lowest fruit yield per hectare, recording a yield of 31.87 tons. These outcomes underscore the profound impact of distinct treatment regimens on the crucial metrics of fruit count and overall yield, revealing the nuanced interplay between biofertilizers, inorganic nutrients, and the resultant agricultural productivity.

Quality attributes: The study outcomes highlight distinctive trends regarding the qualitative attributes of the produce. Particularly, the application of 50% K, 100% N, P + KSB (T_9) yielded remarkable results, registering the highest total soluble solids at 12.40 °Brix. Additionally, this treatment also exhibited the maximum lycopene content, measuring 6.24 mg per 100 grams. These outcomes underscore the treatment's efficacy in enhancing the fruit's sweetness and enriching its lycopene content, a compound associated with antioxidant properties.



SCP: Number of sub creepers per plant	**NFF:** Nodes at which 1st female flower appeared	**DFF:** Days for the appearance of the first female flower
DFFr: Days taken from flower to fruit formation	**NFrP:** Number of fruits per plant	**YP:** Yield per plant

Fig 2 : Effect of Biofertilizers in Combination with Inorganic Nutrients on Growth, Yield Attributing Characteristics of Watermelon (*Citrullus Lanatus* Thunb.)

Table 3: Effect of Biofertilizers in Combination with Inorganic Nutrients on Growth, Yield Attributing Characteristics of Watermelon (*Citrullus Lanatus* Thunb.)

Treatments	Number of sub	Node number	Node number	Days taken to	Days taken to	Days taken from

	creepers per plant	at which the first male flower appeared	at which the first female flower appeared	Appearance of first male flower	the Appearance of the first female flower	flowering to fruit formation
T1: 100 % RDF	2.40de	3.47a	7.43b	41.20d	47.47b	52.73b
T2: 75% RDF	2.13e	2.93b	8.07a	40.47d	46.67b	50.60b
T3: 75% N + 100 % P, K + Azotobacter	3.27b	2.80b	6.07cd	31.13ab	37.27a	42.53a
T4: 75% P + 100 % N, K + PSB	3.27b	2.33bc	5.73cde	32.47bc	38.07a	43.13a
T5: 75% K + 100 % N, P + KSB	2.80cd	2.60bc	5.87cde	31.13ab	37.20a	42.00a
T6: 75% NPK + Azotobacter + PSB + KSB	3.93a	2.60bc	5.93cde	32.80c	38.33a	43.27a
T7: 50 % N + 100 % P, K + Azotobacter	3.40b	2.53bc	6.27c	32.47bc	38.20a	43.33a
T8: 50 % P +100 % N, K+ PSB	3.27b	2.53bc	6.13cd	32.60bc	38.27a	43.27a
T9: 50% K + 100 % N, P + KSB	3.40b	2.60bc	5.53de	32.13bc	37.67a	43.13a
T10: 50 % NPK + Azotobacter + PSB + KSB	3.20bc	2.67bc	5.33e	30.53a	38.53a	3.47bc
S.E. (m) ±	0.15	0.13	0.20	0.47	1.23	0.10
CD @ 5%	0.44	0.37	0.57	1.35	3.57	0.29
CV %	8.43	8.15	5.48	2.39	5.38	5.44

Table 4: Effect of Biofertilizers in Combination with Inorganic Nutrients On Yield and Quality Characteristics of Watermelon (*Citrullus Lanatus* Thunb.)

