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# Potential Benefits of Pomegranate as an Additive in Fish Diet and Fish Products: A Review

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## ABSTRACT

Pomegranate (*Punica granatum)*, commonly known as "Anar", is an ancient fruit. It is preferably consumed due to its pleasing taste and high nutritious value along with some other associated health benefits. These benefits are not only meant for human beings, however, also for the fish. In recent times, scientific interest in pomegranate and its consumption has increased due to its numerous health benefits. Therefore, the current study aimed to review the most recent literature on different properties of the pomegranate. These properties include antimicrobial and antioxidant activities, its effect on hematological and growth parameters along with the role of pomegranate as a preservative in fish and fish products. The current study evaluated previously conducted studies to determine the effect of pomegranate on different systems of fish. Results showed that the intake of pomegranate effectively increased the growth of juvenile fish and dietary value of fish, boosted the hematological and immune responses, as well as feed efficiency and antioxidant activity. Moreover, it also showed antioxidant properties and proved effective for the preservation of fish fillets by reducing lipid oxidation, chemical degradation, and microbial growth in stored fish. Therefore, the incorporation of pomegranate in fish food has numerous applications. However, additional research is required to ascertain the safe limits.

**Keywords:** antioxidant, fish diet, growth, pomegranate, preservation

## Highlights

- Pomegranate is rich in miraculous properties, that is, antioxidant, preservative, antimicrobial, immune stimulator, and growth stimulator.
- Extensive researches have revealed the use of pomegranate in aquaculture industry. It is used as a natural food additive in fish feed to get beneficial effects pertaining to fish production, protection from diseases, and preservation of fish meat.
- Global protein yield can be enhanced using pomegranate as food additive and preservative with safe limits of use.

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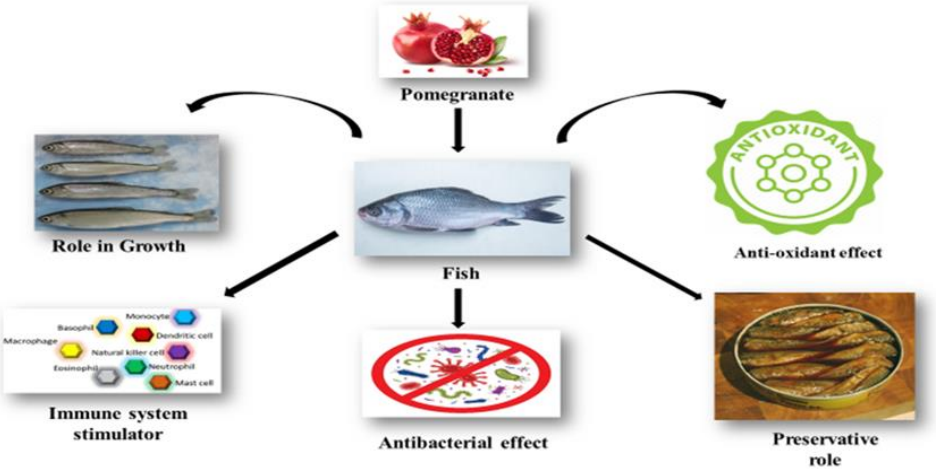
## GRAPHICAL ABSTRACT




## 1. INTRODUCTION

Pomegranate has a history as old as Bible. This fruit has a significant and sacred place in the religion of Jews, Christianity, and Islam as it is acclaimed in their religious books [1, 2]. *Punica granatum* is the scientific name of pomegranate which belongs to the Lythraceae family. The plant of pomegranate is a deciduous shrub. Its outer part is called rind (peel) and it is yellow, red, or pink or a combination of shades. The inner part of the plant is spongy with a yellowish or brown color containing fleshy seeds [3, 4]. This fruit has been found to have countless benefits for human health. Moreover, it has also been found helpful in curing different infections and diseases. Therefore, it is considered as a healing food. Due to its limitless benefits and enormous nutrients, it is universally used in cosmetics, pharmaceutical, and food industries [5]. Moreover, economically, pomegranate has an ample place in the international commercial markets [6].

