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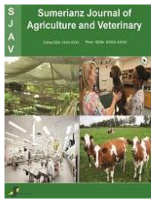


Original Article Open Access

# The Significance of *Spirulina* Meal on Fishmeal Replacement in Aquaculture. A Review

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## Abstract

In fish farming operations, feed accounts for more than half of the total variable operating costs. The costs are mainly contributed by protein source from feed ingredients. Therefore, the potential use of unconventional feed ingredients such as algae, as feed inputs in replacement of high-cost feedstuffs such as fishmeal has been increasing. Among unconventional algae feed ingredients, *Spirulina* which is a fast-growing cyanobacter of large size have been a possible alternative protein source for cultured fish due to high and good quality protein, vitamins and essential fatty acids contents, antioxidant pigments, antimicrobial activity, and anticancer properties. A review was conducted on the significance of *Spirulina* meal on fishmeal replacement in Aquaculture, mostly focus was on finfish culture. About 20 published online journal papers, from Research gate, Google scholar and other online platforms in aquaculture nutrition were reviewed. Among reviewed papers revealed that the amount of fish meal to be replaced with Spirulina in the diet has been in a certain limit, with the positive growth performance, improving non-specific immune activity, enhancing good quality of fillets and increase the quality of eggs at the inclusion levels between 0.5 to 15%. Therefore, this review suggests that 1-20% inclusion level of *Spirulina* can be used to replace fish meal in a diet for effective low feeding costs in both omnivorous and herbivorous fish species.
**Keywords:** Fish growth performance; *Spirulina* meal; Omnivorous fish; Herbivorous fish; Immunostimulants.

## 1. Introduction

In aquaculture operations, proper nutrition has been recognized as a critical factor in promoting normal growth and sustaining fish health. The development of high-quality diets particularly animal and plant-based is a factor that has significantly contributed to the massive expansion of fish farming. In fish farming, feed accounts for more than half of the total variable operating costs [1]. The costs are mainly contributed by protein source from feed ingredients. Therefore, the potential use of unconventional feed ingredients such as algae, as feed inputs in replacement of high-cost feedstuff such as fishmeal has been increasing [2].

Among unconventional algae feed ingredients, *Spirulina* which is a fast-growing cyanobacter of large size (0.5 mm) have been a possible alternative protein source for cultured fish. This is due to high and good quality protein, vitamins and essential fatty acids contents (gamma-linolenic acid) [3]; antioxidant pigments, such as carotenoids (C-phycocyanin C-PC) [4, 5]; antimicrobial activity [6]; and anticancer properties [7]. It also reported to increase feed utilization, physiological activity, stress response, starvation tolerance, disease resistance, and carcass quality [8]. In addition, *spirulina* can be produced by low-cost open pond technologies and are marketed as dry powders, and their nutritional profiles are well-documented.

Several studies have been conducted in both finfish and shellfish using dried *Spirulina* powder as a supplement in diets with promising results. In finfish, Broun [9] and Zeinhom [10] reported positive fish growth performance when fed diets containing algae cells. Also, positive results have been reported in ornamental fish such as Guppy fish [11].

In addition, good results have been documented in shellfish such as white shrimp *Litopenaeus schmitti* [20], in Pacific white shrimp *Litopenaeus vannamei* [12] and *Penaeus semisulcatus* [13]. Therefore, this review aimed to explore the significance of *Spirulina* meal on fishmeal replacement in aquaculture from the field of aquaculture nutrition.

## 2. Methodology

It was a bibliographic review where productions were selected in the form of articles published online mainly from Research gate, Google scholar and other online platforms in aquaculture nutrition. The author contemplates the following data: journals, books, and year of publication.

In addition, the selection was based on the similarity of subjects to the objective of this study, disregarding those that, although revealed in the search result, did not approach the subject from the point of view of *Spirulina* in replacing fishmeal.

# 3. Literature Review

## 3.1. Classification, Origin, and Cultivation of Spirulina

*Spirulina* is a photosynthetic, filamentous, blue-green microalga like a spiral of long thin threads under genus *Arthrospira*, the phylum *Oscillatoriaceae*. It is called blue-green algae (Cynobacteria) because of the presence of both green (chlorophyll) and blue (phycocyanin) pigments in its cellular structure [14]. There are two common important species which are used due to its nutritious value, *Spirulina maxima* and *Spirulina plantensis*.

