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Beneficial roles of Song-Gang stone as a feed additive in aquaculture: a review

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Abstract
Song-Gang® bio-stone (SGS) is a microporous crystalline hydrated aluminosilicate which has found various applications because of their very unique physiochemical characteristics such as ion exchange and absorptive-desorptive properties. Significant progress has been made in recent years on applications of these inorganic adsorbents in different industries including agriculture, aquaculture, water and wastewater treatment. This review article intends to summarize the published reports on the applications of SGS in aquaculture industry. SGS application as a feed additive to enhance fish growth and promote their health and nutritional parameters is the most important discussed areas. According to the technical data that are discussed in this review, SGS should be considered as a material with tremendous potential for application in the aquaculture industry. Considerable amounts of research works are under way to explore other opportunities for application of SGS to benefit aquaculture industry.

Keywords: Song-Gang® bio-stone, Antibiotic replacer, Feed additives, Growth, Immune responses

Introduction

In the last few decades, aquaculture has become the fastest growing food industry in the world. Intensified culture systems cause a variety of health and environmental problems, and animals reared under stress are subject to compromised growth and immune responses (Bondad-Reantaso et al., 2005; Sahin et al., 2014). Aquaculture feeds are formulated with a vast pool of ingredients which are intended to supply nutritional requirements to perform its normal functions, including maintaining a highly effective natural immune system, growth, and reproduction. Many different feed additives are being used in aquatic feed to ensure the dietary nutrients are ingested, digested, absorbed, and transported to the cells (Savira & Suharsono,

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2013). There are various functional feed additives for these purposes, which can be classified by their chemical composition and origin. Potential feed additives should be selected based on their effect, contribution and commercial availability (Bae et al., 2020). Feed additives are nutritive/non-nutritive compounds that would be applied to the diet of fish and shrimps to influence physical or chemical property of the diet (Bai et al., 2015; NRC, 2011). These feed additives have a very different chemical nature and vary considerably in their use in marketable diet formulations for aquatic species.

Additives are used in fish feed to maintain the dietary characteristics of a diet or feed ingredients prior to feeding (e.g., antioxidant, mold inhibitors), improve ingredient dispersion or feed pelleting (e.g., emulsifiers, stabilizers, binders), encourage feed ingestion and consumer acceptance of the product (e.g., feed stimulants, food colorants), promote growth (e.g., growth promoters, including antibiotics and hormones), and supply essential nutrients in concentrated and/or purified forms (e.g., vitamins, minerals, amino acids, cholesterol, phospholipids) (Ajiboye et al., 2012). Dietary additive studies in juvenile fish (Park et al., 2016; Sharifuzzaman & Austin, 2010) are normally conducted for 1–8 weeks (Bondad-Reantaso et al., 2005) whereas in larger fish, longer durations of experimentation may be required to understand the effects of additives in fish (Shin et al., 2014). Feed additives for cultured aquatic animals have impacts on growth performances, immune response, resistance to diseases and intestinal microbial communities (Kesarcodi-Watson et al., 2008; Merrifield et al., 2010; Ringø et al., 2012; Zokaeifar et al., 2012). In order to improve growth and immunity, several of these additives have commercial potential for the promotion of growth and immune responses in the aquaculture industry (Ai et al., 2007; Choi et al., 2004; Güroy et al., 2014; Lee et al., 2015; NRC, 2011; Shahkar et al., 2015). However, in individual fish species, each dietary additive can produce different levels of response and contribute differently to feed cost. Consequently, in the present study, I aimed to review the dietary effects of a natural mineral material, Song-Gang® bio-stone (SGS, Davistone, Busan, Korea) as a growth promoter in fish.

