HARNESSING ARTIFICIAL INTELLIGENCE BASED TOOLS IN EXTENDING THE SHELF-LIFE OF SPIRULINA: HOW AI CAN HELP IN IMPROVING SUPPLY CHAIN OF SPIRULINA AND RELATED PRODUCTS.

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Abstract

Spirulina is awell-known blue-green algae or Cyanobacteria. In recent years, it has gained popularity because of its use as a nutrient rich supplement. It is rich in protein, vitamin and mineral contents. People have started taking it in several forms in their diet or as supplement. However, just like any other edible product, Spirulina has certain limitations when it comes to its shelf-life. It is highly perishable and prone to degradation and spoilage due to the adverse effects of microbial contamination, oxidative stress and exposure to environment. To counter this spoilage of Spirulina, we have developed countless methods of preservation. However, traditional methods have some possible constraints in their efficiency and can only extend the shelf-life up to a certain degree. Thus, we take the help of Artificial Intelligence in this case. AI tools can aid us in further extending the shelf-life of Spirulina and Spirulina products via numerous ways. The aim of this study is to understand various aspects in which AI can help in improving Spirulina market and supplement industries in general.

Keywords: Spirulina, Shelf-life, Degradation, Preservation

INTRODUCTION

Spirulina or Arthrospira platensis(Family = Spirulinaceae) is a member of blue green algae or Myxophyceae, also known as Cyanobacteria. It is a primitive alga. It is spiral shaped like a spring, which gives it its characteristic name. It contains various photosynthetic pigments like Chlorophyll, Carotenoids, Phycobiliproteins like Phycocyanin and Phycoerythrin etc. It also possesses certain bioactive components. As a result of this, Spirulina is widely used in the food industry and nutraceuticals alike.

Spirulina is known for its high protein content, making it very useful for preparation of SCP. Production of Single Cell Protein is thus one of the most crucial applications of Spirulina. Single Cell Protein or SCP refers to some edible protein that is derived from the biomass of certain unicellular micro-organisms that include Algae, Bacteria, Fungi etc. It is an idealsource of protein for human and animalconsumption alike. This provides highly sustainable and cost-effective sources of protein compared to the traditional sources.

Apart from proteins, Spirulina is rich in vitamin and mineral contents. This makes it an ideal food that results in improved energy levels andincreased immunity.It also contains certain essential fatty acids. Essential fatty acids are usually Poly Unsaturated Fatty Acids or PUFA, that cannot be synthesized in our body. Therefore, they must be supplemented through our diet. They are important because they help with the normal function of the bodyand support general well-being. Hence, the overall nutrient profile of Spirulina is excellent. As a result of this, humans have developed newer ways to utilize these nutritional qualities and health benefits of Spirulina via diet and supplements.

Due to the nutritional benefits of spirulina, it is very useful in space missions and ventures. Astronauts take Spirulina along with them into space. They culture Spirulina in the spacecrafts. It provides them with food and nutrients. With the action of photosynthesis, Spirulina can also remove carbon dioxide and replenish oxygen. Research is being conducted on Spirulina to discover more ways to utilize it in space missions.

Spirulina can be eaten raw to obtain the best of what it has to offer, but it remains edible typically only up to 7-10 days after manufacturing.This makes it highly perishable and greatly limits its full potential when being used as food. Thus, we have developed several ways to overcome these issues with Spirulina degradation and to prolong its longevity.

People have started using Spirulina powder and tablets which are dried or modified forms of Spirulina. Such products have much greater shelf-life when compared to raw Spirulina. They can generally last up to 2 years or even more if taken proper care. However, we encounter a whole new set of problems with these supplements.

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Some Spirulina supplements lose their viability when stored for extended periods. They do not easily spoil raw Spirulina. Instead, they start losing the nutritional contents over time. Certain bio-active components of Spirulina start degenerating upon longer storage time. Various proteins, vitamins and minerals start to diminish in this case. This adversely affects the overall nutritional integrity of Spirulina, defeating the purpose of taking the supplements in the first place.

There seems to be this dilemma that while aiming to obtain maximum benefits from Spirulina, there is always the risk of spoilage and while trying to solve the issues of shelf-life and longevity, we must compromise with the quality of the product. At this stage, we can harness Artificial Intelligence based tools to our advantage.

There are numerous ways in which AI based tools can help us in addressing the problem of shelf-life in Spirulina and when doing so,we can also maintain the original nutritional value and integrity of Spirulina products. This ensures that we can solve the issue of spoilage without compromising the quality. This will positively affect the supply chain of Spirulina and can potentially provide a major boost to nutraceutical and supplement market also.