Studies have revealed that pomegranate plant and its various parts (peel, fruit, seed, leaves, and roots) show antibacterial activities against human enteric bacterial infections including *Escherichia coli*, *Salmonella Typhi*, *Shigella spp*, *Staphylococcus aureus*, and *Staphylococcus epidermidis* [7–10]. Antiatherogenic activities of pomegranate have also been reported. It lowers the macrophage oxidative stress and protects the body's nitric oxide from destruction by oxidative stress. Moreover, it also reduces the blood pressure, lowers the carotid intima-media thickness, decreases the oxidation of LDL, restrains the process of angiogenesis, and suppresses the generation and spread of tumor cells [11–14]. A study revealed that pomegranate seed oil (PSO) exhibits effective anti-inflammatory and antioxidant activities that may significantly reduce colitis injury [15].

These miraculous properties of pomegranate are blessings of the fruits' nutritive composition. Pomegranate is used to cure countless diseases and infections

due to its antioxidant, antibacterial, anti-aging, and immune booster properties. Additionally, it also acts as an anticancer agent in the treatment of animals and human beings. In recent times, researchers have put efforts to determine the chemical and nutritional components present in all parts of pomegranate including juice, peel, seed, leaf, bark, and roots [14]. Additionally, several studies have confirmed pomegranate's role in reducing the risk of diabetes, cancer, cardiovascular diseases, and Alzheimer's disease [16–20]. Studies have determined that the pomegranate also exhibits anti-parasitic properties, such as, anti-anthelmintic, crypto sporicidal, anti-amoebic leishmanicidal, giardiacial including other anti-parasitic characteristics as well [21].

## 2. COMPOSITION

Studies have revealed that all parts of pomegranate plant ranging from roots to fruit contain a wide variety of essential nutrients and nonnutritive bioactive compounds which are referred to as phytochemicals. Phytochemicals are the secondary metabolites of plants. These chemicals are the defense molecules produced by plants in response to invaders. Phytochemicals have immense antioxidant and antimicrobial properties and provide tremendous benefits to consumers. The categories of phytochemicals include polyphenols, flavonoids, and flavanol (kaempferol, luteolin, myricetin, quercetin) anthocyanins (cyanidin, delphinidin, pelargonidin 3-glucoside), tannins (ellagitannins and gallotannins: castalagin, casuariin, granatin A & B, punigluconin, punicalin, ellagic acid), triterpenoids, fatty acids, triglycerides, and alkaloids (hygrine, norhygrine, pelletierine, N-methyl pelletierine, sedridine) [1, 22]. Polyunsaturated fatty acids, such as linolenic, linoleic, punicic acid, oleic acid, stearic acid, and palmitic acid are present in various parts of pomegranate plant [5]. Organic acids including ascorbic acid, acetic acid, citric acid, maleic acid, oxalic acid, succinic acid, tartaric acid, and fumaric acid are found in pomegranate. Citric acid is responsible for sourness and malic acid gives sweet taste to pomegranate [23, 24].

Essential nutrients are primary metabolites of the plant including vitamins, minerals, carbohydrates, and fats. Sugars that are present in pomegranate include fructose and glucose (in highest percentage), maltose, sucrose, and mannitol which are the sources of energy and sweetness [25]. Pomegranate contains low protein content in comparison to other fruits. Approximately, 1.03–1.13% of protein is present in pomegranate juice and 2.56% in peel. The presence of protein suggests that the fruit peel may supply essential and non-essential amino acids required for body growth and functions. The fruit peel may improve nitrogen balance and functional protein synthesis [3, 26]. Vitamins and minerals are an indispensable part of diet which are required in small amount, however, are essential for appropriate working of body. Pomegranates are naturally packed with a huge number of vitamins and minerals (major and trace minerals). Vitamins that are found in fruit include vitamin A, C, E, K, pantothenic acid, vitamin B6, and folate [27]. Minerals including major (Potassium, magnesium and sodium) and trace minerals boron, iron, copper, manganese, vanadium, zinc, and aluminum are found in pomegranate peel, seed, and kernels [4].