It is naturally found in the Central Africa region around Lake Chad, Niger, East Africa, along with the Great Rift Valley and Mexico, where it has routinely been used as a human food source [15] and included in the diets of many fishes, including Tilapia [16].

Artificially, it can be cultured in saline and unlined ditches water through simple technology with the supply of essential chemicals/nutrients. The culturing cost depends on the materials and technology used. For instance, Allen [17]; suggested that the *Spirulina* costs approximately 0.5$/kg when cultured in a dug out trench. Normally, *spirulina* is produced using continuous-harvesting technology that maintains exponential growth. Therefore, continuity supplying of the required nutrients are important to maintain an appropriate biomass to be harvested. After matured, *Spirulina* is harvested using suitable cloth material and dried out in the sun [15].

## 3.2. Nutritional Information

*Spirulina* is a nutritionally balanced ingredient for inclusion in fish feeds. It has a protein content ranging between 41-63% by dry weight (Table 1) and contains all ten of the essential amino acids in appropriate levels, except for reduced methionine, cysteine, and lysine (Table 2). Its essential fatty acid profile includes high amounts of polyunsaturated fatty acids (PUFA), and its vitamin and mineral contents are comparable to other in-use fish feed protein sources [17]. Therefore, due to a well-balanced amino acid of *Spirulina* compared with other plant protein makes it a potential replacer of fish meal in aquafeed formulation [12].

**Table-1.** Nutrient composition (%) of *Spirulina platensis* powder on a dry weight basis

| References | Protein | Carbohydrate | Lipid | Ash | Moisture |
|---|---|---|---|---|---|
| Radhakrishnan, *et al.* [18] (g/100g) | 41.2-42.0 | 20.5-23.1 | 13.1-13.7 | 11.9-14.4 | 7.4-9.9 |
| Sirakov, *et al.* [19] (% of dry matter) | 41.4 | - | 18.9 | 5.3 | 9.6 |
| Ghaeni and Matinfar [20] | 46.6 | - | 0.1 | 0.7 | 9.5 |
| Amer [21] | 63 | - | 12 | - | 7.13 |
| Sarker, *et al.* [22] | 61.3 | - | 5.5 | 6.9 | 17.8 |

**Table-2.** Nutritional profile of *Spirulina* in comparison to fishmeal

| ***Spirulina* [22]** | | **Brown fishmeal [23]** |
|---|---|---|
| **Proximate composition ($g100g^{-1}$)** | | |
| Dry matter | 82.2 | 92.28 |
| Crude protein | 61.3 | 67.44 |
| Ash | 6.9 | 12.76 |
| Lipid | 5.5 | 10.52 |
| Crude fibre | 3.0 | 1.46 |
| **Essential amino acids ($g100g^{-1}$)** | | |
| Arginine | 4.10 | 3.67 |
| Lysine | 3.10 | 1.55 |
| Isoleucine | 2.60 | 3.02 |
| Leucine | 4.70 | 4.84 |
| Histidine | 1.00 | 5.05 |
| Methionine | 1.37 | 1.87 |
| Phenylalanine | 2.50 | 2.69 |
| Threonine | 2.70 | 2.71 |
| Tryptophan | 1.20 | 0.72 |
| Valine | 0.30 | 3.41 |

**Source:** Allen [17]

## 3.3. Properties of Spirulina as Fish Feed Ingredients

### 3.3.1. High Digestibility

Unlike other algal species, such as *Chlorella*, *Spirulina* lacks cellulose in its cell wall, which is known to decrease digestibility [22]. Therefore, it's digestibility is comparable to that of the fish meal due to the presence of almost the same nutrients (Table 2). Some fish species such as Tilapia have been reported to efficiently utilize *Spirulina* in their diets due to the increase in digestibility and nutrients uptake through the gut [24].

