iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 10 Issue: X Month of publication: October 2022

DOI: https://doi.org/10.22214/ijraset.2022.47221

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue X Oct 2022- Available at www.ijraset.com

A Review on Application and Future prospects of Algae in Pharmaceutical and Food industry

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***Abstract:** Algae are photosynthesis-producing organisms that can be found in freshwater, wastewater, and aquatic environments. In order to get around a number of high-tech barriers in the algae biomass sector, it is necessary to improve the various activities and research. Algae have the potential to supply novel chemicals and bioactive compounds for the biotechnology industry. The abundance of algal diversity must be utilized for various applications. Algal biomass is a source of energy (biofuels), fertilizer, pollution control, stabilization, nutrition, high-value molecules, and various bioactive metabolites that can be investigated for new drugs in terms of their applicability in local and global markets. Microalgae have been widely used for the production of biomass and biofuel. As a result, large-scale experimental setups have been built to produce a lot of biomass and biofuel. Food, cosmetics, pharmaceutical, and nutraceutical industries all benefit greatly from microalgae. They also produce numerous biomolecules with added value, such as polyunsaturated fatty acids, beta-1,3-glucan, astaxanthin, lutein, phycobiliprotein beta-carotene, and chlorophyll, in addition to the previously mentioned application. The pharmaceutical, cosmetic, food and feed, and nutraceutical industries all use these biomolecules extensively commercially. Furthermore, this review focuses specifically on the broad application potential algae based nonenergy applications, such as pharmaceuticals, food ingredients, pigments and cosmetics by marine algae.*
***Keywords:** Algae, Biomass, Microalgae, Pharmaceuticals, Food, Cosmetics, Pigments*

I. INTRODUCTION

In many marine and freshwater ecosystems, microalgae are the building blocks of life. There are 16 classes and 72,500 species. The three main groups (*Bacillariophyceae*) are diatoms, chlorophytes, and chrysophytes. According to Guiry [1], the biological implications of diatoms, cyanobacteria, and cyanophyceae receive the most attention. These algae are able to withstand harsh conditions and can quickly form a drooping stratum on the water's surface. Algae cultivation and research in several nations aim to produce high-value goods. Microalgal biomass-producing nations like Taiwan, China, Japan, and Germany, among others, have been reported to accumulate 19,000 tons of dehydrated biomass annually and generate USD 5.7 billion in revenue [2]. Biomaterials used in biomedical fields can be produced in extremely high quantities by microalgae. Despite this, red algae and the compounds that come from them have a higher biological activity than other algae, and seaweeds are the source of food and gum for humans. Major components of red and brown algae cell walls, such as agar-agar, alginic acid, and carrageenan, are phycocolloides, which are primarily utilized in the pharmaceutical industry [3]. Anaerobiosis, pH, temperature, osmotic pressure, salinity, and ultraviolet radiation are just a few of the extreme environmental conditions that algal species can withstand and survive in. By counter producing primary metabolites like oleic acids, vitamin E, vitamin B12, lutein, and zeaxanthin, they are able to defend its cellular components [4]. Additionally, even in the presence of harsh conditions, secondary metabolites are produced. These metabolites are effective against pathogenic fungi and viruses thanks to their antibiotic and antimicrobial properties [5]. Microalgae are excellent sources of value-added products like proteins, polysaccharides, lipids, polyunsaturated fatty acids, pigments, vitamins, and minerals [6]. Algae are numerous prominent metabolites serve a variety of physiological functions and also have health-promoting properties. The biomass of various algae has been studied to investigate numerous bioactive molecules, and several cultivation methods have been examined to improve product accumulation high-end goods.

The development and use of biorefinery, which allows the production of a variety of products from the same harvested microalgal biomass in as little as a few days, has recently attracted a lot of interest to the microalgal biotechnology industry [7]. These products include chlorophylls, carotenoids, carbohydrates, lipids, proteins, nucleic acids, and nutraceuticals. Additionally, the utilization of natural pigments such as carotenoids derived from microalgae in nutraceuticals and cosmetics enhances their significance [8].

