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Spirulina: A Potential Nutraceutical Agent and Its Medical Applications

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Abstract: *Spirulina is a blue-green microalga widely recognized as a valuable nutraceutical agent due to its rich nutritional composition and diverse biomedical properties. The present study aimed to evaluate the phytochemical constituents and biological activities of the ethanolic extract of Spirulina. The dried spirulina powder was extracted using ethanol through the Soxhlet extraction method. Preliminary qualitative phytochemical screening of the extract revealed the presence of several bioactive compounds, including flavonoids, flavonols, tannins, phenols, saponins, steroids, terpenoids, carbohydrates, and proteins, while alkaloids, glycosides, and starch were absent. The antioxidant activity of the extract was evaluated using the DPPH free radical scavenging assay. The results demonstrated strong antioxidant potential, with IC_{50} values of <200 µg/ml for both the standard and the spirulina extract. The anti-inflammatory activity of the extract was also assessed and showed significant inhibitory activity with IC_{50} values of <200 µg/ml, comparable to the standard drug. In addition, the antidiabetic activity was determined using a α-amylase inhibitory assay, where the spirulina extract exhibited an IC_{50} value of 444.4 µg/ml, while the standard showed an IC_{50} value of 471.4 µg/ml. The presence of these bioactive phytoconstituents may contribute to the significant antioxidant, anti-inflammatory, and antidiabetic activities observed in the extract. These findings highlight the potential of Spirulina as a nutraceutical agent with promising biomedical applications, suggesting its possible use in the prevention and management of oxidative stress related disorders, inflammatory conditions, and metabolic diseases such as diabetes.*

Keywords: Spirulina, nutraceutical agent, phytochemical screening, antioxidant activity, anti-inflammatory activity, antidiabetic activity, biomedical applications

I. REVIEW OF LITERATURE

Belay et al. reported that *Spirulina platensis* is a blue-green microalga widely recognized as a nutraceutical due to its rich composition of proteins, vitamins, essential fatty acids, minerals, and antioxidant pigments such as phycocyanin. These components contribute to its therapeutic and nutritional value in human health.

Priyanka et al. highlighted that spirulina contains approximately 50–70 % protein along with essential amino acids, carotenoids, and phenolic compounds. Because of its dense nutritional profile, it is commonly used as a dietary supplement and functional food ingredient.

Wu et al. described spirulina as an important functional food because it contains bioactive compounds such as phycocyanin, polysaccharides, carotenoids, and polyunsaturated fatty acids, which possess antioxidant, anti-inflammatory, antiviral, and anticancer activities.

Gershwin et al. demonstrated that spirulina exhibits strong immunomodulatory properties by enhancing the activity of macrophages, natural killer cells, and T-cells, thereby strengthening the immune response against infections and environmental toxins.

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Finamore et al. reported that spirulina supplementation can reduce symptoms of allergic rhinitis by inhibiting histamine release and lowering inflammatory cytokines such as IL-4, indicating its anti-allergic and anti-inflammatory potential.

Prete et al. suggested that spirulina may help in the management of diabetes by improving glucose metabolism and insulin sensitivity. Certain peptides isolated from spirulina inhibit enzymes like α-amylase and α-glucosidase, which are involved in carbohydrate digestion.

Mazokopakis et al. observed that spirulina supplementation can significantly reduce total cholesterol, LDL cholesterol, and triglycerides while increasing HDL cholesterol, thereby helping in the prevention of cardiovascular diseases.

Wu et al. also reported that spirulina possesses antimicrobial and antiviral activities due to the presence of phenolic compounds, peptides, and sulfated polysaccharides, which can inhibit the growth of bacteria, fungi, and certain viruses.

Wu et al. further explained that spirulina demonstrates anticancer potential by reducing oxidative stress and inducing apoptosis in cancer cells through bioactive compounds such as phycocyanin.

Recent clinical studies have shown that spirulina supplementation can reduce inflammatory markers such as IL-1β and IL-6 and improve physical and cognitive health indicators, suggesting its role as a supportive therapy for chronic diseases associated with oxidative stress and inflammation.