LITERATURE REVIEW

Major factors that lead to spoilage of Spirulina:

1.   Contamination by Microbes:
A major contributing cause to the spoiling of spirulina is microbial contamination. During growing, harvesting, or processing, Spirulina products may become infected with microorganisms like bacteria, fungi, and undesirable algae. If correct hygiene and handling practices are not followed, these pollutants may spread.

Bacterial Contamination: It has been observed that contaminated Spirulina samples contain a variety of bacteria, including Salmonella, Escherichia coli, and Staphylococcus aureus (Gong et al., 2007). By generating toxins, these microbes can contaminate food and cause foodborne diseases. The safety and nutritional value of spirulina are seriously jeopardized by the presence of dangerous microorganisms.

Fungal Contamination: Spirulina frequently contains fungi, such as Aspergillus species, particularly in warm, humid environments. Mycotoxins produced by fungus spores on Spirulina can further deteriorate the product's quality and safety (Gonzalez et al.,2017).

Algal Contamination: Spirulina culture tanks may become contaminated by other algae, especially poisonous species like Microcystis and Anabaena. This can result in the generation of toxic substances such microcystins that are damaging to humans (Xia et al., 2015). The product's safety and quality may be jeopardized by these algal blooms, which could cause spoiling.[1][2][3]

2.   Oxygen:
Oxygen plays a vital role in oxidative stress, which is a primary factor in spirulina deterioration. The components of spirulina, particularly the proteins, lipids, and pigments, are oxidatively destroyed by high oxygen exposure.

Oxidative Stress: By breaking down vital nutrients, exposure to oxygen, particularly oxidative stress, can harm the biological components of spirulina. Oxidative conditions can also damage phycocyanin and other antioxidants found in spirulina (Guevara et al., 2005).

Lipid Peroxidation: Spirulina's polyunsaturated fatty acids are susceptible to severe oxidative damage. When these lipids oxidize, peroxides are produced, which may affect the spirulina's quality (Marcone, 2012). The product's nutritional value may be diminished because of this oxidative damage.[4][5]

3.   The temperature:
Temperature has a significant impact on the stability and preservation of spirulina. High temperatures can cause irreversible harm to spirulina's cellular structure and nutritious components.

Protein Denaturation: High temperatures cause proteins' secondary, tertiary, and quaternary structures to break down. Once proteins regain their fundamental structure and shed their complex forms, they become inactive and worthless. This significantly reduces the nutritional value of spirulina, especially its protein content (Ramu et al., 2015).

Vitamin Degradation: Heat has a negative impact on the vitamins in spirulina, particularly B12 and E. These temperature-sensitive vitamins, which degrade rapidly in hot environments, reduce the health benefits of spirulina (Muller et al., 2001).[6][7]

4. Moisture:

Another important factor that could speed up spirulina degradation is moisture. High humidity can result in microbial growth and nutritional loss because spirulina is extremely sensitive to moisture.

Microbial Growth: Bacterial and fungal infections are more likely to occur in damp settings, hastening the rotting process. Because they produce enzymes that break down proteins and lipids, microorganisms that prefer moist environments can rapidly destroy spirulina (Li et al., 2016).

Diminished Antioxidant Properties: Moisture also affects spirulina's antioxidant capacity. High moisture content can reduce the presence of vital antioxidants like phycocyanin, which are necessary for its nutritional benefits (Shi et al., 2017).[8][9]

5. Light:

Light exposure is one of the primary reasons why spirulina spoils. Spirulina need light to flourish, however prolonged or intense exposure to light may degrade its quality.

Degradation of Photosynthetic Pigments: The main photosynthetic pigments of spirulina, such as chlorophyll and phycocyanin, are light sensitive. These pigments degrade with extended exposure to intense light, reducing its unique blue-green color and nutritional value (Brito et al., 2018).

Nutrient Degradation: Light exposure can also speed up the breakdown of other nutrients, including vitamins and essential amino acids. This degradation process may significantly reduce the nutritional value of spirulina (Karthikeyan et al., 2019).[10][11]

METHODOLOGIES

Given below are few of the multiple ways in which AI tools can help us overcome different difficulties that have been mentioned above.

1. Nutrient tracking by AI:

AI can analyze Spirulina samples during production and storage to track the amount of nutrients contained within Spirulina. Thus, we can note the effects of different preservation methods and storage techniques on the nutritional quality of Spirulina. This can allow us to determine the best ways of preservation and storage. The data collected here can prove to be very useful later. Thus, we can be certain that there is no spoilage and minimum loss of nutrients. Hence, the nutritional values of the product remain intact, and we can ensure the superiority of the product.