Nature of Song-Gang® bio-stone

Naturally occurring minerals are homogeneous material formed from one or a compound of elements through geological processes. Natural minerals are generally soil-based particles altered by the weathering action of bio-stone containing silicon dioxide (SiO_2) at 40%–80% and aluminum oxide (Al_2O_3) at 10%–30% as the main components (Yoon & Park, 2009). They can be used with other mineral oxides as effective and useful feed additives such as iron oxide (Fe_2O_3), calcium oxide (CaO), magnesium oxide (MgO), potassium oxide (K_2O), sodium oxide (Na_2O) and titanium oxide (TiO_2) in the diets for animal (Yoon & Park, 2009). Some studies have suggested a possible improvement of growth, immune response and water quality by supplementing natural minerals in fish diets (Table 1). Naturally occurring minerals may also fight gastrointestinal diseases by mixing with noxious compounds, altering nutrient usage in the intestine, and positively impacting animal health (Lv et al., 2015; Zhang et al., 2013). Natural mineral feed additives have some potential as replacements for antibiotics (Safaeikatouli et al., 2011; Yenice et al., 2015). In livestock, minerals delay the transit time of feed in the intestine. This mechanism of action improves acid capacity and feed use rate (Kermanshahi et al., 2011), increasing the absorption of moisture and the ability to trade in ions, thereby reducing the incidence of intestinal stools and harmful gasses which improve the environment (Joo et al., 2007). Feed quality improvements include inhibition of the survival of fungi and harmful bacteria and adsorbing toxins in the feed, thus improving the health of cultured livestock (El-Melegy et al., 2015). SGS is a naturally sourced and purified mineral material from the Republic of Korea comprising predominantly of iron oxide (Fe_2O_3), silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), potassium oxide (K_2O), sodium oxide (Na_2O), titanium dioxide (TiO_2), etc. (Lee et al., 2015; Won et al., 2017). It is considered to be one of the important naturally sourced mineral materials that improves the health status of fish (Choi et al., 2004; Lee et al., 2015; Won et al., 2017). For the confirmation of ingredients of mineral mixture, the X-ray fluorescence spectrometer (XRF) (ARL PERFORM'X, Thermo Fisher Scientific, Waltham, MA, USA) was used to determine the mineral composition of the mixture (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, K_2O, Na_2O, TiO_2) according to the method (KSE3076) of Korean standards for mine (Korea Standard Association, 2002). In brief, a certain amount of each of the pulverized sample and a binder (polyvinyl chloride or PVC dissolved in toluene) was added carefully, mixed and pressed in a hydraulic chamber to form a pellet. The sample chamber (analyzer) of the spectrometers was then fitted with the pellet and the X-rays emitted at a voltage (up to 30 kV), and with a current (up to 1 mA). The software attached to the spectrometer was then calibrated and operated for around 30 to 60 seconds, and the results were then displayed automatically (Table 2). These natural minerals are like zeolites,

Table 1. Effects of natural minerals and their effects in various fish species

Natural minerals	Zeolite		Montmorillonite	Bentonite	Mordenite
Fish species	Tilapia (*Tilapia zillii*)	Rainbow trout (*Oncorhynchus mykiss*)	Rainbow trout (*O. mykiss*)	Rainbow trout (*O. mykiss*)	Rainbow trout (*O. mykiss*)
Addition concentration range (%)	0, 1, 2	0, 1	0, 1, 2, 4	0, 2.5, 5	0, 2.5, 5
Optimum concentration (%)	1	1	1 or 2	5	2.5
Fish size (g)	1.08 ± 0.01	87.9	0.5 ± 0.03	104.2 ± 0.7	104.2 ± 0.7
Duration (days)	45	150	90	90	90
Effects	↑ PER, ↓ Total ammonia	↑ WG, FE	↑ WG, SGR, FE, non-specific humoral immune responses	↑ WG, FE, SGR	↑ WG, FE, SGR
Water temperature (℃)	24.6 ± 0.77	11.4–14.0	10.6 ± 2	14.0–16.0	14.0–16.0
pH	8.33 ± 0.18	7.29–7.52	7.0 ± 0.2	NT	
DO (mg/L)	6.27 ± 0.66	10.4–11.2	7.0 ± 0.1	6.0–9.0	6.0–9.0
Source	Yıldırım et al. (2009)	Obradović et al. (2006)	Karimi et al. (2020)	Eya et al. (2008)	Eya et al. (2008)

↑ symbol, increase; ↓ symbol: decrease .
PER, protein efficiency ratio (%); WG, weight gain (%); FE, feed efficiency (%); SGR, specific growth rate (%/day); NT, not tested.