II. INTRODUCTION

Spirulina (Arthrospira platensis), a filamentous blue-green microalga belonging to the class Cyanophyceae, has gained considerable attention worldwide due to its exceptional nutritional composition and diverse therapeutic properties. It has long been used as a dietary supplement and functional food because of its high content of proteins, vitamins, minerals, essential fatty acids, and bioactive compounds that contribute to human health and disease prevention (Habib et al., 2008; Khan et al., 2005; Nuhu, 2013). The increasing interest in nutraceuticals derived from natural sources has further highlighted Spirulina as an important candidate for promoting health and preventing chronic diseases (Pandey et al., 2010; Priyanka et al., 2023).

Spirulina is particularly valued for its rich biochemical composition, including proteins, essential amino acids, carotenoids, phenolic compounds, vitamins such as B-complex vitamins, and minerals such as iron, calcium, and magnesium (Belay, 2002; Musa et al., 2024; Spínola et al., 2024). These constituents play a vital role in improving nutritional status and supporting various physiological functions. In addition, Spirulina contains several biologically active pigments such as phycocyanin, chlorophyll, and β-carotene, which exhibit strong antioxidant properties and contribute to its therapeutic potential (Kumar et al., 2017; Romay et al., 2003).

The antioxidant activity of Spirulina has been widely reported and is mainly attributed to its phenolic compounds, flavonoids, and phycocyanin content, which help neutralize free radicals and reduce oxidative stress in biological systems (Wu et al., 2016; Chen et al., 2012). Oxidative stress is closely associated with the development of various chronic diseases, including cardiovascular disorders, diabetes, and cancer. Therefore, the consumption of antioxidant-rich foods such as Spirulina may play an important role in preventing oxidative damage and improving overall health (Brand-Williams et al., 1995; Kumar et al., 2011).

In addition to its antioxidant properties, Spirulina has demonstrated several pharmacological activities, including anti-inflammatory, immunomodulatory, antimicrobial, and metabolic regulatory effects. Studies have shown that Spirulina supplementation may help improve lipid metabolism, enhance immune response, and reduce inflammation (Wu et al., 2016; Romay et al., 2003). Furthermore, experimental and clinical investigations suggest that Spirulina may improve glucose metabolism and insulin sensitivity, indicating its potential role in the management of metabolic disorders such as diabetes (Nishanth & Anuradha, 2015).

Recent clinical studies and systematic reviews have also reported that Spirulina supplementation may contribute to the management of obesity-related metabolic disorders and improve cardiovascular health parameters (Bohórquez-Medina et al., 2021). Due to these diverse health-promoting effects, Spirulina is increasingly recognized as a promising nutraceutical with potential applications in functional foods, pharmaceuticals, and dietary supplements (Karkos et al.,

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2011; Singh et al., 2023; Verma et al., 2024). Moreover, the biotechnological cultivation of microalgae such as Spirulina allows sustainable production of valuable bioactive compounds, making it an important resource for future nutritional and therapeutic applications (Pulz & Gross, 2004).

Therefore, considering its rich nutritional profile and broad spectrum of biological activities, Spirulina has emerged as a valuable nutraceutical with significant potential in promoting health and preventing various diseases. The present study focuses on exploring Spirulina as a potential nutraceutical agent and evaluating its medical applications.

III. MATERIALS AND METHODS

Food-grade Spirulina powder was obtained from local manufacturers Sangli (Maharashtra).Representative samples of the Spirulina powder were analyzed for phytochemical composition. The entire chemical used in the study is of analytical grade and purchased locally.

3.1. Qualitative phytochemical analysis

Twenty grams of *Spirulina powder* biomass was extracted with 250 mL of ethanol. The extraction mixture was filtered to remove insoluble material, and the filtrate was concentrated under reduced pressure using a rotary evaporator. The resulting extract was then subjected to antioxidant, anti-inflammatory, anti- diabetic and qualitative phytochemical screening to detect the presence of major secondary metabolites such as saponins, terpenoids, alkaloids, steroids, glycosides, flavonoids, carbohydrates and phenolic compounds. The phytochemical tests were performed according to standard procedures reported by Harborne J. B. **(1998)**.

