ECRONICON OPEN ACCESS

EC MICROBIOLOGY
Review Article

Recent Improvements in Increasing Plant Yield: A Systematic Review

Ajibade OA*, Sodimu EO, Bamigboye OO, Oladipo EK, Oni MO, Adeosun IJ, Olotu TM, Kaka MO and Oyawoye OM

Department of Microbiology, Adeleke University, Ede, Osun State, Nigeria

***Corresponding Author**: Ajibade OA, Department of Microbiology, Adeleke University, Ede, Osun State, Nigeria.

Received: March 12, 2020; **Published:** March 13, 2023

Abstract

The survival of man is largely dependent on plants which serve as the major source of food. The increasing world population and the search for eco-friendly ways of food production have spurred researchers into studies bordering on sustainable means of plant improvement. Over the years, newer methods of food production have been discovered and explored. The aim of this review is to examine the recent improvement in increasing plant yield. Authors searched through four scientific online databases using the following keywords (improvement + plant yield) AND (plant yield + increase). After the exclusion of some articles based on pre-determined criteria, 32 articles were selected. Older ways of improving plant growth are giving way to newer ones. Recent improvements that have been used in increasing plat yield include genome editing using CRISPR/Cas9, application of Nano fertilizer, plant microbiome system, and improving photosynthesis and phenotyping. The employment of these newer means of improving plant yield will be a bane to food insecurity, food safety, climate change, and other associated food production problems.

Keywords: *Plant yield, Nanofertilizer, Genome Editing, Plant Microbiome*

Introduction

To fulfill the growing demand for food, as well as the problems posed by climate change, crop yields must be significantly increased [1]. Crop yields will be insufficient to feed the world's population by 2050 if current trends continue [2]. Food insecurity and malnutrition are currently among the most important public health challenges, claiming countless lives in underdeveloped countries [3]. Even maintaining the current level of food per capita will be a difficult task in the future due to the continued loss of arable lands and the presence of unfavorable environmental circumstances such as drought, salinity, floods, illnesses, and so on. To achieve food security for future generations, the globe must produce 50% to 100% more food than it does now, despite forecasted harsh environmental circumstances [4].

During the green revolution of the mid-twentieth century, the use of agrochemicals and high-yielding crop varieties generated through traditional plant breeding procedures resulted in a major increase in crop output in India. Nevertheless, conventional plant breeding alone cannot meet the world's ever-increasing food needs [3]. Agricultural biotechnology is proving to be an effective supplement to traditional ways of addressing the world's demand for high-quality food. We now have access to vast gene pools that can be used to impart desirable features in economically significant crops thanks to contemporary plant biotechnology technologies. Genetically modified (GM) crops can help us meet the demand for crop varieties that are high-yielding, nutritionally balanced, and resistant to biotic and abiotic stress [5-7].

Plant

Plants are multi-cellular organisms that use photosynthesis to make their own food and they belong to the kingdom "Plantae". Plant species are more than 300,000 species; examples are grasses, shrubs, and trees. They produce most of the oxygen in the world and are important in the food chain, as many organisms eat plant or plant-eating organisms. The study of plants is called botany. Plants are autotrophs which means they make their own food. They can do this through photosynthesis, which is the creation of nutrients from sunlight such as sugars and carbon dioxide. It occurs in the chloroplasts, which contain carotenoids and chlorophyll, these molecules absorb light energy and convert it into a usable form. Prominent Characteristics of Plant include the followings: These are multicellular and composed of eukaryotic cells. Except in bacteria and cyanobacteria, these cells can also be found in other species. They use photosynthesis to produce their own food in which processed oxygen is released. Starch serve as food reserve and storage for photosynthesis; Plants are non-motile unlike other organisms but they are not exactly unable move. They show other sort of movement limitation in response to light, such as unidirectional movement of plant parts, phototropism, and of Mimosa's leaves folding in response to contact; They have alternation of generations in their life cycle meaning plants have the haploid gametophyte that can produces gametes and the diploid sporophyte [8].

Plant growth

Living organisms use the series of the strategies of differentiation beginning from the single cell to preserve and improve their shape and dominant structure. The increase in the volume and mass of plants with or without the formation of new structures such as organs, tissues, cell organelles or cells is known as plant growth. Improvement cell and tissue specialization and replica are commonly associated with growth [9]. Plants need the following factors to grow: light and temperature (Photosynthesis), air, soil, water, nutrients, space, and time.