#### 3.3.2. Inclusion Levels

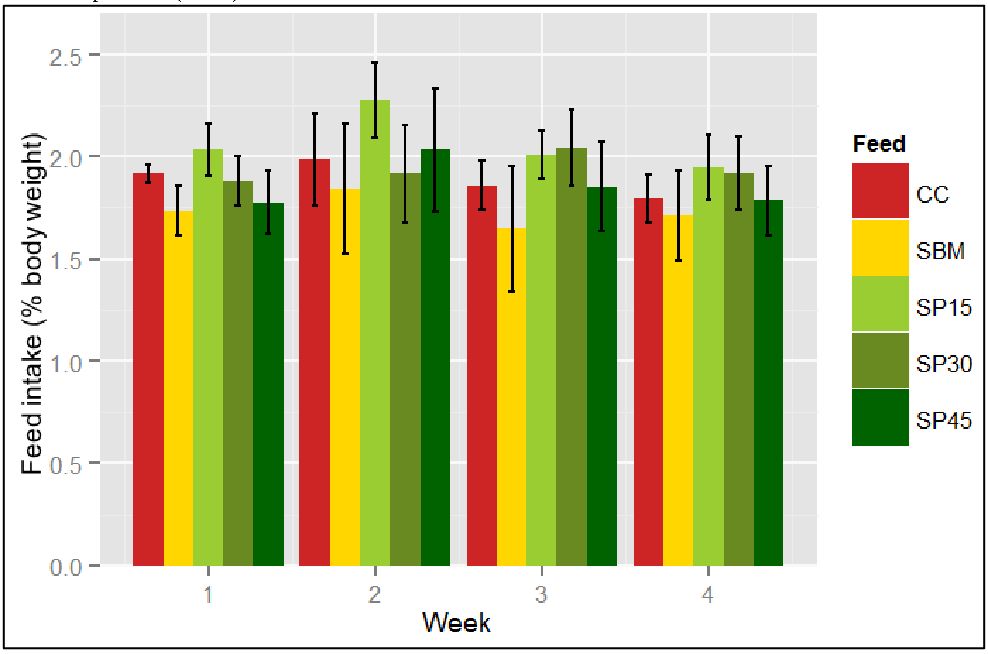
The low levels less than 15% (Table 3) of fishmeal replaced with *Spirulina* is uniformly positive and it has been shown to impart a number of additional benefits such as improving feed intake (Figure 1), growth and survival rate, boosting the immune system, increase fillet color and firmness, and reduce feeding costs. For instance, taste and texture of Striped Jack (*Pseudocaranx dentex*) were reported to be improved when supplied with 5% dietary *Spirulina* [25]. However, high inclusion levels of *Spirulina* as a main protein source or in excess of 15% when replacing fishmeal have been reported. Ruangsomboon, *et al.* [26]; reported that Red Tilapia fed 30% *Spirulina platensis*, contained more carotenoids than individuals fed less *Spirulina*, demonstrating that *Spirulina* can be exploited as a pigment source for incorporation in Red Tilapia diets to produce coloration and gain market acceptance.

Similarly, Olvera-Novoa, *et al.* [23]; indicated the usefulness of *Spirulina* for partial replacement up to 40% of the fish meal protein in Nile tilapia diets. Also, Abu-Elala, *et al.* [27] reported the significant improvement of PER and FCR in *Spirulina* supplemented group versus control.

**Table-3.** *Spirulina* inclusion levels resulted in better performance in a particular fish species

| References | *Spirulina* inclusion levels (%) | Fish species tested |
|---|---|---|
| Mustafa, *et al.* [28] | 5 | Nile tilapia (*O. niloticus*) |
| Watanuki, *et al.* [29] | 2 | Striped Jack (*P. dentex*) |
| Sirakov, *et al.* [19] | 10 | Rainbow trout (*O. mykiss*) |
| Kim, *et al.* [30] | 5 | Parrotfish (*O. fasciatus*) |
| Teimouri, *et al.* [31] | 7.5 | Rainbow Trout (*O. mykiss*) |
| Jana, *et al.* [32] | 5 | Pangus (*P. sutchi*) |
| Amer [21] | 1 | Nile tilapia (*O. niloticus*) |
| Allen [17] | 15 | Nile tilapia (*O. niloticus*) |
| Abu-Elala, *et al.* [27] | 10 | Nile tilapia (*O. niloticus*) |
| [Wahbi and Sangak [33]] | 10 | Nile tilapia (*O. niloticus*) |

**Figure-1.** Mean tilapia weight gain (%), length gain (%), and feed intake (% body weight) (mean ± standard error) plotted over the duration of the study for *Spirulina* diet experiment (n=3-5)




CC-Commercial Control, SBM-Soy Bean Meal, SP-*Spirulina* @15%,30% &45% Source: Allen [17].