## 3. APPLICATIONS OF POMEGRANATE IN AQUACULTURE

Aquaculture production has increased universally to encounter the increasing demand for aquatic animal proteins. Land and water resources are limited; therefore, this situation has enforced fish farmers to increase fish production. However, such an increase in fish rearing is stressful which negatively affects the health of fish. One of the practical approaches in aquaculture industry to improve fish health is supplementation of fish diet with feed additives. These additives are easily added in fish feed formulation which positively affect the host. In aquaculture, numerous classes of natural feed additives can be used [28]. Many plant species with therapeutic effects and biologically active substances have been examined to determine their beneficial effects in aquaculture. Many researchers have used the extracts of various parts of pomegranate plant and fruit as natural additive supplements in fish diet and found their possible beneficial effects on various aspects of fish health (including growth, body composition, immunity, antioxidant system, blood chemistry, and organ functioning) and stored fish products.

### 3.1. Effect on Growth Parameters

Pomegranates are rich in vitamins, biologically active tantalizing substances that can be used to improve the health and growth parameters [29]. Several researchers have investigated the effects of pomegranate by-products on various aspects of aquaculture. Seeds of pomegranate contain phenolics and tannin compounds which are appetizing in nature and can enhance the growth of fish [30]. The growth performance of fish Nile tilapia (*Oreochromus niloticus*) decreases when fed with pomegranate peel extract (PPE) at following percentage, that is, 0.1, 0.2, 0.3, and 0.5 % in diet [31]. Supplementation of up to 1% of PSO (pomegranate seed oil) in diet of rainbow (*Oncorhynchus mykiss*) improves the growth of fish [32]. Another finding shows that Nile tilapia *(O. niloticus)*, treated with 3% and 5% diets, results in good protein efficiency ratio. Furthermore, the use of up to 5% per kg pomegranate peel (PP) in the diet of Nile tilapia may improve the growth parameters [33]. A significant drop in growth performance of Nile tilapia (*O. niloticus*) at 3% and 5% per kg PP in diet was also reported by [34]. Significant reduction in final weight and specific growth rate of gold fish (*Carassius auratus*) supplemented with 4% PPE was reported by Motlagh et al. [35]. The growth performance of Nile tilapia (*O. niloticus*) remains unaffected when provided PP extract at the rate of 0.3% and 0.5% per kg [36]. The use of 1% or 2% pomegranate per kg in diet lowers the feed conversion ratio (FCR) values in rainbow trout (*O. mykiss*). While, the addition of 4% per kg pomegranate in diet results in high FCR and low specific growth rate (SGR) values [37]. Supplementation of 0.05% of peel extract (PE) diet also decreases the FCR of rainbow trout (*O mykiss*). Decrease in final weight also occurs in rainbow trout after feeding with 0.025% and 0.1% of PE [38]. An addition of 1%, 1.5%, and 2% of PPE in diet results in growth retardation of *Cyprinus carpio* (common carp). Supplementation of 0.5% of PP is considered as the best diet to improve different aspects of growth in carp [28]. Supplementation of PSO in diet of juveniles carp (*C. carpio*) fish has the potential to increase the growth performance and accumulation of punicic acid in muscles which improves the dietary values of fish [39].

Reduction in food consumption and calories intake may be due to the presence of substantial quantity of polyphenols and high fiber content of PP powder [40]. Due to polyphenol's anti-angiogenic activities, polyphenols may result in reduction of growth and fat tissues [41]. Some researchers have suggested that mild calorie restriction might provide multiple health benefits, such as extending the lifespan of diverse organisms and regulating the functions of immune system [33]. The use of pomegranate in combination with other fruit peels and dietary substances also shows beneficial outcomes. A diet containing a mixture of three fruit peels extract (pomegranate, orange, and banana) improves the growth of Nile tilapia [42]. Yellow corn can be replaced by PE up to 10% in fish diet (of *O. niloticus*) with the addition of Allzyme. The use of 5% PP with Allzyme in fish food leads to efficient utilization of their feed [43].

### 3.2. Effect on Immune System

The pomegranate acts as an immune-stimulant which builds up the immune system [44]. Therefore, it is helpful in improving the immunity of fish. This property of pomegranate is due to the presence of several polyphenols, polysaccharides, and hydrolysable tannins, calcium, magnesium, and some minerals [45]. Minerals are an essential part of diet which perform a range of functions in body. Several minerals (magnesium, iron, copper, zinc, selenium) are required for the efficient working and regulation of immunological processes including innate and adaptive responses of body [46].

