Review Article

A Comprehensive Review on Influence of N, Ca and& Nano Fertilizers on Growth Yield and Quality of Strawberry (*Fragaria* × *ananassa*Duch.).

Abstract

Strawberry cultivation represents a significant sector within the agriculture industry. The use of nitrogen (N), calcium (Ca), and nano fertilizers has emerged as an essential practice to improve both the yield and quality of strawberries. This comprehensive review aims to explore the multifaceted influence of these fertilizers on *Fragaria* × *ananassa*Duch., encompassing growth, quality, and environmental considerations. The study begins with an examination of historical perspectives and existing research, identifying gaps in the literature. The methodology includes a rigorous selection process for studies, with data extraction, quality assessment, and statistical analysis. The effects of N, Ca, and nano fertilizers on growth yield are thoroughly examined, considering their combined and individual contributions. The quality of strawberries is assessed based on physical appearance, nutritional content, and sensory characteristics, highlighting the role of these nutrients in color development, size, texture, vitamin content, sugar-acid balance, flavor, and aroma. The environmental impact is another critical aspect, exploring the effect on soil quality, including nutrient leaching, soil structure, microbial activity, and long-term health. The impact on surrounding ecosystems considers aquatic and terrestrial effects, biodiversity considerations, and the associated sustainability considerations. These encompass resource efficiency, environmental compliance, life cycle analysis, and integration with sustainable agricultural practices. Findings indicate that while N, Ca, and nano fertilizers significantly enhance growth and quality, careful management is essential to mitigate potential environmental concerns. The application of nano fertilizers presents promising opportunities for precise nutrient delivery, promoting efficiency, and sustainability. The review concludes by emphasizing the importance of continued research, innovation, and responsible management of these fertilizers in achieving a harmonious balance between productivity, quality, and environmental stewardship. The insights provided in this review contribute valuable knowledge to both scientific and agricultural communities, offering guidance for future research and best practices in strawberry cultivation.

Keywords:*Calcium, Nitrogen,Nano-fertilizers, Strawberries, Sustainability*

Introduction

Strawberry (*Fragaria* × *ananassa*Duch.) is one of the most popular and economically significant berry crops cultivated worldwide [1]. This fruit is cherished for its sweet taste, vibrant color, and pleasant aroma, contributing to its popularity among consumers [2]. The cultivation of strawberries dates back to ancient times, but the modern cultivated versions began to be developed in the 18th century [3]. The plant thrives in temperate regions and requires specific care in terms of soil, water, and nutrients.Nitrogen (N) and calcium (Ca) are essential macronutrients that play a vital role in the growth and development of strawberry plants.

Nitrogen is key to leaf and stem growth, while calcium contributes to cell wall stability and root development [4].Nano fertilizers have emerged as a novel and promising avenue for nutrient delivery [5]. Utilizing nanoparticles to encapsulate essential nutrients allows for targeted and controlled release, thereby increasing efficiency and potentially reducing environmental impact [6].Nitrogen (N): Integral to photosynthesis, nitrogen affects the plant's color and vitality [7].Calcium (Ca): Essential for cell division and elongation, calcium's deficiency can lead to deformation in fruits [8].Nano Fertilizers: Representing a new era of precision agriculture, nano fertilizers provide nutrients in a controlled manner, enhancing nutrient uptake and minimizing losses [9].The synthesis of N, Ca, and nano fertilizers in strawberry cultivation represents an interdisciplinary field of research. The optimization of these nutrients is paramount to enhancing the growth, yield, and quality of strawberry crops [10]. As global demand for strawberries continues to increase, there is a growing need to understand how these vital nutrients can be manipulated to maximize production while maintaining sustainability [11]. It conflicting studies and limited comprehensive reviews make it essential to collate and analyze existing research, providing a holistic understanding [12].The main objectives of this review are:To summarize existing research on the influence of N, Ca, and nano fertilizers on strawberry cultivation.To evaluate the effectiveness and potential drawbacks of these nutrients in different agricultural contexts.To provide recommendations for best practices in nutrient management for strawberry growers.To identify gaps in the existing literature and propose directions for future research in this domain.