### 3.4. Significance of Spirulina

#### 3.4.1. Dietary Supplement

*Spirulina* has gained considerable popularity in the health food industry and increasingly as a protein and vitamin supplement to aquaculture diets. It has long been used as a dietary supplement by people due to very high macro- and micro-nutrient contents. In addition, it requires simple technology in cultivation, harvesting, and processing [32].

In aquaculture, it may have the potential to be used as a natural feed supplement for increasing fish growth due to the presence of some compounds. Milié, *et al.* [34] and Estrada, *et al.* [35] reported that phenolic compounds can increase the shelf-life of foods, hence increase nutrients supply. Additionally, the studies of [36]; Olvera-Novoa, *et al.* [23]; and Nandeesha, *et al.* [37]; have shown that the blue-green algae *Spirulina platensis* holds potential for inclusion in diets of various fish species due to its attractive nutrient profile and digestibility.

*Spirulina* has already been tested as a substitute protein source for many omnivorous and herbivorous fish species. In finfish culture, the study conducted by Ayyappan, *et al.* [38] clearly demonstrated the advantages of

*Spirulina* meals in their quality as additives in the feed for carps. They established that Rohu and Mrigal carp showed a better growth rate in comparison to those received for the Indian carp and common carp. Also, Sandbank and Hepher [39]; reported equal or even higher growth rates in *Cyprinus carpio*, where diets containing 25% algae meal, replacing 80% of the dietary fishmeal.

In addition, it has been used to replace up to 40% of fish meal protein in tilapia *O. mossambicus* and up to 7% in parrot fish *Oplegnathus fasciatus [23, 30]*. Nandeesha, *et al.* [37] and Guroy, *et al.* [40] reported that body weight gains of fish increased linearly with increasing the level of algae in the fish diet at levels less than 25%.

In shellfish culture, the addition of *Spirulina* in the diet of giant freshwater prawn (*Macrobrachium rosenbergii*) significantly improved growth, survival and feed utilization regardless of supplementation level in the range of 5-20%. Partial replacement of fish meal with *Spirulina* has also been evaluated in juvenile Pacific white shrimp, *Litopenaeus vannamei*, with promising results Hanel, *et al.* [12]. Also, the potential of *Spirulina* as a nutrient source in diets for abalones such as for *Haliotis midae [41, 42]* or *Haliotis asinina [43]* is reported too.

### 3.4.2. Modulation of the Host Immune System

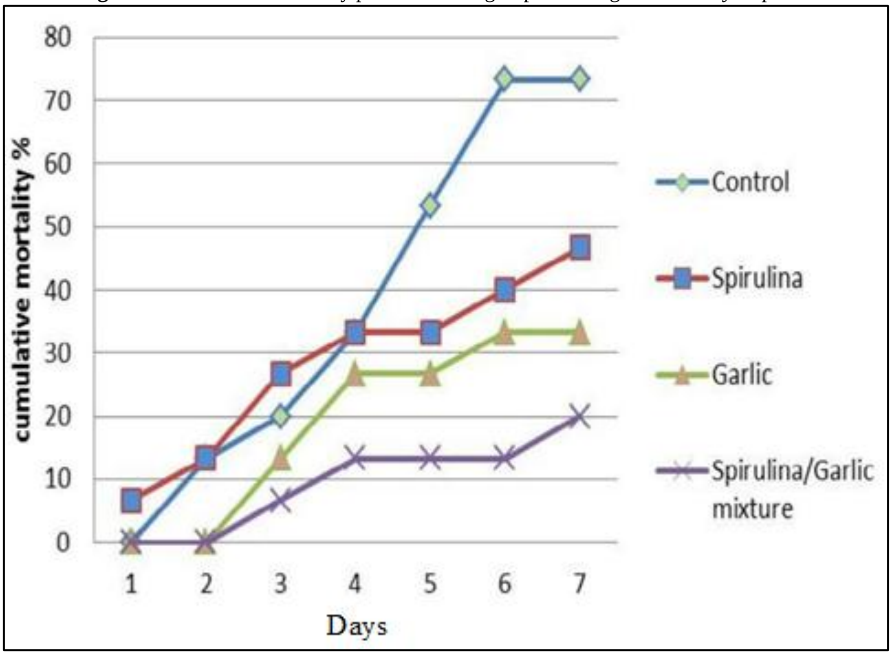
Since *Spirulina* also is regarded as a rich source of antioxidant pigments such as carotenoids**,** phenolics, tocopherols, and phycocyanin [14, 35, 43]; it has been reported to be associated with modulation of the host immune system [44] and other biological systems [34, 35]. According to literature, *Spirulina* as feed additives, improve growth, feed efficiency, carcass quality, and physiological response to stress and non-specific immune activity in several species of fish [8, 29, 45, 46].