Numerous types of microalgae generate these valuable compounds, including -carotene, astaxanthin, phycocyanin, and polyunsaturated fatty acids (PUFA). In the bioenergy and pharmaceutical sectors, these molecules can be employed, among other things, as functional compounds or storage components [9]. Due to its potential medical advantages, such as cancer therapy agents, the synthesis of omega-3 fatty acids, carotenoids, and phycobiliproteins (PBPs) from microalgal biomass has gained considerable attention in recent years. The high costs and low biomass productivity of microalgal bioprocessing significantly impede the industry's ability to compete economically and the industrialization of microalgal biotechnology. The capital cost of the microalgal process can be decreased by the use of numerous techniques and fractionation, which separate distinct high-value products [10]. Other potentially important molecules, such as proteins and carbohydrates, are either disregarded or underestimated while a specific chemical, such as astaxanthin or flavanoids, is currently being extracted. The current review article seeks to give a general overview of microalgae uses in the food, cosmetics, pigment, and pharmaceutical industries.

II. TYPES OF ALGAE

A. Microalgae

Microalgae are minute, unicellular, prokaryotic algae with a diameter of 1–50 m, sometimes known as blue-green algae or cyanobacteria. Some of them have the ability to grow heterotrophically and photographically. Their metabolism is powered by carbon and radiation energy, very much like the oxygenic photosynthesis of terrestrial plants [11]. They can be seen alone, in groups, or in clusters. Microalgae include phosphorus, calcium, iron, vitamins A, B, C, and E, as well as folic acid, biotin, beta-carotene, pantothenic acid, and vitamin B12 [12]. Some microalgae species may adapt to phosphorus depletion; in some of these species, non-phosphorus membrane lipids can be employed in place of phospholipids [13].

B. Macroalgae

Eukaryotic, macroscopic, multicellular macro-algae are commonly referred to as seaweeds. The marine water or sea water that has the lightest is where macroalgal species live [14]. Being benthic plants, their capacity to survive depends on how firmly they are anchored to the seafloor or a layer of solid rock below them. The thallus, lamina, kelp, holdfast, and frond sorus of macro-algal species are simple in structure, in contrast to terrestrial plants, which have complicated tissue and organ organization [15]. Macroalgae may be categorized into three primary categories according on their level of pigmentation [14].

1) *Chlorophyceae* (green algae)
2) *Phaeophyceae* (brown algae)
3) *Rhodophyceae* (red algae)

III. PIGMENT PRODUCED BY ALGAE

A. Red algae

The red protein pigment phycoerythrin is produced by red algae together with chlorophyll. This pigment gives red algae its color because of its capacity to absorb blue light while reflecting red light [16]. A covalent link is created between the protein and phycobilin’s with chromatophores. The presence of the aforementioned pigment in these algae species allows them to perform photosynthesis [17]. Red algae are sometimes utilized in cosmetics, such as Irish moss and *Gracillaria* species. *Porphyria* species, etc.

B. Green algae

Chlorophyll, a pigment used in photosynthetic processes and capable of storing light energy, is produced by it. Similar to this pigment is hemoglobin, the red pigment present in human red blood cells. It keeps the algal species from drying out by moisturizing it and supplying oxygen to its exposed surface. It also has anti-inflammatory qualities [18]. There are several types of green algae that are utilized in cosmetics, including *Chlorella vulgaris*, *Ulva lactuca*, and others. Beta-carotene, which may be produced from *Dunaliella salina*, is used in dietary supplements and colourants as a nutraceutical since it is a precursor to vitamin A [19].

C. Brown algae

A brown algal pigment called fucoxanthin is included in the chloroplast. It also has anti-inflammatory properties and inhibits tyrosinase while promoting the production of collagen, a structural protein that tends to scatter with ageing and aids in reducing or controlling skin pigmentation. Additionally, it slows down the skin's ageing process. The pigment also hydrates the skin and maintains the cells functioning properly [20]. *Laminaria digilata, Postelsiapa maeformis*, a few species of brown algae used in cosmetics, *Isochrysis spp*., and other species are examples.