3.2. Antioxidant activity

The antioxidant activity of *Spirulina* extract was evaluated using the DPPH free radical scavenging assay with Ascorbic acid as the standard antioxidant. The assay was performed at different concentrations ranging from 200–1000 µg/ml to determine the free radical scavenging potential of the extract. The percentage inhibition increased with increasing concentration, indicating a concentration-dependent antioxidant activity of the spirulina extract. Similar methodologies and results have been reported in previous studies evaluating the antioxidant potential of spirulina and other natural products (Brand-Williams et al., 1995; Wu et al., 2016; Khan et al., 2005; Pulz & Gross, 2004; Belay et al., 1993).

3.3. Anti-inflammatory activity

The anti-inflammatory activity of Spirulina extract was evaluated in vitro using Diclofenac sodium as the standard drug. The assay was performed at different concentrations ranging from 200–1000 µg/ml to determine the inhibitory potential of the spirulina extract. The results demonstrated that the percentage inhibition increased with increasing concentration, indicating concentration-dependent anti-inflammatory activity of the extract. (Romay et al., 2003; Wu et al., 2016; Khan et al., 2005; Karkos et al., 2011; Kumar et al., 2017).

3.4. In vitro Antidiabetic activity

The in vitro antidiabetic activity of *Spirulina* extract was evaluated using the α-amylase inhibition assay with acarbose as the standard drug. The assay was carried out at different concentrations ranging from 200–1000 µg/ml to determine the inhibitory effect of the spirulina extract on carbohydrate-digesting enzymes. The results showed that the percentage inhibition increased with increasing concentration, indicating concentration-dependent antidiabetic activity of the spirulina extract. (Khan et al., 2005; Wu et al., 2016; Nishanth & Anuradha, 2015; Karkos et al., 2011; Belay et al., 1993).

3.5. Statistical Analysis

The values are presented as the means ± standard deviation (SD). The differences were analyzed using Student's t-test.

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IV. RESULTS

4.1. Phytochemical analysis

The results of the preliminary qualitative phytochemical analysis are shown in Table 1.

Table 1: The qualitative Preliminary phytochemical analysis

Group Compounds	Ethanolic extract of spirullina
Alkaloids	-
Flavonoid	+
Glycoside	-
Phenols	+
Saponin	+
Steroids	+
Terpenoids	+
Starch	-
Carbohydrate	+
Proteins	+
Flavonol	+
Tannins	+

The qualitative phytochemical screening of the ethanolic extract of *Spirulina* revealed the presence of several bioactive compounds. Flavonoids, flavonol, tannins phenols, saponins, steroids, terpenoids, carbohydrates, and proteins were detected in the extract, as indicated by positive reactions. However, alkaloids, glycosides, and starch were not observed in the ethanolic extract. The presence of these phytoconstituents suggests that *Spirulina* may possess potential biological and nutraceutical properties.

4.2. Antioxidant activity

The antioxidant activity of the *Spirulina* extract was evaluated using the DPPH free radical scavenging assay and compared with the standard antioxidant Ascorbic acid as shown in Table 2. The results show that both the standard and the spirulina extract exhibited concentration dependent antioxidant activity, with percentage inhibition increasing as the concentration increased from 200 to 1000 µg/ml.

At the highest concentration (1000 µg/ml), the standard showed 87% inhibition, while the spirulina extract showed 85% inhibition, indicating a comparable free radical scavenging ability. The IC_{50} value of the standard was 300 µg/ml, whereas the spirulina extract showed an IC_{50} of 314.3 µg/ml, which is slightly higher than the standard.