Importance of plant

It can be said that plants on Earth are primarily meant to sustain or maintain life by providing energy and structural elements for the use of other organisms. Plants are useful in many respects, but they are primarily used as food and medicine for humans and animals.

Medicinal plants are considered as rich assets of ingredients that can be used in drug synthesis and improvement [10]. Some plants are considered as a necessary source of diet and as a result of that, they are encouraged for their therapeutic values. Examples of these plants are pepper, walnuts, ginger, green tea, aloe, pepper and turmeric etc. Lately, medicinal herbs have been the source for pharmaceutical manufacturing and it has been used for treatment recipes of frequent ailments [11]. Plants serve as the major food resources for humans. It can be said that almost 80% of human foods are gotten from plants and also almost all organisms devour plants [12].

Plant yield

There is nothing more vital to human health than an adequate supply of food when it comes to calories and nutrition. Over the last 50 years, a lot the world population are suffering from malnutrition which occurred due to lack of access to food. Over this period, we have seen surpluses of the essential crops, which make shortages a very far-off problem for most of the population. The main foodstuffs produced in 2013 which are considered to be important had been maize (1,018 Mt), paddy rice (746 Mt), wheat (713 Mt), and soybean (276 Mt) all are in terms of millions of metric tons (Mt). They account for about two-thirds of calories that are consumed globally [2]. Notably, the current world population which is more than 7 billion is expected to increase to 9.5 billion by 2050, a 35% increase.

Materials and Methods

The paper review commenced with electronic database searches on Google Scholar (http://scolar.google.com/), Jstor (http://www.jstor.com), Scielo (http://scielo.org) and PubMed (http://www.ncbi.nlm.nih.gov/pubmed), using the following keywords: (Improvement + Plant Yield) AND (Plant Yield + Increase). This procedure allowed the selection of published papers on the recent improvements in in-

creasing plant yield. Papers that did not report on the recent improvements were excluded. There were limitations regarding the year and date of publication, since the review is about recent improvements. Papers older than five years were excluded. In addition, there were also no restriction on particular plants, the review is based on general plants.