IV. ALGAE IN PHARMACEUTICALS

In recent year, algae play a main role in the pharmaceutical industry. The pharmaceutical businesses in India, where the pace of growth is growing every year, currently account for 70% to 80% of the market. There are many algae types which are very feasible for the mankind that enriches in beneficial factors. For example, of algal types cyanobacteria which is also known as blue green algae that are been mostly used in antibiotics and also used for the pharmacologically active compounds. Antimicrobials, antivirals, therapeutic proteins, antifungals, and other significant products generated from algae play an increasingly important role in the pharmaceutical business [21,22]. Antioxidant, anticancer, and antiviral capabilities are the three main traits that algae possess [23]. The polyphenols, vitamins, and phycobiliproteins found in algae are considered to have the most potent water-soluble antioxidant capabilities. The suppression of cancer growth that results in the regression of premalignant lesions is largely attributed to antioxidants [24,25]. According to the study on algae, the process of scavenging free radicals and the active oxygen that aids in cancer prevention are two ways that algae contribute to the prevention of oxidative damages. The key factor of the antioxidants is to fight out various diseases that includes chronic disorder, inflammation etc. The polyphenols act as one of major antioxidant that are mostly present in marine algae, in which is also known as phlorotannin's. Anticancer activity acts in most of the marine algae which involves with a wide range of properties. The main use of the anticancer activity acts as a good antibiotic property in which it inhibits many dangerous diseases. Algae is utilised in the treatment of oral cancer because it has anti-inflammatory and antioxidant characteristics, including carotenes. Algae floral chemicals are also employed as cancer treatments. Researchers and the pharmaceutical corporations are actively researching this area of anticancer [26]. The cyanobacterium *S. platensis* has strong antioxidant levels, which contribute to the anticancer effectiveness in aqueous extracts from algae, which also exhibit anticancer action [27]. The earliest evidence of antiviral capabilities came from brown algae, which has a broad spectrum of action that entirely blocks the virus. The significant finding paved the path for antiviral chemotherapy [28]. Carrageen, an algal polysaccharide generated from red algae, is used to combat certain viruses, including the influenza virus, DENV, HSV-1, HSV-2, HPV, and HRV. Brown algae-derived alginate is utilised in the treatment of HIV, IAV, and HBV.

The elements in algae provide a more sophisticated action that targets cancer treatments and is more beneficial due to their chloroplasts and photosynthetic organelles. The genetic properties of small algae were discovered through this application and extensive study, and they aid in the destruction of hazardous cancer cells, paving the way for tumour therapies. This activity was crucial in figuring out the role of algae in the pharmaceutical industry. Additionally, algae are quite good at folding proteins into intricate three-dimensional structures.

There are different types of algae in the medicinal aspects in which it differs at the medicinal properties and also form a unique action from others. The few forms of algae and their medicinal cures [29-34] are been entitled below in Table 01.

Types of algae	Medicinal cures
Enteromorpha	Used to treat haemorrhoid parasitic disease, goitre, coughing and the bronchitis and also has a capacity to reduce fever and ease pain
Acetabularia	Used to treat urinary disease and also takes place in edema.
Sargassum	Used for treating cervical lymphadenitis, diminishes inflammation, induces urination.
Laminaria	Used for treating the thyroid problems and other forms of urinary diseases that are been more vigorously infected.

Table 01: Types of Algae and their Medicinal cures

According to the study, microalgae are crucial in the creation of anti-cancer medications. One of these components, cryptophycin, was extracted from blue-green algae and has proven to be very effective in the creation of anti-cancer medications. Major factors that have been seen in the microalgae that create alkaloidal neurotoxins such saxitoxin and polyketide, which act in having anti-inflammatory and anti-cancer characteristics [35–40]. Other kinds of macroalgae include the alkaloids that are the precursor of anti-cancer medications.

V. ALGAE IN COSMETIC INDUSTRY

Several secondary metabolites generated from algae have been associated to skin benefits [41]. As a consequence of a global trend toward goods that are viewed as healthful, environmentally sustainable, and ecologically sourced, the cosmetics industry has financed research and development of new products that contain components or extracts from natural sources. Algae are naturally exposed to oxidative stress, and as a result, they develop a number of effective defence mechanisms against reactive oxygen species and free radicals. These systems also enable the production of compounds that can protect cosmetics from the damaging effects of UV radiation by acting similarly to the organic and inorganic filters currently available on the market [42]. In actuality, when grown in the presence of UV light, *C. vulgaris*, *Nostoc*, and *Spirulina platensis* produce more carotenoids and chlorophyll [43]. Additionally, due to their antioxidant capabilities, these compounds may help prevent the oxidation of oil in formulations, particularly in emulsions with a lot of oily components [42]. Fucus vesiculas extract lessens the look of dark circles beneath the eyes by promoting the expression of heme oxygenase-l (HO-l), a molecule that prevents heme formation on the skin by eliminating heme catabolites. In topical preparations, the extract's anti-inflammatory and antioxidant capabilities may diminish fine lines and wrinkles and enhance the look of eye bags.