This indicates that the spirulina extract possesses strong antioxidant activity, although it is slightly less potent than ascorbic acid, suggesting its potential as a natural antioxidant source

Table 2 Antioxidant activity of spirulina compared with standard ascorbic acid

Concentration µg/ml	% Inhibition of standard	% Inhibition of spirulina
200	43±0.22	42±.20
400	57±o.18	56±0.16
600	69±0.17	64±0.14
800	76±o.022	75±0.17
1000	87±0.21	85±0.15

Values are expressed as mean±SEM (n=3)

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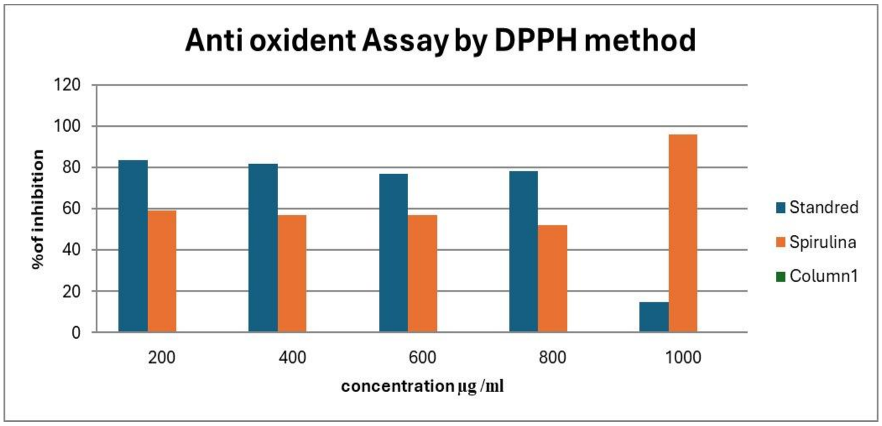


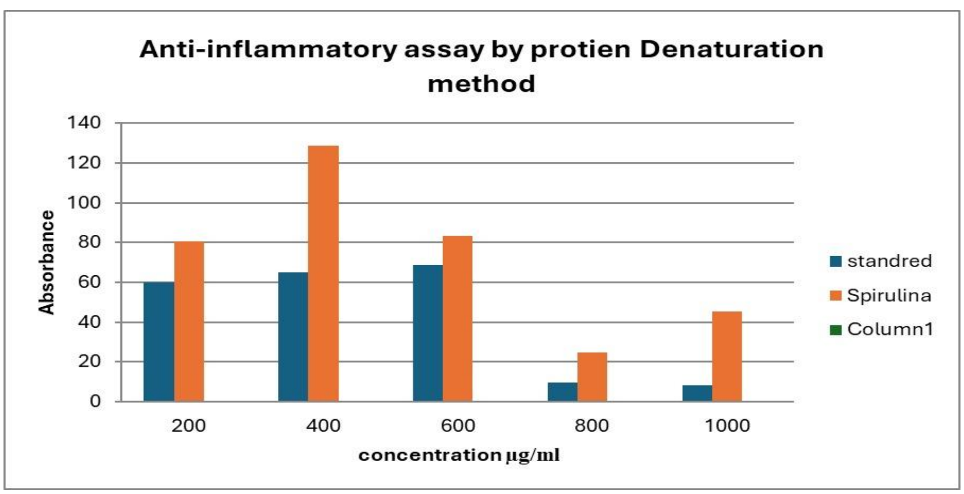
4.3. Anti-inflammatory activity

The anti-inflammatory activity of Spirulina was evaluated and compared with the standard drug Diclofenac sodium. The results demonstrated a concentration-dependent increase in percentage inhibition shown in Table 3. As the concentration increased from 200 to 1000 µg/ml, the percentage inhibition of the spirulina extract increased from 70% to 92%, while the standard showed inhibition from 81% to 99%. Both the standard and spirulina extract exhibited IC_{50} values below 200 µg/ml, indicating strong anti-inflammatory activity. Although the standard drug showed slightly higher inhibition, the spirulina extract also demonstrated significant anti-inflammatory potential, suggesting that it may serve as a natural source of anti-inflammatory compounds.