Treatments	**Number of fruits per plant**	**Yield per hectare (t)**	**Total Soluble Solids (^{O}Brix)**	**Lycopene (mg/100g)**
T_1: 100 % RDF	2.47f	31.87f	12.20a	5.46b
T_2: 75% RDF	2.33f	33.42f	11.80ab	1.63f
T_3: 75% N + 100 % P, K + *Azotobacter*	3.27cde	50.55de	12.10a	4.67c
T_4: 75% P + 100 % N, K + PSB	3.40bcd	54.48cd	9.75de	4.76c
T_5: 75% K + 100 % N, P + KSB	3.13de	47.54de	10.30cd	3.82d
T_6: 75% NPK + *Azotobacter* + PSB + KSB	3.80a	71.66a	9.20e	1.71f
T_7: 50 % N + 100 % P, K + *Azotobacter*	3.53abc	54.27cd	11.10bc	4.45c
T_8: 50 % P +100 % N, K+ PSB	3.60ab	64.52ab	9.83de	2.57e
T_9: 50% K + 100 % N, P + KSB	3.00e	44.27e	12.40a	6.24a
T_{10}: 50 % NPK + *Azotobacter* + PSB + KSB	3.47bc	60.02bc	9.10e	2.65e
S.E. (m) ±	**0.10**	**2.44**	**0.32**	**0.15**
CD @ 5%	**0.29**	**7.07**	**0.94**	**0.46**
CV %	**5.44**	**8.26**	**5.07**	**7.05**

Conversely, the treatment involving 75% NPK + Azotobacter + PSB + KSB (T_6) displayed comparatively lower total soluble solids, recording a value of 9.20 °Brix. Similarly, this treatment yielded the lowest lycopene content among the studied treatments. The application of 75% RDF (T_2) corresponded to the lowest lycopene content, measured at 1.63 mg per 100 grams. These findings accentuate the dynamic influence of different treatment combinations on the flavor-enhancing attributes of total soluble solids and the health-promoting aspect of lycopene content in watermelon fruits.

The application of biofertilizers to the soil resulted in a significant improvement in vine length compared to plants treated solely with chemical fertilizers, indicating a positive impact of biofertilizers on plant growth. This finding is particularly valuable as it suggests a sustainable and environmentally friendly alternative to traditional chemical fertilizers. Furthermore, the treatment combining 75% NPK fertilizer with *Azotobacter*, PSB, and KSB resulted in the highest number of sub creepers per plant. This suggests that the synergistic effects of these beneficial microbes with NPK fertilizers contribute to enhanced plant growth. The presence of *Azotobacter*, PSB, and KSB enhances soil nutrient cycling and creates a favourable environment for optimal plant development These results are in line with the findings of Sonkamble *et al.* (2022), Patel *et al.* (2022) and Jyoti and Tiwari (2020).

Moreover, the application of 50% NPK fertilizer along with *Azotobacter*, PSB, and KSB led to a reduction in the number of nodes required for the appearance of the first female flowers. This indicates that the presence of beneficial microorganisms positively influences flowering patterns. The improved nutrient uptake and utilization facilitated by these microbes may contribute to the earlier onset of female flowers. This finding holds practical significance for farmers as it can help improve crop productivity and shorten the time required for fruit production. Additionally, the treatment with 75% NPK + *Azotobacter* + PSB + KSB yielded the maximum number of fruits per plant and the highest overall yield per hectare. This underscores the effectiveness of this treatment in promoting fruit production. The presence of *Azotobacter* and PSB, which enhance nutrient fixation and solubilization, likely plays a crucial role in improving nutrient availability and utilization, leading to increased productivity. These results are in line with the findings of Ghosh *et al.* (2016), Kharat *et al.* (2021) and Sonkamble *et al.* (2022) in watermelon, Thriveni *et al*. (2015) in bitter gourd and Azarmi *et al.* (2009) in cucumber. Furthermore, treatment T_9, which included a balanced ratio of 50% K and 100% N, P, along with KSB, demonstrated an increase in Total Soluble Solids (TSS) and Lycopene content. This suggests that the balanced NPK ratio and the presence of KSB contribute to improved nutrient uptake and utilization. The higher TSS and Lycopene content have the potential to enhance the quality and nutritional value of the fruits, making this treatment beneficial for producing high-quality crops. These results are supported by the findings of Tahir *et al*. (2018) in Watermelon.