They could also increase collagen synthesis, which might lessen the look of eye bags. Additionally, using sunscreen and cosmetics might delay or even stop the ageing process of the skin [44]. Some secondary metabolites of specific microalgae can prevent blemishes, cure seborrhea, heal injured skin, delay the healing process, and maintain moisture in the skin [45]. Red microalgae extracts are also found in skin care, sun protection, hair care, emollient, revitalising, or regenerating care products, anti-aging lotions, and anti-irritant peelers [46–48]. Algae are frequently utilised as thickeners, water-binders, and antioxidants in cosmetics.

VI. ALGAE IN FOOD INDUSTRY

In developed nations, obesity, heart disease, diabetes, and other health issues are brought on by a diet high in calories and a modern lifestyle. Because of this, there is a demand for foods that can improve health by adding vitamins, minerals, PUFA, and other nutrients to the diet. Additionally, consumers' preference for natural ingredients over synthetic ones made it very appealing. Algae are a remarkable but understudied natural source of biologically active compounds. Beta-1,3-glucan, which is an active immunostimulant, a scavenger of free radicals, and a limiter of blood lipids, appears to be the most important substance in *Chlorella*.

The role of cyanobacteria as Antibacterial, anti-viral, anti-tumor and food additives have been well established and most promising aspect of microbial biotechnology is successful micro discovery. Role of antioxidants found in algae studies on the hypo cholesterol emic effect that is attributed various components such as lipoprotein lipase activity, chlorophyll content and phycocyanin and increased the levels of linoleic and arachidonic acids by 29% and 24%, respectively [49]. Biomass from microalgae was primarily utilized in the health food industry. However, this is due to the fact that using traditional foodstuffs' functional qualities and natural ingredients is one way to create new products that are both appealing and healthy. Around the world, there are numerous combinations of microalgae or mixtures with other foods. Algae farming holds a significant market share in the food industry. Due to their abundance of health-promoting compounds (such as carotenoids, astaxanthin, omega-3, and docosahexaenoic acid), eyelash ingredients were typically utilized as dietary supplements in powder, capsules, and tablets. The use of these components (or derived components) in food composition is a recent trend. The number of listed beverages containing microalgae or macroalgae has significantly increased in the past five years, as has the quantity of food consumed throughout the year. 13,090 new food products containing algae or components derived from it were introduced worldwide between 2015 and 2019, of which 5720 were introduced in Europe and 436 in Spain. Algae were incorporated in a variety of ways based on the ingredient that was used (whole dried biomass or a purified component) and the purpose that they served in the formulation (a dye agent or a functional component). Due to its adaptability, there are numerous dining options. Producers and consumers alike may be somewhat perplexed when deciding between eyelash-enhanced and unenhanced products. It can be affected by a variety of consumer choices, such as nutrition labels and the mention of eye strain designation [50].

VII. FUTURE PROSPECTS OF ALGAE IN VARIOUS INDUSTRIES

Biomass of microalgae has a number of useful bioactive components. When compared to the sources of biofuels of the first and second generations, microalgae species are reported to have a high rate of photosynthetic conversion of sunlight. Four methods can be used to directly convert biomass from microalgae into biofuel. Trans esterification, thermochemical conversion, biochemical conversion, and microbial fuel cell are all examples of these [51]. The type of project specification and the availability of raw biomass are two examples of factors that influence the choice of a suitable process.

The raw material from microalgae biofuels is biologically processed during the biochemical process. This conversion includes photobiological hydrogen generation, anaerobic digestion, and fermentation [52]. The fermentation of microalgae into alcohol yields bioethanol. Using yeast, the microalgae fraction that contains cellulose, starch, and other organic components will be transformed into alcohols. Biogas could also be produced by anaerobic digestion of microalgal biomass.