Table 3 Percentage inhibition of spirulina extract in Anti-inflammatory activity

Sr no.	concentration(µg/ml)	% Inhibition of std	% Inhibition of spirulina extract
1	200	81±0.15	70±0.25
2	400	85±0.17	75±0.21
3	600	89 ±0.16	79±0.22
4	800	94±o.18	83±0.24
5	1000	99 ±0.21	92±0.19

Values are expressed as mean±SEM (n=3)



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4.4. Antidiabetic activity

The in vitro antidiabetic activity of Spirulina extract was evaluated using the α-amylase inhibition assay and compared with the standard drug Acarbose as shown in Table 4. The results showed a concentration-dependent increase in percentage inhibition for both the standard and the spirulina extract.

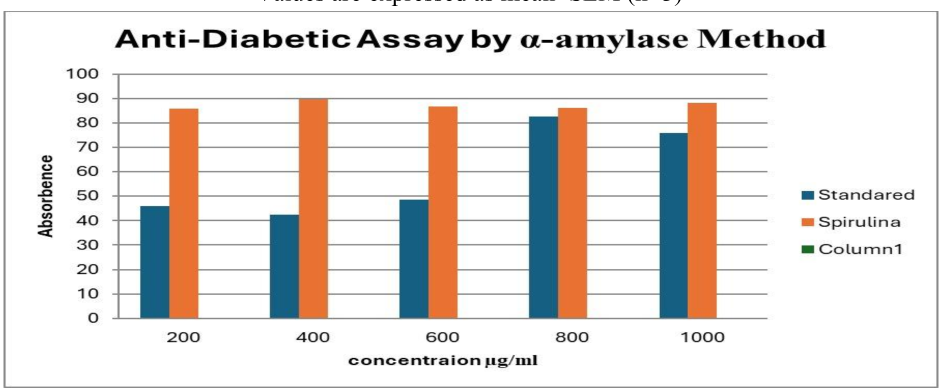
As the concentration increased from 200 to 1000 µg/ml, the inhibition of the spirulina extract increased from 32% to 82%, while the standard showed inhibition from 42% to 87%. The IC_{50} value of the spirulina extract (444.4 µg/ml) was slightly lower than that of the standard (471.4 µg/ml), indicating a comparable and effective α-amylase inhibitory activity.

These results suggest that *Spirulina* possesses significant antidiabetic potential and may help in controlling postprandial blood glucose levels.

Table 4 Results representing in vitro antidiabetic activity of spirulina in comparison with standard acarbose

Concentration µg/ml	% Inhibition of standard	% Inhibition of spirulina
200	42±0.12	32±.19
400	45±o.15	46±0.16
600	59±0.17	64±0.15
800	75±o.021	72±0.17
1000	87±0.11	82±0.19

Values are expressed as mean±SEM (n=3)



V. DISCUSSION

The present study investigated the phytochemical composition and biological activities of the ethanolic extract of Spirulina, focusing on its antioxidant, anti-inflammatory, and antidiabetic potential. Preliminary qualitative phytochemical screening revealed the presence of several important bioactive constituents, including flavonoids, phenols, saponins, steroids, terpenoids, carbohydrates, and proteins, while alkaloids, glycosides, and starch were absent. These phytochemicals are widely recognized for their diverse pharmacological properties and contribute significantly to the therapeutic potential of natural products. Similar findings regarding the phytochemical composition and medicinal significance of *Spirulina platensis* have been reported previously (Kanojia et al., 2019).

Flavonoids and phenolic compounds identified in the extract are well known for their strong antioxidant properties. These compounds play a crucial role in neutralizing free radicals and reducing oxidative stress in biological systems. Oxidative stress is associated with the development of various chronic diseases, including cardiovascular disorders, diabetes, and inflammatory conditions. The presence of saponins and terpenoids may further contribute to the antimicrobial, anti-inflammatory, and immune-modulating properties of spirulina. Steroids are also known to exhibit significant pharmacological activities, including anti-inflammatory and metabolic regulatory effects, which may enhance the therapeutic value of the extract (Kanojia et al., 2019).