Lysozyme is a key player in defense system of fish [47]. Lysozyme and antibodies, as part of humoral immune response, are involved in opsonization, recognition of foreign particles, and killing of germs [28]. An increasing trend of lysozyme activity was reported by Sonmez et al. after feeding the fish with pomegranate containing diet [38]. Diet containing 5% or 10% PP improves the quantity of lysozyme and IgM in tilapia (*O. niloticus*) [43]. Experimental diets containing 1%, 2%, 3%, 5%, 10%, 15%, and 20% PP also result in increasing the activity of lysozyme and antibodies in *O. niloticus* [48]. Pomegranate rich diet also plays a protective role against metal toxicity and *Aeromonas hydrophila* in *O. niloticus* [31, 36]. Experiments have also revealed that PP diet helps in reviving the immunity of AgNPs exposed tilapia fish [34]. Feed containing a mixture of pomegranate, banana, and orange extract is also effective in boosting the lysozyme activity in Nile tilapia [42].

The activity of lysozyme and antiprotease also increases in cat fish (*Clarias gariepinus*) under the challenge of mercury toxicity [49]. The supplementation of PPE in diet of common carp was also found helpful in increasing the components of innate immunity at a dose of 0.5% and in reducing stressful conditions [28]. In rainbow trout, feed containing 3% and 4% of pomegranate per kg of diet, cause an increase of C3 and C4 proteins and IgM antibodies [37].

### 3.3. Effect on Antioxidant System and Hematological Parameters

The consumption of fish is the rich source of proteins, minerals, vitamins, and omega 3 fatty acids. Due to the beneficial effects of fish food and fish products on human health, their production has increased globally to fulfill the requirements of human beings. However, rearing of fish under intensive culture and limited resources leads towards stressful

conditions for the fish [50, 51]. Stress influences the fish in a negative way and leads to the elevated rate of metabolism and production of reactive oxygen species. Moreover, stress also causes the stimulation of antioxidant system of the fish to protect the body from its damaging effects. Catalase (CAT), glutathione peroxidase (GPx), superoxide dismutase (SOD) glutathione, thioredoxin, vitamin C, and vitamin E are the components of antioxidant defense system [52]. The components of this system are involved in removal and deletion of harmful ROS molecules. Oxidative stress may occur due to improper working of oxidant defense system and damage the body by DNA hydroxylation, degradation of proteins, peroxidation of lipids, and cell death [53]. Oxidative stress also results in the appearance of alanine aminotransferase (ALT) and aspartate aminotransferase (AST) into blood and increase in the levels of malondialdehyde (MDA) [28]. Oxidative stress can be managed and reduced by the consumption of pomegranate by-products in fish diet. Pomegranates are rich in antioxidant compounds, such as protochatechuic acid, gallic acid, pyrogallol, coumaric acid, catachine, rosmarinic acid, rutin, naringeen, myrcetin scoplatin, and hisperdin. Hence, pomegranate by-products can be helpful in improving the antioxidant defense system [34].

Pomegranate rich diet causes a significant increase in the level of RBCs, haematocrit, and haemoglobin in common carp fish [54]. Another study shows that PP diet also increases the levels of glucose, triglyceride, and total protein in *O. niloticus* [48]. Pomegranate containing diet reduces the levels of cholesterol, aminotransferase, aspartate aminotransferase, creatinine, and urea in the blood of Nile tilapia [36, 43, 48].

According to a finding, an increase in the RBCs count of fish occurs when the fish are fed with 1% and 2% of pomegranate per kg of diet, while the level of hemoglobin and hematocrit increases with a 1% pomegranate diet. A 1% pomegranate in diet was also found helpful in reducing the cholesterol level [37]. The use of PSO (0.5 and 1 gram of oil per kg) in fish feed results in an increase in the concentration of RBC, Hb, and MCHC. However, the concentrations of ALP, AST, and ALT in fish decrease at 0.5% and 1% PSO [32]. The levels of SOD and CAT activity in fish are also elevated through pomegranate supplemented diet [34, 36]. Findings suggest that feeding the fish at a rate of 0.025% and 0.05% with pomegranate per kg of diet leads to an increase in the activity of SOD [38]. A fish feed containing a mixture of extracts of three fruits (1% of each; pomegranate, banana, and orange) may cause an increase in the concentration of albumin, globulin, and total protein in blood circulation of fish [42].