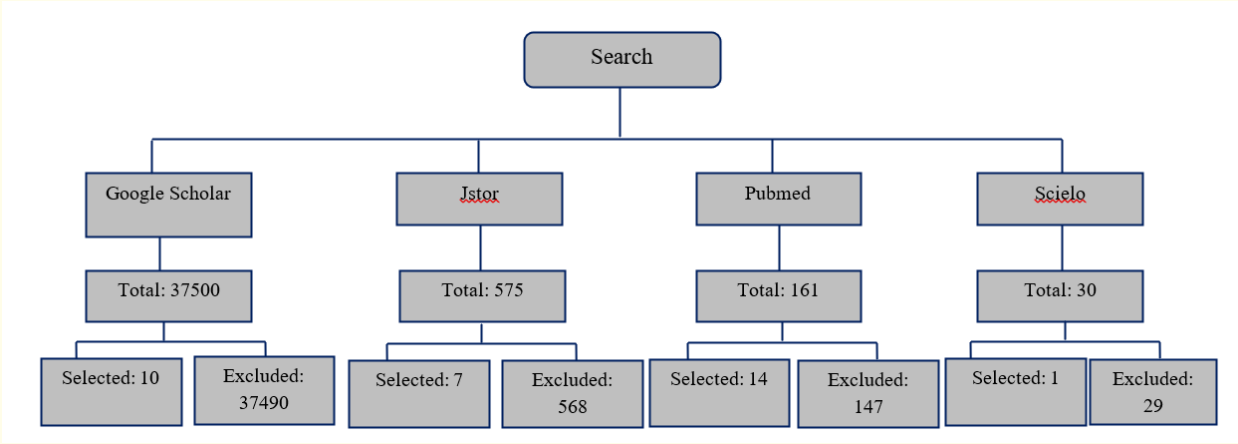

Figure 1: *Total articles selected in four different databases.*

Application of nanofertilizers

Nanofertilizers are vital tools in agriculture to improve crop development, yield and quality parameters with increment supplement use productivity, lessen wastage of fertilizers and cost of culture. Nanofertilizers give increasing surface territory and greater accessibility of supplements to the yield plant which help to expand these quality parameters of the plant (Such as protein, oil substance, and sugar content) by upgrading the pace of response or amalgamation process in the plant system. They are beneficial over traditional fertilizers because they improve soil fertility yield and crop quality parameters, they are nontoxic and less harmful to people and the environment, and they reduce cost and maximize benefit. In addition, nanotechnology can be applied to soil nutrition by designing formulations in two ways, i.e., powdered, encapsulated, or buried fertilizers in the nanomaterial; and nano fertilizer types and other growth-promoting materials. Several research studies have revealed that the application of nano fertilizer significantly increases crop yield over control or without application of nanofertilizer is mainly due to increasing growth of plant components and metabolic processes such as photosynthesis leading to higher photosynthesis accumulation and translocation to economic components of plants. The use of nano-particulate foliar as a fertilizer significantly increases plant yield [14]. Indian farming is feeling the pain of green creative fatigue. Over the past 50 years, fertilizer use has increased exponentially from 0.5 (1960's) to 24 million tons (2015), which correlates to a four-fold increase in food grain production (254 million tons). It has been observed that plant yield has started to stagnate as a result of imbalanced fertilization and a decrease in soil organic matter content. The optimum 4:2:1 NPK fertilizer ratio is suitable for crop production while in India the current ratio is kept at 10:2:1. To reach a target of 300 million tons of food grains and feed the burgeoning population the country would need 45 million tons of nutrients compared to 23 million tons of current consumption. A second Green Revolution is required on the world. Nanofertilizers are thought to have the potential to revolutionize farming [15].

Fertilizers coated or encapsulated with nanoparticles

To stop fertilizer wastage, reduce dose, and extend efficiency, some particular nanomaterial may coat, bind or encapsulate the fertilizer. Nano and sub nano-composite coating and binding aid in altering nutrient release from the fertilizer capsule. In this context, research

shows that the use of a nanocomposite consisting of nitrogen, phosphorus, potassium, micronutrients, mannose and amino acids improved nutrient absorption and use by grain crops. Also, double-hydroxide nanocomposites layered in zinc–aluminum were used for the controlled release of chemical compounds that act as regulators of plant growth. *Gliricidia sepium* nanocomposites with urea-modified hydroxyapatite nanoparticles showed a steady and persistent release of nitrogen over time at three different pH values.

Photosynthesis improvement

Photosynthesis is the basis of the planet's primary productivity. One such route poses improving photosynthesis, with simulations indicating that it could have a significant transformative influence on increasing crop productivity. Photosynthesis is a sequence of biochemical reactions utilizing sunlight to reduce atmospheric CO_2 in carbohydrates and release O_2 as a by-product. The first photosynthetic species (Archean Eon) emerged at least 2.5 billion years ago and were single-celled ocean-dwelling prokaryotes. Photosynthesis was therefore originally an aquatic process that existed in a significantly reduced atmosphere [16]. Photosynthesis is obviously a pillar of human civilization and, as such, an object of intense basic and applied research in the face of increasing pressure to feed a growing population. One key goal for increasing crop productivity and yields is to improve photosynthesis efficiency. Rubisco is central to photosynthesis, which is a vital but often rate-limiting component [17].

Engineering rubisco

In certain plants, the quantity, rate of movement, and state of the rubisco enzyme that catalyzes the photosynthetic carbon fixation of the intercellular spaces of the leaf regulates the rate of photosynthesis under saturated light. and partial stomatal closure conditions due to abiotic stress or mild irradiance. Rubisco is a relatively slow catalyst and requires large amounts to maintain high photosynthetic concentrations, which is why this enzyme alone can account for more than 25% of leaf nitrogen. Raising the abundance of rubisco, i.e. raising the photosynthetic efficiency, would increase photosynthesis at high irradiance and high temperatures under ambient CO_2 concentrations.