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The qualitative phytochemical analysis also confirmed the presence of proteins in the ethanolic extract of Spirulina, supporting its nutritional and therapeutic importance. Spirulina is widely recognized as one of the richest natural sources of protein, containing approximately 60–70 % protein by dry weight, which is considerably higher than many conventional protein sources such as beef. Proteins are essential macromolecules responsible for maintaining the structural integrity and functional activities of cells and tissues. In addition, proteins present in spirulina may contribute to several biological processes, including the regulation of glucose metabolism and enzymatic activities (Bhairam et al.).

Previous studies have reported that spirulina proteins and their derived bioactive peptides may exhibit antidiabetic properties by influencing glucose metabolism. Spirulina may act in a manner similar to insulin or stimulate the β-cells of the islets of Langerhans, thereby enhancing insulin secretion and reducing blood glucose levels. Furthermore, spirulina has been reported to improve hemoglobin levels and reduce glycated hemoglobin (HbA1c) due to its high iron content, which may contribute to improved glycemic control. Bioactive peptides produced during the digestion of spirulina proteins, along with its fiber content, may also stimulate insulin release and decrease glucose absorption in the intestine, thereby contributing to its potential antidiabetic activity (Medina et al., 2021).

In addition to proteins, carbohydrates were also detected in the extract, indicating its nutritional value. Spirulina contains approximately 13.6 % to 25 % carbohydrates depending on the species and cultivation conditions. The carbohydrate fraction mainly consists of sugars such as glucose, mannose, galactose, xylose, and glycogen, which contribute to its high digestibility and nutritional quality. Because of these properties, spirulina is considered a valuable functional food and dietary supplement, particularly beneficial for elderly individuals and individuals suffering from intestinal malabsorption disorders (Bhairam et al.).

The presence of flavonoids and phenolic compounds detected during phytochemical screening further supports the antioxidant potential of Spirulina. These bioactive constituents act as effective free radical scavengers and help neutralize reactive oxygen species (ROS), thereby protecting biological systems from oxidative damage. Previous investigations have reported that spirulina possesses significant antioxidant potential due to the presence of phenolic compounds, flavonoids, and pigments such as phycocyanin (Priyanka et al., 2023). These compounds are known to protect cells from oxidative damage and may play an important role in preventing several chronic diseases, including cancer and diabetes. Additionally, these bioactive compounds have demonstrated anti-inflammatory, antiviral, and anticancer activities, further highlighting the therapeutic and nutraceutical importance of spirulina (Spínola et al., 2024; Nuhu, 2013).

The antioxidant activity of the ethanolic extract of Spirulina was evaluated using the DPPH free radical scavenging assay and compared with the standard antioxidant ascorbic acid. The results demonstrated a concentration-dependent increase in free radical scavenging activity. As the concentration increased from 200 to 1000 µg/ml, the percentage inhibition of the spirulina extract increased from 42 % to 85 %, while the standard ascorbic acid exhibited inhibition ranging from 43 % to 87 %. These findings indicate that the antioxidant activity of the spirulina extract is comparable to that of the standard antioxidant, suggesting the presence of potent antioxidant compounds in the extract. Similar antioxidant potential of Spirulina has also been reported in previous studies (Khan et al., 2005).

The gradual increase in antioxidant activity with increasing concentration suggests that the bioactive constituents present in spirulina are capable of donating hydrogen atoms or electrons to neutralize free radicals. This mechanism is essential in reducing oxidative stress caused by reactive oxygen species. The observed antioxidant activity may be attributed to phytochemicals such as flavonoids, phenols, tannins, and terpenoids detected during the phytochemical screening of the extract. These compounds are widely recognized for their ability to scavenge free radicals and protect biological systems from oxidative damage (Belay, 2002).

The results obtained in the present investigation are consistent with previous studies that describe spirulina as a rich source of antioxidant compounds such as phycocyanin, phenolic compounds, and carotenoids, which significantly contribute to its free radical scavenging activity (Wu et al., 2016). Furthermore, spirulina extracts and their protein hydrolysates have been reported to possess strong antioxidant activity due to the presence of bioactive peptides and

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pigments (Chen et al., 2012). Environmental and cultivation conditions may also influence the antioxidant capacity of spirulina, as variations in growth conditions can affect the production of antioxidant compounds (Kumar et al., 2011).