### 3.4. Antimicrobial Activity of Pomegranate

The infectious diseases in fish may cause illnesses and leads towards the mortality of fish. Resultantly, it would influence the health of fish as well as their demand and consumption rate. Therefore, a number of medicinal plants have been used in aquaculture for the treatment of diseases found in fish. Among these plants, pomegranate is the one which has attracted the attention of farmers due to its excellent antimicrobial properties [36]. Studies reveal that a fish feed containing a 2% of PE per kg of diet efficiently lowers the count of gram-negative bacteria in intestine of *C. auratus*. However, it does not affect the aerobic and lactic acid bacterial count [35]. The incorporation of PSO in diet of rainbow trout has been found effective

against the *Yersinia ruckeri* that causes red mount disease in fish. Fish feed containing PSO increases the survival rate of rainbow trout against pathogen *Y. ruckeri* [32]. Diet supplemented with 0.3% and 0.5% of PE per kg showed antibacterial activity against *A. hydrophila* in Nile tilapia. Researchers observed about a 20-30% lower rate of mortality in fish fed with experimental diet than in control diet groups of fish [36]. Studies have suggested that a mixture of three fruit extracts (pomegranate, orange, and banana) provides remarkable protection against *A. hydrophila* pathogens. Feeding the fish with diet containing 1% of each fruit peel extract may provide up to 90% survival against bacterial *A. hydrophila* infection. While, in case of *Saprolegnia sp* infection, same diet may provide a 100% survival rate. The supplementation of 3% of PPE in diet can provide up to 70% survival rate against *A. hydrophila* [42]. According to findings, pomegranate leaf acetone extract was also found beneficial to retard the growth of *A. hydrophila* (extracted from gold fish) [55]. The extract of *P. granatum* also has the potential to inhibit the growth of fungus, *Saprolegnia parasitica* which causes saprolegniasis, in fish [56].

### 3.5. Role as Preservative

Human beings consume fish as food worldwide. It is not only an economical and easily available food, however, it is also considered as a healthy and nutritious food [57]. Moreover, it is a rich source of proteins, vitamins (A & D), minerals, (magnesium, calcium and phosphorus) and poly unsaturated fatty acids. In addition to its nutritional importance, it also plays an important role to protect the fish body from different diseases [58]. Fresh fish being highly fragile provide favorable conditions (in term of pH, nutrient richness, and water content) required for the growth of microbes [59]. Keeping in view all the benefits of fish meat, there is a need to supply the fish and fish products for the good of public in different forms by preserving it to increase its consumption [60]. The industry of seafood preservation is growing rapidly to meet the demands of proteins for growing population of the world. The preservation of fish meat and fish products plays an essential role to extend the storage time and nutritional values of meat [61]. For preservation of fish products, different synthetic preservatives are used to halt the degradation of food. These preservatives prevent the spoilage of the fish which immediately occurs after the harvesting of fish. Spoilage changes the flavor, smell, and appearance of the fish which makes them unfit for human consumption. These changes occur due to bacterial activity, chemicals, and enzymes. Bacterial activities are involved in the production of Trimethylamine (TMA) which gives ammonia like flavor. It is formed by the reduction of Trimethylamine oxide (TMAO) to TMA by gram negative bacteria. Enzymatic reactions result in autolytic and proteolytic degradation of fish body, while the chemical changes involve the production of free radicals and peroxides due to the lipid oxidation [62, 63]. However, these synthetic preservatives are unsafe to use as they can lead to cancer in human beings [64]. Therefore, researchers investigated the role of extracts of different parts of plants and oils. These include carvacrol and thymol essential oil [65], cinnamon oil [66], rosemary and sage tea extract [67], thyme essential oil [10], rosemary essential oil [68], eucalyptus essential oil [69], *Allium paradoxum* and *Eryngium caucasicum* extracts [70], tomato plant extract [71], rosemary extract [72], green hull extract [73], and mint extract [59] as a preservative for fish meat and fish food items. Many researchers also

investigated the role of pomegranate and by-product's extract as a preservative. PE possesses phenolic compounds (punicalagin, punicalin, gallic acid, and ellagic acid) which make it a good antioxidant antimicrobial agent [74]. PE helps in the preservation of fillets of silver carp (*Hypophthalmichthys molitrix*) by reducing the chemical degradation of oxidation of lipids. The extract also helps in lowering the levels of TVBN (total volatile basic nitrogen), TBA, and microbial count. Extract's effectiveness enhances using liposomal encapsulation [75, 76].