Plant microbiome system

The plant microbiome system is used to create a beneficial community of organism that can be used in the context of suppressing plant diseases or insects and also to increase yield. Plants team up with microbes, including those that colonize internal tissues. Because the microbiome is closely involved in plant health and acts as a source of additional genes accessible to plants when necessary by producing antimicrobials or interfering with virulence factors, many plant microbiomes act antagonistically towards plant pathogens. In particular, *actinomycetes* are known to produce a wide range of antibacterial, antifungal, antiviral, nematicidal and insecticidal compounds. Other bacteria include *Pseudomonas fluorescens* which produces the antifungal compound diacetylphloroglucinol (DAPG). Example of plant microbiome that promotes plant growth is *Azospirillum brasilense.* It increases expression of genes involved in root colonization and plant growth promotion [18].

As a result of the proven benefits of biosupplements on plant yields, soil fertility, and fertilizer output, the global biosupplement market is expected to rise by 14 per cent between 2014 and 2019. Plant microbiome system is an essential segment of the biosupplements. Given the discovery of many potential plant microbiomes, appropriate biotechnological processing and the longevity of the bacteria's shelf-life remain obstacles to be addressed for their productive use as biosupplements. Here the plant microbiome Gram-negative strain *Kosakonia radicincitans* DSM 16656 (family Enterobacteriaceae) which promotes plant growth was processed biotechnologically and applied in a maize field in Germany. *K. radicincitans* formulations which are solid or liquid were diluted in water and sprayed on young corn plants (*Zea mays L.*). Stability tests of formulated bacteria during shelf-life were conducted under storage conditions of 4°C and -20°C. Parallel to this, the bacterial formulations were examined at three different field plots with different soil properties. Maize yield was reported at harvest time, and both formulations increased silage and maize grain yields. The total land used for maize cultivation in Germany was 4,163 million hectares, and Germany produced a total of 4,017,800 tons of maize.

Phenotyping

Based on non-destructive image analysis, data management, and modeling, plant phenotyping has emerged as a cutting-edge technology that plays an important role in plant and agronomic sciences, namely the design of new crops, the characterization of genetic resources responses to the environment and the improvement of crop breeding and management (i.e. precision farming). The implementation of such technologies is therefore necessary for sustainable agro-food operations, thus maximizing the use of natural resources such as water and soil. Phenotyping is an evolving science of that ties genomics with plant physiology and agronomy. It has become a rapidly evolving topic in agricultural research based on a long tradition of manual selection in plant breeding, now also involving the development of automated high-throughput approaches for field applications as well as basic plant research. Quantitative analysis of the relationship between the genotype environments is thus an essential step towards increasing plant efficiency. Although regulated conditions allow for measurements with high precision, field phenotyping presents challenges for measurement of relevant traits in a highly variable environment with respect to robust sensors [19].

Investments in facilities for phenotyping have taken place all over the globe over the last decade including in Europe. Plant phenotyping can be performed with identical targets and outcomes at different levels of biological organization. In the Mediterranean countries plant phenotyping was used to increase plant yield. The countries of the Mediterranean are significant producers of tomatoes, legumes, cereals, nuts, olives and olive oil, grapes and wine. With 63.9 million tons of vegetables grown in 2016 using plant phenotyping, vegetable production accounted for 13.7% of Europe's agricultural output. Italy, Portugal and Spain are also important centers for the production of tomatoes and tomato pastes. Spain (33.4 per cent), Italy (18.7 per cent) and France (11.4 per cent) are the largest producers of fruit in Europe. Olives, grapes, apples, oranges and peaches are the main components of fruit production in Europe and are primarily grown in Mediterranean countries such as Italy, Spain, Portugal and Greece [20].

Genetic engineering

The engineering of the genome of some plants to have desired traits responsible for increase plant yield has been embarked upon. This however, has some challenges and is also not accepted in some parts of the world. We cannot deny that this is a formidable way of increasing plant yield especially in the face of increasing population and dwindling arable land.

Plant biotechnology has the ability to solve a variety of agricultural and societal concerns. Genetic techniques are being utilized extensively for value addition in food crops through enrichment with quality proteins, vitamins, iron, zinc, carotenoids, anthocyanins, and so on to decrease yield losses owing to various challenges (biotic and abiotic). Additional current projects involve increasing the shelf life of fruits and vegetables in order to drastically reduce post-harvest losses of perishable products [3]. However, due to the ongoing battle between plants and pathogens, pathogens have evolved and mutated to be able to defeat specific resistance genes present in plants, and can infect plants and reduce yield to levels of up to 80 to 90% in the worst conditions depending on the aggressiveness of new isolates, susceptibility level of the wheat crop, environmental conditions, and crop developmental stage. Certain techniques involving transgenesis and cisgenesis are employed to improve crop yield.