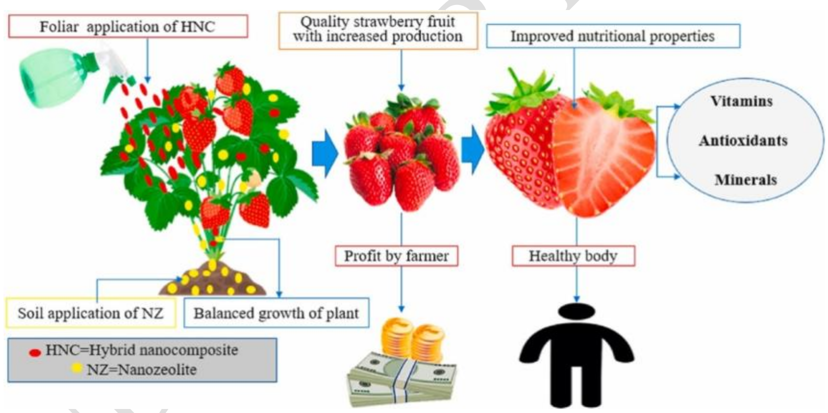

Image 1: Representation of Strawberry through Nano fertilizer
(Source: https://www.sciencedirect.com/)

Literature Review

Nitrogen has been recognized as an essential nutrient for plants since the early 19th century [13]. Initially sourced from natural deposits such as guano, synthetic ammonia fertilizers started to be produced in the early 20th century with the development of the Haber-Bosch process [14]. This technological innovation revolutionized agriculture, enabling higher crop yields [15].Calcium's role in plant growth was identified in the late 19th century [16]. Historically, lime was used to supply calcium to crops, with a dual purpose of adjusting soil pH [17]. The importance of calcium in cell wall formation and stability has led to its continued use in modern agriculture [18].Nano fertilizers represent a more recent development in agricultural technology. Since the early 2000s, researchers have explored using nanotechnology to enhance nutrient delivery [19]. This has led to the creation of nano-formulations that allow for targeted and controlled release of nutrients, improving efficiency, and sustainability.Numerous studies have focused on the influence of nitrogen on strawberry growth. For instance, Kellar*et al.*[20] found that nitrogen positively affected leaf and stem growth but needed to be carefully managed to avoid excessive vegetative growth. Optimal nitrogen levels could enhance fruit size and yield in strawberries.Research on calcium's effect on strawberries has revealed its critical role in root development and fruit quality [21]. Calcium application could reduce fruit deformation and improve shelf life.The emerging field of nano fertilizers has shown promising results in strawberry cultivation. By using zinc oxide nanoparticles, resulting in increased fruit weight and antioxidant content. These findings increased nutrient uptake and reduced losses with nano fertilizers.Comparative studies with other fruits and crops provide insights into the unique needs and responses of strawberries to N, Ca, and nano fertilizers.Strawberries vs. Tomatoes: While both require similar nitrogen levels, strawberries exhibit higher sensitivity to calcium deficiency, resulting in specific deformation symptoms not found in tomatoes [22].In Strawberries vs. Grapes, Both crops respond well to nano fertilizers, but strawberries appear to show greater improvements in nutrient uptake efficiency.In Strawberries vs. Cereal Crops, unlike cereal crops, strawberries require careful management of nitrogen to avoid excessive vegetative growth, which can negatively impact fruiting [23].Despite extensive research, several gaps remain in understanding of the role of N, Ca, and nano fertilizers in strawberry cultivation.In lLong-term eEffects,fFew studies have addressed the long-term impacts of these nutrients on soil health and sustainability [24].Interactions with oOther N\nutrients; Limited research has explored the interactions between N, Ca, and other essential nutrients in strawberries.Nano Fertilizer Safety; though promising, more research is needed to assess the environmental and human health impacts of nano fertilizers.Specific Recommendations: A lack of region-specific studies may limit the generalizability of findings across diverse agricultural contexts [25].

Comment [L1]: Number of studies/references are available on long term effects but we can say limited studies in case of straw berry

Methodology

The methodology section of this review encompasses the design, strategy, and steps undertaken to compile, analyze, and assess the literature on the impact of N, Ca, and nano fertilizers on strawberry cultivation. This approach aligns with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [26].Subject Matter:Studies focusing on the impact of N, Ca, and nano fertilizers on strawberry growth, yield, and quality were included [27].Several electronic databases,including PubMed, Scopus, Web of Science, and Google Scholar, were searched using relevant keywords such as "strawberry", "nitrogen", "calcium", "nano fertilizers", and combinations thereof.An initial screening was conducted by reviewing titles and abstracts, followed by a full-text review against the inclusion and exclusion criteria.Data was systematically extracted from selected studies, including authors, year of publication, location, experimental design, key findings, and conclusions.A qualitative synthesis was conducted to summarize and interpret the findings. Themes were identified, and patterns were analyzed to understand the influence of N, Ca, and nano fertilizers on strawberry cultivation [28].A quality assessment was performed using the Newcastle-Ottawa Scale (NOS) for observational studies and the Cochrane Collaboration's tool for randomized trials [29]. This ensured that the studies met standards for selection, comparability, outcome, and overall scientific quality [30].