Findings reveal that PE can be used for the preservation of fillets of tilapia. This is because it effectively reduces the values of TVB-N, peroxide, and microbial count (Enterobacteriaceae, yeast, pseudomonads, and mesophilic bacteria) in fillets of tilapia. The storage life of fillets can be enhanced using methanolic extract of PP as a preservative [77]. Pomegranate can also be used to preserve the fillets and sausage of rainbow trout. It improves the sensory parameters, palatability of fillets, and prevents the chemical degradation [60, 61]. According to Zhuanga et al., fillets of bighead carp (*Aristichthys nobilis*) can also be preserved using pomegranate. It shows an effective inhibitory role against the *Pseudomonas*, *Shewanella*, and *Aeromonas* bacteria. Additionally, it is also effective in maintaining the freshness of meat [78]. PE is also effective in fish pattie preservation. It plays an effective role in the inhibition of gram-positive bacteria, that is, *L. monocytogenes*. It effectively lowers the TVC and coliform count in fish patties [79]. The use of pomegranate as a preservative increases the shelf life of fish burgers. It has the potential to maintain the sensory parameters and stability of fish burger during the storage period [80, 81]. Experiments have proved that pomegranate can increase the shelf life of stored fish products for about 3 weeks [81]. Researchers have confirmed the antioxidant and antibacterial properties of pomegranate and ginger extract for preservation of fish (*Cyprinus carpio*) meat [82]. According to Pal et al. PE is effective to preserve the fish, as it significantly reduces the formation of peroxides, secondary lipid oxidation, and aerobic plate count. Hence, food processing industry is likely to use PPE in replacement to synthetic antioxidants [64].

**Table. 1.** Effects of Pomegranate on Fish

| Authors | Year | Pomegranate Peel Extract/ Leaf Extract/ Seed Oil | Effect | Reference |
|---|---|---|---|---|
| Abdollahzadeh et al. | 2014 | Methanolic Peel Extract | Showed antibacterial properties against *S. epidermidis* and *S. aureus*. Powerful inhibition of *L. acidophilus*, *S. mutans*, and *S. salivarius* observed at concentration of 8 mg/ml and 12 mg/ml MEPGP | [10] |
| El-Sayed et al. | 2014 | Peel Powder | Replaced yellow corn up to 10% in diet of *Oreochromis niloticus.* Improved immunological parameters but no effect on blood parameters | [43] |
| Badawi & Gomaa | 2016 | Peel Extract | Improved the functioning of kidney, Liver, and immune system | [31] |

| Authors | Year | Pomegranate Peel Extract/ Leaf Extract/ Seed Oil | Effect | Reference |
|---|---|---|---|---|
| Tarkhasi | 2016 | Peel Extract | Reduced lipid oxidations and microbial count | [76] |
| Emadi et al. | 2017 | Pomegranate Seed Kernel Meal | Showed appetite stimulant properties and accelerated growth parameters | [30] |
| Acar et al. | 2018 | Seed Oil | Showed resistance against *Y. ruckeri*, improved blood, and growth parameters | [32] |
| Zakeri et al. | 2018 | Seed Oil | Increased growth of juvenile fish and dietary value of fish | [39] |
| Zhuanga et al. | 2019 | Aqueous and Ethanolic Peel Extract | Effectively lowered the growth of microbes in fish fillets and showed preservative properties | [78] |
| Toutou et al. | 2019 | Peel Powder | Improved the body composition, performance, and feed utilization at the rate of 5g per kg | [33] |
| Badrey et al. | 2019 | Peel Powder | Improved the immunity, liver, and kidney functioning in *O. niloticus* | [48] |
| Motlagh et al. | 2020 | Peel Extract | Inhibited the growth of gram-negative bacteria but no effect on aerobic bacteria or lactic acid bacteria count. Reduction in growth parameters | [35] |
| Saad et al. | 2020 | Peel Extract | Mixture of 1% pomegranate and 1% *Moringa oleifera* extract diminished the *E. coli* growth and can be used as preservative for preservation of fish products | [51] |
| Ganjian et al. | 2020 | Peel Extract | Proved effective for preservation of fish fillets. Reduced lipid oxidation, chemical degradation, and microbial growth in stored fish | [75] |
| Munir et al. | 2020 | Peel Extract | Increased the immunity of *O. niloticus* against *Aeromonas hydrophila* and improved antioxidant activity | [36] |
| El-Bouhy et al. | 2020 | Peel Powder (in diet and water) | Boosted the hematological, immune parameters, and improved fish health as well as counteracted the sub-chronic mercury toxicity | [49] |
| Netam et al. | 2020 | Peel Extract | Extended the storage life span of *Labeo rohita* streaks by inhibiting lipid peroxidation | [83] |
| Avazeh et al. | 2021 | Peel Powder | 1% of peel in diet improved the immunity, growth rate, and utilization of feed | [37] |
| Hamed & Abdel-Tawwab | 2021 | Peel Powder | Increased the immunological and oxidative activities of fish in response | [34] |