Transgenesis and cisgenesis are quick and efficient ways of introducing genes into a specific line to improve one or more features. Transgenesis characteristics have been sold in several crops for over 20 years, and transgenic cotton, soybean, corn, and canola (rapeseed) have been traded on worldwide markets since then. There are country-specific regulations that may prohibit the use and marketing of some items. The genome editing of some plants to have a sequence that promote high plant yield has been done.

Different biological systems have been developed and investigated to modify the genome of living organisms. The most frequently used system is CRISPR/Cas9 [21]. This technique has been successfully applied to different biological systems and is characterized by the exact modification of a specifically targeted sequence. Although the technology implies specific structural changes in targeted sequences

in the genome of an organism, it is not considered as a technology involving genetically modified traits based on gene introduction from an unrelated species. Consequently, the CRISPR/Cas9 gene-editing technique has revolutionized biology, including plant biology. This new tool also opens numerous new avenues on how to improve plant responses to the environment. Some aspects include improving plant responses to different pathogens. Taking advantage of this technique, defeated resistance genes could be slightly modified based on sequence knowledge of effective genes to release new effective genes.

Use of microbial inoculants to enhance plant growth and productivity

Another interesting option is the use of microbial biocontrol agents to protect plants against pathogen-caused illnesses [22]. Microbial biocontrol agents are plant microbes such as bacteria, fungi, and viruses, that can be utilized to control plant diseases. Microbial biocontrol agents can help to reduce the usage of synthetic pesticides, which can be hazardous to the environment and human health [23]. According to recent studies, using microbial inoculants can enhance plant production by up to 30%. This is accomplished through microbial inoculant interaction with plant roots, which results in root development stimulation, the release of plant growth-promoting hormones, and the synthesis of enzymes that break down soil nutrients [24]. The use of microbial inoculants to boost plant growth and production is one of the most promising ways to increase crop yield [25]. Microbial inoculants are helpful microorganisms that are given to the soil or plant surface to promote plant development, increase nutrient uptake, and protect the plant from infections [26]. The employment of microbiological approaches to boost plant production has considerable promise for addressing food security and sustainable agricultural concerns.

There are other recent ways in which plant yield can be increased to meet the increasing demand and they include; Improvement in algal lipid production [27], Integration of sensory analysis into plant breeding [28], soil properties improvement [29], Application of small RNAs which have emerged as an attractive tool used by plant biologists to decipher the plant function but also to develop plants with improved and novel traits by manipulation of both desirable and undesirable genes to increase yield. But the best among the recent improvements in the application of nanofertilizer and nanotechnology is because it increases the plant yield and it also adds to the plant nutrients making the plant healthy for consumption.

Conclusion

Without a doubt, to ensure the longevity of man and the world, other means of producing foods must be explored that will be eco-friendly and high yielding. The 32 selected papers published within the last 5 years met the inclusion criteria. Hence, articles reviewed highlights the recent ways of improving plant yield, Improvement in photosynthesis was considered revising 4 papers from different databases. The recent ways of improving plant yield have the potential to increase the long-term sustainability of food production and greater yield. Plant Microbiome is the most suitable means of improving plant yield due to its eco-friendly nature and high sustainability. Among these recent improvements, plant microbiome systems should be rated the best followed by the application of Nanofertilizer. because plant microbiome does not only increase plant growth, it also protects plants i.e. its biocontrol and biofertilizer attributes. It is anticipated that in the future, plant microbiome system will begin to replace other ways of increasing plant yield.

Bibliography

1. Passioura JB. “Phenotyping for drought tolerance in grain crops: when is it useful to breeders?” *Functional Plant Biology* 39 (2012): 851-859.

2. Ray DK., *et al*. “Yield trends are insufficient to double global crop production by 2050”. *PLoS ONE 8* (2013): 1-15.

3. Datta A. “Genetic engineering for improving quality and productivity of crops”. *Agriculture and Food Security* 2.15 (2013): 1-13.