When compared to the production of biodiesel from microalgae lipids, biogas produced from microalgae is regarded as a biogas with a high energy content and yield. The biogas produced through anaerobic digestion has a composition of 50 to 70 percent CH_4, 20 to 30 percent CO_2, 0.1 to 0.5 percent H_2S, and traces of water, N_2, NH_3, and SO_2.A promising raw material for biological processing is microalgae biomass, which has the capacity to produce components of highly valuable bioactive substances [53]. It focuses on using a bio-refinery method to extract various products from microalgae. In addition to the production of biodiesel, extracted lipids can be utilized as health supplements in the form of PUFA; Proteins and carbohydrates can be used in diets and the fermentation industry, but the pharmaceutical and cosmetic industries heavily rely on specialized microalgae-derived products like vitamins and pigments. To obtain components with a high production speed, simple operation, higher yield, and lower costs, various technologies are being investigated [54]. Proteins, vitamins, pigments, fatty acids, lipids, and phenolic compounds are some of the lash species that are commercially exploited-carotene, lutein, canthaxanthin, astaxanthin, and fucoxanthin are well-known to be produced by the algae *Haematococcus pluvialis, Dunaliella salina, Chlorella sps, Scenedesmus sps, Spirulina platensis, Botryococcus braunii*, and diatoms, respectively. Algae pigment composition, on the other hand, varies from species to species and from environment to environment [55]. Stressful conditions like nutrient deficiency have been observed to increase the pigment accumulation of most algal species. There are approximately 30,000 species of microalgae, which are photosynthetic microorganisms. Based on their morphological characteristics, groups of algae are categorized as *Cyanophyta* (such as blue-green algae), *Phaeophyta* (such as brown algae), *Rhodophyta* (such as red algae), and *Chlorophyta* (such as green algae). Carotenoids, on the other hand, help to classify algae into ten main categories [56].

Despite the fact that synthetic pigments are against the law in many nations due to their harmful effects on human health, they are still utilized for a variety of purposes in numerous other nations. Consumer preference for natural carotenoids over synthetic ones is driving an increase in global demand for carotenoids. Carotenoids, chlorophylls, or Phycobilin proteins may be the predominant pigment in a particular alga, depending on the class and species. The harvesting, processing, extraction, and purification of algal cells make mining and processing carotenoid pigments from microalgae extremely challenging [57]. Carotenoids extracted from microalgae biomass must be harvested, analysed, extracted, purified, and then processed in order to be commercialized. The cell walls of some microalgal species are tough and difficult to break. Bowl and pestle, two-phase extraction, grinding, ultrasound, microwave, thawing, freezing, supercritical fluid extraction, and edible oils are all methods that can be used to disrupt the cell wall. The particular kind of algae determines which method of extraction is best [58]. Using a mortar and pestle, carotenoids were extracted from the cells of *D. salina, H. pluvialis, S. platensis, B. braunii, and Chlorococcum sps*. This approach is suitable for a bench-scale process, not an industrial scale-up process.

VIII. CONCLUSION

Algae have the potential to be a source of bioactive materials for the beauty and medicinal industries. Compounds made from algae have exceptional biological activity and distinctive chemical structures. They are also "natural and healthful" since they include harmless ingredients. Diverse marine algae species have a variety of qualities without any toxicity and a strong safety profile. Many different biologically active chemicals with noteworthy effects are created by algae. Algae-derived chemicals are superior than synthetic substances used in the manufacture of different foods and medications. It functions as photoprotection and is utilised in skincare products. Studies on the possible use of algae for improving human health have gained prominence during the last several decades in a variety of fields. Due to their abundance in bioactive molecules, chemicals obtained from microalgae are highly sought after in the pharmaceutical, nutraceutical, cosmetic, animal feed, biological waste treatment, and other multifunctional industries. Microalgae are important sources of natural bioactive substances including carotenoids, PUFAs, proteins, polysaccharides, and glycolipids, which have the potential to cure diseases like cancer, inflammation, Alzheimer's, CVDs, malaria, leishmaniasis, TB, HIV, and others. Additionally, it was discovered that several physiologically active marine algal components, such as carotenes, dolostatins, majusculamides, and aflatoxins, had very positive health effects. Therefore, scientists should investigate the possible uses of marine algae's bioactive components in cutting-edge medicinal research and biotechnology. Biomaterials made from algae have a bright future in the pharmaceutical and cosmetic industries. However, there is still a lack of conclusive evidence regarding the bioactive substances found in algae, necessitating extensive research to produce major algae compounds that can be used in biomedical applications. Accurate results will become apparent once the product is marketed and put to public testing.