It has been observed that higher doses of NPK fertilizer do not always result in better growth of sub creepers, as evidenced by the treatment with 100% RDF (T_1) producing the fewest sub creepers per plant. This highlights the negative impact of excessive nitrogen from chemical fertilizers on plant growth. It underscores the significance of proper dosage and management of chemical fertilizers to prevent adverse effects on plant development. Moreover, treatment T_6 (75% NPK + *Azotobacter* + PSB + KSB) exhibited the lowest Total Soluble Solids (TSS) value. The presence of PSB and Azotobacter, potentially leading to increased nitrogen availability, could explain the lower TSS content in this treatment. Additionally, the imbalanced nutrient ratios in T6 may have contributed to a decline in fruit quality. This finding emphasizes the importance of carefully considering nutrient ratios and their interaction with beneficial microorganisms to achieve optimal fruit quality.

The utilization of biofertilizers, including *Azotobacter*, PSB, and KSB, in combination with NPK fertilizers, demonstrates promising outcomes in stimulating plant growth and development. This discovery is intriguing as it highlights the potential advantages of harnessing the synergistic interplay between beneficial microbes and chemical fertilizers to optimize overall plant growth and increase crop yield. The consistency of these findings across various studies involving different crops, such as watermelon and ridge gourd, further reinforces the effectiveness of this approach. The positive impact of Treatment T_9 (50% K + 100% N, P + KSB) on Total Soluble Solids (TSS) and Lycopene content suggests that maintaining a balanced NPK ratio and incorporating KSB can significantly influence the uptake and utilization of nutrients by plants. This finding emphasizes the importance of nutrient equilibrium and the role of specific microorganisms in enhancing plant nutrition. However, the contrasting outcome observed in Treatment T_6 (75% NPK + *Azotobacter* + PSB + KSB), with lower TSS values, underscores the intricate interactions between nutrient availability, microbial activity, and fruit quality. Further investigation is necessary to gain a deeper understanding of the underlying mechanisms that contribute to these effects. These results are in line with the findings of Sonkamble *et al.* (2022), Patel *et al.* (2021) and Jyoti and Tiwari (2020).

Conclusion

The findings of the study underscore the complexities of nutrient application in achieving optimal growth and yield in crops. While the use of NPK fertilizers alone is a common practice, our research reveals that excessive nitrogen application can detrimentally impact plant development. However, our study demonstrates that the integration of beneficial microorganisms, including *Azotobacter*, PSB, and KSB, alongside NPK fertilizers, can revolutionize crop outcomes. This symbiotic approach enhances soil nutrient cycling, fostering a conducive environment for plant growth and yield enhancement, thus steering agriculture towards sustainability.

Nonetheless, it's important to acknowledge that the perfect blend of NPK fertilizers and beneficial microorganisms is context-dependent, contingent on specific crops and environmental factors. The integration isn't a universal remedy, demanding nuanced calibration to suit distinct agricultural settings. Notably, our investigation highlights that among the diverse biofertilizer combinations, the application of 75% NPK + *Azotobacter* + PSB + KSB emerges as a frontrunner in driving vegetative growth, yield parameters, and yield contributing attributes. Similarly, the application of 50% K + 100% N, P + KSB excels in enhancing total soluble solids (°Brix) and lycopene content (mg/100g).

In light of these findings, it's imperative to disseminate awareness among farmers regarding the potential benefits and limitations of this approach. Equipping them with guidance on the strategic application of these treatments can lead to enhanced watermelon productivity and improved quality. Ultimately, we envision our research serving as a stepping stone towards propelling sustainable agriculture, playing a pivotal role in the ongoing endeavor to shape a more ecologically conscious agricultural landscape. Moreover, we anticipate that our study will set the stage for further exploration and investigation in this field, propelling the frontiers of knowledge and practice in sustainable crop cultivation.

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