4. Datta A. "GM crops: dream to bring science to society". *Agricultural Research Journal* 1 (2012): 95-99.

5. Ghosh S., *et al*. "The N-glycan processing enzymes α-mannosidase and β-D-1 N acetylhexosaminidase are involved in ripening-associated softening in the non climacteric fruits of capsicum". *The Journal of Experimental Botany* 62 (2011): 571-582.

6. Chakraborty S., *et al*. "Next generation protein rich potato by expressing a seed protein gene AmA1 as a result of proteome rebalancing in transgenic tuber". *Proceedings of the National Academy of Sciences of the United States of America* 41 (2010): 17533-17538.

7. Kamthan A., *et al*. "Expression of a fungal sterol desaturase improves tomato drought tolerance, pathogen resistance and nutritional quality". *Scientific Reports* 2.951 (2012): 1-15.

8. Simpson MG. "Plant Systematics". 2nd edition. Burlington, MA: Elsevier Inc (2010): 740.

9. Brukhin V and Morozova N. "Plant Growth and Development- Basic Knowledge and Current Views". *Mathematical Modelling of Natural Phenomena* 6 (2011): 1-53.

10. Hassan BAR. "Medicinal Plants (Importance and Uses)". *Phamaceutica Analytica Acta* 3.10 (2012): 1.

11. Khan AM. "Introduction to Medicinal Plants". National Health Portal (2016).

12. Bennett BC., *et al*. "Plants as food". *Economic Botany* 14 (2018): 1-29.

13. Ray DK., *et al*. "Yield trends are insufficient to double global crop production by 2050". *PLoS ONE* 8 (2013): 1-15.

14. Liu XM., *et al*. "Advantages of Nanofertilizers over traditional fertilizers". *Journal of Plant Nutrition and Soil Science* 11 (2015): 14-18.

15. Quresh A., *et al*. "Nanofertilizers: A Novel Way for Enhancing Nutrient Use Efficiency and Crop productivity". *International Journal of Current Microbiology and Applied Sciences* 7.2 (2018): 3325-3335.

16. Niklas KJ. "Plant Evolution 1st edition". Chicago, USA: University of Chicago Press (2016): 560.

17. Ort DR., *et al*. "Redesigning photosynthesis to sustainably meet global food and bioenergy demand". *Proceedings of the National Academy of Sciences of the United States of America* 112.28 (2015): 8529-8536.

18. Compant S and Sessitch A. "A review on the plant microbiome: Ecology, functions, and emerging trends in microbial application". *Journal of Advanced Research* 19 (2019): 29-37.

19. Avni R., *et al*. "Wild emmer genome architecture and diversity elucidate wheat evolution and domestication". *Science* 357 (2017): 93-97.

20. Großkinsky DK., *et al*. "Phenotyping in the fields: dissecting the genetics of quantitative traits and digital farming". *The New Phytologist* 207.4 (2015): 950-952.

21. Li J., *et al*. "Gene replacements and insertions in rice by intron targeting using CRISPR-Cas9". *Nature Plants* 2 (2016): 139-145.

22. Singh RP., *et al*. "The plant microbiome: an emerging frontier in plant sciences". *Plant Pathology and Microbiology* 8.7 (2017): 1 -2.

23. Environmental Protection Agency. Pesticides: Health and Safety (2016).

24. Lugtenberg B and Kamilova F. "Plant-growth-promoting rhizobacteria". *Annual Review of Microbiology* 63 (2009): 541-556.

25. Glick BR. "Plant growth-promoting bacteria: mechanisms and applications". *Scientifica* (2012): 1 -15.

26. Mendes R., *et al*. "The rhizosphere microbiome: significance of plant beneficial, plant pathogenic, and human pathogenic microorganisms". *FEMS Microbiology Reviews* 37.5 (2013): 634-663.

27. Banerjee A., *et al*. "Improvements in algal lipid production: a systems biology and gene editing approach". *Critical Reviews in Biotechnology* 38.3 (2017): 369-385.

28. Joanna L., *et al*. "Integration of Sensory Analysis into Plant Breeding". *Agrociencia Uruguay* 23.1 (2019): 1-15.

29. Kamthan A., *et al*. "Small RNAs in plants: recent development and application for crop improvement". *Frontiers in Plant Science* 6.208 (2015): 1-15.

Volume 19 Issue 4 April 2023