In addition, it is effective as an immunomodulator [47]; due to activation of protein synthesis and somatic growth which reduces fish mortality (Figure 2). Mustafa, *et al.* [28] reported that the addition of small amounts of algae to Red sea bream feed can exert pronounced effects on growth, lipid metabolism, body composition, and disease resistance. Similar results have been reported by Dernekbasi, *et al.* [11] in the guppy, [48] in African sharptooth catfish and Nandeesha, *et al.* [37] in Indian carps.

### 3.4.3. Enhancement of Immunostimulant and Resistance Against Diseases

The therapeutic uses of *Spirulina* and it's biological derivatives in human medicine are promoting their applications in aquaculture especially in tropical and sub-tropical countries where it has been cultivated [15]. The inclusion of *Spirulina* in the fish diet as a feed additive or as a partial replacer of the expensive fishmeal imposes significant promotions in fish growth, coloration, reproduction and fish quality [31, 45, 49, 50]. Previous studies suggested that bioactive constituents of *Spirulina* like phycocyanin, β-carotene, γ linolenic acid, and phenolic compounds give this type of macrophytes its powerful antioxidant, antimicrobial, immunostimulant, and resistance against diseases [29, 51, 52].

**Figure-2.** Cumulative mortality percent of fish groups challenged with *A. hydrophila*.




**Source:** Abu-Elala, *et al.* [27].

### 3.4.4. Biofuel

In recent years, there has been great interest in the potential of algae as a biofuel feedstock. In *Spirulina*, it has often been proposed that the protein portion remaining after lipid extraction might be a useful input for animal feeds [53]. However, the algae chosen for biofuel production may not be optimal for use as a feed input, and the economic pressure for the lowest-cost methods of fuel production is likely to result in protein residues with contamination that makes them unfit for use as feed [54].

### 3.4.5. Increases Fish Digestibility

The importance of phytobiotics as additives in aquaculture feed is increasingly recognized as a feed for young and adults fish [33]. *Spirulina* improves digestion through the production of extra cellular enzymes (protease and lipase) and able to direct fats in the fish for growth rather than storage [55]. It contains 60-70% by weight protein, vitamins B-12, carotene, minerals, essential amino acids (62%) and fatty acids [40]. Its lipid contents are similar to that of vegetable oils [56]; rich in linoleic 18:2n6 and linolenic 18:3n3 acids and their C20 derivatives [57, 58]. Some of the cyanobacteria tend to contain large quantities of the total fatty acids, polyunsaturated fatty acids (PUFA) (20-60%), Eicosapentaenoic acids 20:5n3 and Arachidonic acids 20:4n6 that influence reproductive performance in fish [59]. Therefore, the highly digestible protein, vitamin B12, and minerals help in fish growth [27].

### 3.4.6. Improve Fish Reproduction

Studies have reported the effect of *Spirulina* on fish reproduction. According to Lu and Takeuchi [60]; using *Spirulina* as the main feed to Nile tilapia resulted in the increase of egg quality and quantity. Hence, enhanced seed production. Similar studies have been conducted in yellow tail cichlid, *Pseudotropheus acei* [49], in goldfish, *Carassius auratus* [61], swordtail [55] and bassa fish, *Pangasius bocourti* [62].

### 3.5. Challenges

There are several challenges which associated with the conversion of plant-based materials such as algae to fed ingredients. For instances, culturing of live food is, however, expensive and complicated. Prepared diets, on the other hand, not only provide the essential nutrients that are required for normal physiological functioning but also may greatly contribute to reducing the cost of production by eliminating or minimizing reliance on the live food and its often expensive associate infrastructure [20].