Influence on Growth Yield

Nitrogen is an essential macronutrient required for the growth and development of plants [31]. Its influence on strawberry cultivation has been extensively studied, revealing several key effects:Nitrogen plays a crucial role in promoting vegetative growth in strawberries. It aids in chlorophyll production, thereby enhancing photosynthesis [32]. Increased nitrogen levels have been found to stimulate leaf and stem growth, resulting in robust plants [33].The availability of nitrogen also influences the fruiting process. Adequate nitrogen levels have been shown to increase fruit size, weight, and overall yield in strawberries [34]. Excessive nitrogen application can lead to overly vigorous vegetative growth at the expense of fruit production [35].Nitrogen management requires careful consideration of soil type and environmental conditions. Incorrect application can lead to leaching, negatively impacting soil health and environmental sustainability [36].Calcium is another vital nutrient for strawberries, playing a key role in cell wall structure and stability [37].Calcium has been shown to promote root development in strawberries. Well-developed roots aid in water and nutrient uptake, contributing to overall plant vigor [38].Calcium applications have been linked to improvements in fruit quality, including reduced fruit deformation and increased shelf life [39]. The increased calcium content in fruits also has potential health benefits for consumers [40].The interaction between calcium and other nutrients, particularly magnesium and potassium, must be considered when managing calcium levels in strawberry cultivation.Nano fertilizers represent an innovative approach to nutrient delivery, offering the potential for targeted and controlled release [41].Several studies have demonstrated that nano fertilizers enhance nutrient uptake in strawberries, leading to more efficient use of applied nutrients [42].Research indicates that the use of nano fertilizers results in improved growth, yield, and quality of strawberries. The targeted delivery of nutrients minimizes losses, reducing the overall application rates required [43].The use of nano fertilizers also has implications for environmental sustainability, with potential reductions in runoff and leaching. It's concerns about potential environmental and health risks must be addressed [44].Recent studies have begun to explore the combined application of N, Ca, and nano fertilizers in strawberry cultivation. These works suggest potential synergistic effects, with improved growth and yield compared to individual applications [45].The integration of N, Ca, and nano fertilizers enables more tailored nutrient management, with the potential to optimize each nutrient's benefits [46].Understanding the complex interactions between these nutrients and managing them effectively in a combined approach remains a challenge. Continued research is required to develop clear guidelines and best practices.

Comment [L2]: N in combination of optimum contents of other nutrients results in robust plant strength rather N alone which may result in luxurious growth but not provide strength.

Influence on Quality of Strawberry

The application of nitrogen, calcium, and nano fertilizers has been found to significantly influence the color development in strawberries. Nitrogen availability is directly linked to chlorophyll synthesis, which affects the green coloration of unripe fruit and contributes to color changes during ripening [47]. Nano fertilizers targeting calcium have also been observed to maintain vibrant color in ripe strawberries [48].Fertilizers play a crucial role in determining the size and shape of strawberries. Adequate nitrogen supply has been linked to increased fruit size [49], while calcium aids in maintaining a uniform shape. Research using nano fertilizers to provide balanced nutrition has shown potential for optimization of size and shape [50].Calcium's role in cell wall stability directly affects the texture and firmness of strawberries. Studies have shown that targeted calcium applications can reduce softening and improve the firmness of fruits, thus extending their shelf life [51].Strawberries are known for their high vitamin C content. Research has shown that appropriate nitrogen levels can enhance the synthesis of vitamin C, whereas excessive nitrogen might decrease it [52]. Nano fertilizers targeting specific nutrient delivery can be used to fine-tune vitamin content.Calcium applications not only improve fruit quality but also enhance the mineral composition, including calcium content in the edible fruit part. The utilization of nano fertilizers for delivering essential minerals has been found to enhance this aspect [53].The sugar and acid balance, which significantly influences the taste of strawberries, is also affected by fertilization practices. Balanced nitrogen levels have been associated with optimal sugar accumulation [54]. The introduction of nano fertilizers to precisely control nutrient delivery has shown promise in fine-tuning this balance [55].The taste and flavor of strawberries are complex characteristics influenced by numerous compounds. Nitrogen levels have been found to affect the synthesis of flavor compounds [56], while calcium is linked to maintaining flavor intensity. Recent studies on nano fertilizers indicate potential for enhancing taste and flavor through targeted nutrient delivery [57].Strawberries' aroma is one of their most appealing characteristics. The composition of volatile compounds contributing to aroma is influenced by fertilization practices. Research has shown that balanced nutrition, particularly nitrogen, can enhance specific aroma compounds [58].Sensory analysis studies involving consumer panels have demonstrated that the appearance, taste, and aroma of strawberries can be optimized through precise nutrient management, including the use of nano fertilizers. These improvements align with consumer preferences for appearance, texture, and flavor, leading to increased market acceptance [59].