In addition to antioxidant activity, the anti-inflammatory potential of Spirulina extract was evaluated and compared with the standard drug diclofenac sodium. The results showed a concentration-dependent increase in percentage inhibition, where the spirulina extract exhibited inhibition ranging from 70 % at 200 µg/ml to 92 % at 1000 µg/ml, while the standard drug showed inhibition from 81 % to 99 %. Although the standard drug demonstrated slightly higher activity, the spirulina extract also showed remarkable anti-inflammatory potential. Similar results have been reported in earlier studies, where spirulina extracts demonstrated significant anti-inflammatory activity due to the presence of bioactive compounds such as flavonoids and phenolic compounds (Wu et al., 2016; Khan et al., 2005).

The IC_{50} value of both the standard and spirulina extract was found to be less than 200 µg/ml, indicating strong inhibitory activity. The anti-inflammatory activity of spirulina is mainly attributed to the presence of phycocyanin, a pigment-protein that inhibits inflammatory mediators and enzymes involved in inflammatory pathways (Romay et al., 2003). Additionally, phenolics, flavonoids, and terpenoids present in spirulina contribute to its anti-inflammatory and antioxidant effects by reducing oxidative stress and inhibiting the production of inflammatory cytokines (Karkos et al., 2011; Kumar et al., 2017).

The in-vitro antidiabetic activity of Spirulina extract was also evaluated using the α-amylase inhibition assay in comparison with the standard drug acarbose. The results revealed that both the standard and spirulina extract exhibited concentration-dependent inhibition. As the concentration increased from 200 to 1000 µg/ml, the percentage inhibition of spirulina increased from 32 % to 82 %, while the standard showed inhibition from 42 % to 87 %. These findings suggest that spirulina extract possesses significant α-amylase inhibitory activity, although the standard drug exhibited slightly higher inhibition.

The antidiabetic activity observed in the present study may be attributed to the presence of bioactive compounds such as phenolics, flavonoids, and polysaccharides, which are known to inhibit carbohydrate-digesting enzymes and reduce glucose absorption in the intestine (Khan et al., 2005; Wu et al., 2016). Spirulina also contains phycocyanin and other antioxidant compounds that have been reported to improve glucose metabolism and insulin sensitivity (Nishanth et al., 2015). Furthermore, spirulina supplementation has been shown to reduce blood glucose levels and improve metabolic parameters in diabetic conditions (Belay et al., 1993; Karkos et al., 2011).

Overall, the findings of the present study confirm that Spirulina possesses significant phytochemical constituents that contribute to its antioxidant, anti-inflammatory, and antidiabetic activities. These results support the growing evidence that spirulina can serve as a valuable nutraceutical agent with potential applications in the prevention and management of oxidative stress-related diseases, inflammatory disorders, and metabolic conditions such as diabetes.

VI. CONCLUSION

In conclusion, the present study demonstrated that the ethanolic extract of *Spirulina* contains several important phytochemical constituents, including flavonoids, flavonols, tannins, phenols, saponins, steroids, terpenoids, carbohydrates, and proteins. These bioactive compounds are known to contribute to various therapeutic properties. The extract exhibited significant biological activities, including strong antioxidant activity determined by the DPPH free radical scavenging assay, notable anti-inflammatory activity comparable to Diclofenac sodium, and promising antidiabetic potential through the α-amylase inhibition assay when compared with Acarbose.

The results suggest that the presence of these phytoconstituents plays a significant role in the observed antioxidant, anti-inflammatory, and antidiabetic activities. Therefore, *Spirulina* can be considered a valuable natural nutraceutical with potential biomedical applications. These findings support its possible use in the prevention and management of oxidative stress–related disorders, inflammatory diseases, and metabolic conditions such as diabetes. However, further studies, including isolation of active compounds and in vivo investigations, are required to validate its therapeutic potential and clinical applications.

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