| Authors | Year | Pomegranate Peel Extract/ Leaf Extract/ Seed Oil | Effect | Reference |
|---|---|---|---|---|
| | | | to AgNPs toxicity and lowered the negative effects of toxicity | |
| Sabeeh et al. | 2021 | Peel Extract | Extended the storage period of fish meat. Showed antioxidant and antimicrobial activity | [82] |
| Panza et al. | 2022 | Peel, Seeds, and Juice | Extended the storage time of fish products and maintained sensory standards | [81] |
| Abou-Taleb | 2022 | Peel Powder | Enhanced the cooking parameters and stability of fish burgers during storage | [80] |
| Jafari et al. | 2022 | Peel Extract | Improved immunity under cadmium toxicity by increasing PPE concentration in common carps | [84] |
| Salehi1 et al. | 2022 | Ethanolic and water extract of fruit and rind | Showed antioxidant properties against lipid oxidation in stored fish fillets | [61] |
| Mostafa & Yassin | 2022 | Ethanolic Extract | Extracts of *S. aromaticum* and *P. granatum* showed antifungal properties to prevent *Saprolegnia parasitica* growth in fish with low toxicity to fish | [56] |
| Sonmez et al. | 2022 | Aqueous Methanolic Extracts of Peel | Boosted the immune responses, feed efficiency, and antioxidant activity | [38] |
| Pal et al. | 2022 | Peel Extract | Proved as a good antioxidant in fish preservation, retarded the growth of microbes, and reduced lipid oxidation | [64] |
| Çağlak, et al. | 2022 | Pomegranate Peel Extract | Showed preservative and antioxidant properties for production of sausage from fish fillets | [60] |
| Sayed-Lafi et al. | 2023 | Peel Extract (raw, aqueous and ethanolic) | Ameliorated the blood parameters of fish with supplementation at the rate of 1% PP | [54] |
| Sheeba et al. | 2023 | Leaf Acetone Extract | Retarded the growth of *Aeromonas hydrophila* isolated from diseased gold fish | [55] |
| Yousefi et al. | 2023 | Peel Meal | 5g per kg peel in diet improved the immunity of fish and acted as anti-stress | [28] |
| Al-Sokary et al. | 2023 | Methanolic Peel Extract | Showed good preservative properties during storage of fish fillets. Minimized the growth of microbes and improved the shelf life of stored fillets | [77] |

## 4. CONCLUSION

The current study concluded that the pomegranate has tremendous applications in aquaculture since it contains numerous vital compounds. It is a well-known fact that fruit/plant extracts contain a complex mixture of numerous constituents and, in most of the cases, it is unclear whether a single or a mixture of compounds are responsible for the observed effects. Many *in vivo* and *in vitro* studies revealed high nutritional potential of *Punica granatum* extract. However, further researches are required to explain the mechanism of action, pharmacokinetics, and synergistic effects of the compounds present in pomegranate.

## CONFLICT OF INTEREST

The authors of the manuscript have no financial or non-financial conflict of interest in the subject matter or materials discussed in this manuscript.

## DATA AVAILABILITY STATEMENT

The data associated with this study will be provided by the corresponding author upon request.

## FUNDING DETAILS

No funding has been received for this research.

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