2. Making predictive models for shelf-life estimation:

Based on the data we collect on ideal storage conditions; we can develop AI models which considernumerous factors that affect the quality of Spirulina in either positive or negative manners. Such models, using some algorithms, can predict how long the Spirulina product will remain stable under specific conditions. This gives us some future insights into the shelf-life so that we can work on extending it.

3. Real time monitoring of environmental conditions and storage conditions:

AI powered sensors can continuously monitor environmental conditions like temperature, light etc. during both manufacturing and storage. These sensors can alert the manufacturers to take appropriate steps if the current conditions deviate too much from the ideal range. This allows us to control those factors immediately and thus, avoid the spoilage that could have occurred otherwise.

4. AI supported automated systems for maintaining ideal conditions:

We can possibly use AI and develop a certain system that can control and change the storage conditions according to the current requirements of the product. Such a system can change variables like temperature, light exposure etc. as per need, all by itself. This also means that we can reduce the need for human intervention in controlling the storage conditions.

5. Optimization of drying processes with the help of AI:

Drying is a quite common practice in preservation of Spirulina. Freeze drying and Spray drying are probably the two most used techniques in preservation by drying. This can significantly increase the shelf-life of Spirulina by eliminating all moisture from the product. However, on the downside, Spirulina can potentially undergo a huge nutrient loss because of drying. The heat can denature proteins and degenerate much of vitamins and minerals, rendering them completely useless in many cases. AI can analyze drying parameters that include temperature, drying time, circulation of air, just to name a few. It can then suggest the best ways of drying that will have sufficient effect for preservation, while dealingno to negligible damage to the bio-active components of Spirulina.

6. Use of preservative chemicals with different properties:

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AI can help us to analyze the chemical properties and bioactivity of Spirulina and suggest appropriate preservatives that should be used in corresponding conditions. BCPA, Chitosan and Natamycin are a few well known preservatives that have a variety of properties like anti-oxidative, anti-microbial, anti-fungal etc. AI can also suggest alternative natural preservatives that can be used in place of chemical ones. Such chemicals, synthetic or natural, can reduce oxidative stress and can negate the effects of moisture. They also provide protection to Spirulina against the infestation of bacteria, fungi, algae and other such microbes.

7.   Customized preservation techniques according to type of product:

AI can further help in the preservation department by recommending specific preservation techniques based on the type of product. Spirulina in different forms such as raw, powder, tablet, liquid etc. can have preservation methods better suited to the form. AI can predict the best preservation method in these cases to minimize the chances of spoiling by many folds.

8.   Visual inspection by AI:

AI supported vision systems can keep a constant 'watch' on Spirulina. It can easily detect subtle visual changes like change in color, texture, shape etc. AI can detect these changes at a level that may not even be noticeable by the human eye. Any such changes can hint at some potential contamination, spoilage or degradation of quality in general.

9.   Microbial detection via AI:

Various biosensors, backed up by AI, can detect all microbial contamination. This enables the manufacturers to take appropriate preventive measures in the early stages when the contamination is not that widespread. In the case that the problem took a while to be addressed, AI can also help in determining whether the product is still safe for consumption or not.

10.   Smart packaging solutions:

AI can develop better packaging methods that can further enhance the shelf-life of Spirulina. Light-proof and air-tight packing, use of oxygen and moisture absorbing sachets, flushing of nitrogen during packaging etc. can be considered. AI can recommend the best suited options according to the situation. It can also choose the best packaging materials and designs to minimize spoilage and retain freshness.

CONCLUSION

Spirulina is a nutrient dense food product that finds various applications in human diet and supplements. It provides a variety of essential nutrients to us that help in improving health and general well-being of the body. However, the full-scale exploitation of these health benefits is often held back by several factors like shelf-life, environmental variables, microbial contamination etc. Traditional methods of preservation manage to solve these issues up to a certain degree only. These traditional methods cannot bypass the loss of nutrients that occur as a sort of 'side effect' of the processing that must be done during the application of the preservation techniques. Thus, we turn to AI to solve our problems for us. AI, with its abilities, can predict the best storage conditions for Spirulina. It also suggests the best suited preservation method and most appropriate chemical preservatives that must be applied. It can constantly monitor the samples for detection on any possible spoilage or contamination. Thus, AI can potentially address all the problems related to the shelf-life, contamination and nutrient loss that cannot be solved via traditional methods. The implications of AI can be that we can export Spirulina internationally. This will open a whole lot of possibilities for the market of food and nutraceutical sector.

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