In contrast, the high-value microalgae such as *Spirulina* that is used in fish hatcheries are generally produced in closed culture systems to exclude contaminating organisms, and they cannot be dried before use without adversely affecting their nutritional and physical properties, greatly reducing their value as feeds. Inevitably their production costs are higher, but their exceptional nutritional value justifies the extra expense.

## 4. Discussion

Currently, *Spirulina* is considered by the United Nations as the possible "best food for the future" or "Super food" Ravi, *et al.* [63]. It contains highly digestible protein (60-70%) with all essential amino acids, polyunsaturated fatty acids (PUFA) such as γ-linolenic acid, vitamins, minerals and various photosynthetic pigments [64, 65]. However, some researchers reported having crude protein ranging from 41%-63% on a dry weight basis.

Basing on the literature reviewed, *Spirulina* reported having a significantly higher protein and growth results for both omnivorous and carnivorous fish species. This is due to the fact that; *Spirulina* is comparable in digestibility to fishmeal [22]. In addition, fish species that typically consume *Spirulina*, including Tilapia, have been found to have low stomach pH when full, which facilitates cyanobacteria lysis, and therefore increases digestibility [24].

The amount of fish meal to be replaced with *Spirulina* in the diet has been in a certain limit. Most literature has been reported the positive growth performance, improving immunity and egg quality, and increased fillet quality at the inclusion levels between 0.5 to 15%. For instance, Parrotfish (*Oplegnathus fasciatus*) fed 5% *Spirulina* experienced significantly higher weight gain, protein efficiency ratios, feed intake, and lower feed conversion ratios than the fishmeal control [30].

Similarly, Rainbow Trout (*Oncorhynchus mykiss*) experienced the highest weight gain when fishmeal was replaced with 7.5% *Spirulina* [31]. Also, low inclusion level (2%) has been reported to increase non-specific immune activity, the taste, and texture of Striped Jack (*Pseudocaranx dentex*) [29, 45, 46]. This might be due to depressed lipid content in muscle [25].

In addition, at 5% inclusion levels, Tilapia displayed increased muscle quality, increased firmness, and fibrousness of raw meat [28]. However, at high inclusion levels (30%), can also increase fillet color and firmness, and increases market acceptance [26].

Therefore, in the overall, growth, immune system response, color, and taste of many fish species, including Tilapia, fed low levels of *Spirulina* improved. However, high inclusion levels of *Spirulina* have been reported in some species. According to literature, the growth results for diets containing 15% to 30% *Spirulina* protein have been encouraging. Golden Barb (*Puntius gelius*) displayed significantly increased growth rates when 20% of the fishmeal in their diets was substituted for *Spirulina* [66].

Similarly, Silver Seabream (*Rhabdosargus sarba*) fed a diet containing up to 50% *Spirulina* did not suffer negative growth effects compared to a fishmeal control and had a similar feed conversion ratio (FCR) [67]. In addition, Tilapia have been fed diets containing 43% *Spirulina* without growth or feed intake being negatively impacted and had a better FCR than a corn gluten meal control [54].

In contrast, Other studies, have found that high *Spirulina* inclusion results in depressed growth rates. Sharma and Panta [68]; and El-Sayed [67] suggest that *Spirulina* inclusion above 30% is detrimental to fish growth. Similarly, Olvera-Novoa, *et al.* [23] reported elevated growth rates in diets containing 10% and 20% *Spirulina* protein but halved growth rates in diets containing more than 40% *Spirulina* compared to a fishmeal control. Also, Ungsethaphand, *et al.* [69] recorded in significant improvement in growth performance of hybrid tilapia after Spirulina supplementation. The difference of Spirulina concentration, source, raw or dried, fish species and rearing conditions may be reasons for these variable results.

## 5. Conclusion

Given the nutritional composition of *Spirulina* and its relative digestibility, it should be a viable alternative protein source for use in aquafeeds provided that feed intake is maintained. Therefore, for effective fish growth performance, quality of fillets, immune system modulation and low feeding costs, the inclusion level of *Spirulina* should be less than 20%. However, due to conflicting results in the literature regarding high inclusion levels of *Spirulina* up to 50%, the author suggests that more research evaluating the grow-out potential of *Spirulina,* and pinpointing factors affecting its effectiveness should be undertaken.

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