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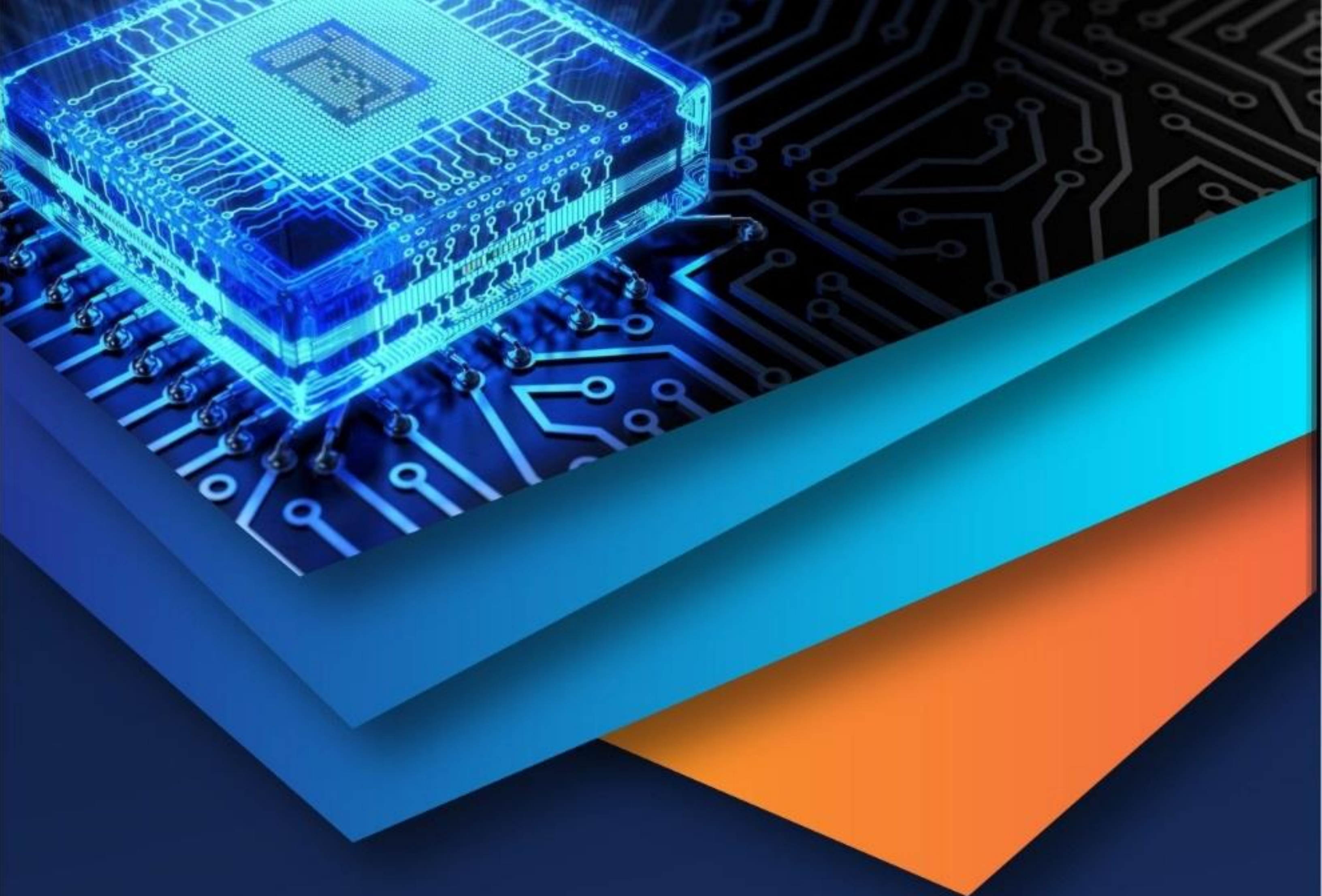

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