Environmental Impact

Nitrogen and other nutrients can lead to soil and water pollution when mismanaged. Leaching of nitrogen compounds into groundwater and runoff into surface waters can lead to a range of environmental issues [60]. Application of nano fertilizers might reduce this risk through controlled release mechanisms [61].Calcium has been shown to play a vital role in maintaining soil structure by promoting the aggregation of soil particles [62]. This can reduce soil erosion and enhance water retention, contributing to the overall health of the soil.The use of nitrogen, calcium, and nano fertilizers can affect soil microbial communities. Balanced nitrogen management promotes microbial activity, leading to improved soil fertility [63]. Excessive nitrogen application may inhibit certain beneficial soil organisms [64].Careful management of nitrogen, calcium, and nano fertilizers is essential for long-term soil sustainability. Over-reliance on these nutrients without proper management can lead to soil degradation and loss of fertility over time.Nutrient runoff, particularly nitrogen, can lead to eutrophication in aquatic ecosystems. This process can result in algal blooms and depletion of oxygen in water bodies, adversely affecting aquatic life [65].Nitrogen deposition from agricultural fields can impact nearby terrestrial ecosystems. Excess nitrogen can alter soil pH and nutrient dynamics in forests and grasslands, potentially affecting plant communities and wildlife [66].The use of fertilizers, including nano fertilizers, must be carefully managed to avoid potential impacts on local biodiversity. This includes consideration of potential toxicity to non-target organisms and unintended effects on plant and animal communities [67].The development and utilization of nano fertilizers present an opportunity for greater resource efficiency in agriculture. By enabling targeted nutrient delivery, these fertilizers may reduce the overall application rates required, conserving resources [68].The use of nitrogen, calcium, and nano fertilizers must align with environmental regulations and standards. Compliance with these guidelines ensures responsible stewardship of natural resources and minimizes environmental harm [69].A comprehensive understanding of the environmental impact of these fertilizers requires life cycle analysis, taking into account production, transportation, application, and eventual disposal or recycling [70].Sustainability considerations extend beyond the simple application of fertilizers. Integrating best practices for fertilizer management with other sustainable agricultural practices, such as crop rotation and conservation tillage, can enhance both environmental and economic sustainability [71].

Comment [L3]: It is just general statement not specific to strawbwrries

Conclusion

Comment [L4]: Conclusion is very general type not conforming specificallytostrawbwerry needs to be modified keeping in view the title of article.

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The comprehensive review of nitrogen, calcium, and nano fertilizers in strawberry cultivation illustrates their profound influence on growth yield, quality, and environmental impact. These fertilizers play a vital role in enhancing the physical appearance and nutritional content of strawberries, while also offering potentials for targeted nutrient delivery. Their application must be carefully managed to preserve soil quality, protect surrounding ecosystems, and align with broader sustainability goals. Continued research and innovation, including the development and utilization of nano fertilizers, can lead to optimized agricultural practices that balance productivity, quality, and environmental stewardship.

Comment [L5]: Is not considered as different fertilizer but it is mode of application of fertilizer applicable to mostly N fertilizer at present

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Comment [L6]: The uniformity in style of references presentation may be maintained as per Journal Guidelines. Give full name avoid abbreviations.

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Comment [L7]: Expand to full avoid abbrevtions