Table 2. Chemical composition of the natural mineral materials of Song-Gang® bio-stone (% DM, dry matter basis)

Minerals	Song-Gang® bio-stone
SiO_2	73.4
Al_2O_3	15.5
Fe_2O_3	0.87
CaO	0.91
MgO	0.09
K_2O	4.31
Na_2O	4.19
TiO_2	0.03

Values are means of duplicate samples.

which are commonly used in aquaculture as an additive. Zeolite mainly has a SiO_2 component and other components of the primary mineral source, some of which are micronutrients (Roland & Kleinschmit, 1996).

Effects of Song-Gang® bio-stone in fresh water and marine fish

The previous studies of SGS in fish are summarized in Table 3. The effectiveness of SGS has been evaluated as a dietary supplement for a variety of cultured aquatic organisms. Evaluations of this sort generally consider time-course, dosage, and the responses of fishes or crustaceans to experimental exposure as seen in their growth performances, immune status and disease resistance. The SGS is a rich mineral source, which reduces the entry of pathogenic bacteria through the adsorption of harmful gas. It is free of toxins and heavy metals, and is recognized as having some potential as a healthy, low-cost dietary additive for commercial aquaculture (Bae et al., 2020). This discussion consists of a summary of the reactions of freshwater and marine fishes to experimental SGS supplementation. Feeding trials have been reported in fresh water species such as rainbow trout (*Oncorhynchus mykiss*), and juvenile Amur catfish (*Silurus asotus*), the catadromous Japanese eel (*Anguilla japonica*), and marine species including olive flounder (*Paralichthys olivaceus*). Rainbow trout, (*O. mykiss*) exhibited enhanced weight gain and improved immune status in response to SGS supplemented diets as compared with controls (Won et al., 2017). These increases were comparable to beneficial responses observed in response to other dietary additives, leading the authors to conclude that this mineral supplement has potential applicability as a replacement for antibiotic treatments currently in use. A similar trial of SGS dietary supplementation in juvenile Amur catfish (*S. asotus*) demonstrated significant growth and immune status enhancements as compared with controls, also suggesting that this mineral feed additive offers an economically appealing option for improved performance in this species (Amoah et al., 2017). Bae et al. (2008) investigated the effects of dietary supplementation of SGS either alone or in combination with a "feed stimulant" in juvenile Japanese eels (*Anguilla japonica*). These au-

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Table 3. Summary of the previous studies on Song-Gang® bio-stone (SGS) in fish diet

	Japanese eel (*Anguilla japonica*)	Rainbow trout (*Oncorhynchus mykiss*)	Rainbow trout (*O. mykiss*)	Amur catfish (*Silurus asotus*)	Olive flounder (*Paralichthys olivaceus*)	Olive flounder (*P. olivaceus*)
Addition concentration range (%)	0, 0.7	0, 0.4	0, 0.4	0, 0.4	0, 0.4	0, 0.4
Optimum concentration (%)	0.7	0.4	0.4	0.4	0.4	0.4
Fish size (g)	15 ± 0.1	2.7 ± 0.02	261.5 ± 3.5	4.95 ± 0.05	10.98 ± 0.13	5.26 ± 0.17
Duration (weeks)	8	8	22	8	8	8
Effects	↑ WG, FE, SGR, PER, survival	↑ FE, PER, ↑ FE, PER, SOD, MPO, LYZ activities, survival	↑ WG, FE, SGR, PER, SOD, MPO, LYZ, NBT activities	↑ WG, FE, SGR, PER, SOD	↑ SOD, MPO, LYZ, survival	↑ WG, FE, SGR, MPO, NBT activity, survival
Water temperature (℃)	25 ± 1	15 ± 0.5	15 ± 4.5	25.0 ± 0.1		18 ± 1.0
pH	NT	7.5 ± 0.3	7.6 ± 0.3			
DO (mg/L)	NT	Near saturation	6 ± 0.6			
Source	Bae et al. (2008)	Won et al. (2017)	Won et al. (2017)	Amoah et al. (2017)	Oncul et al. (2017)	Bae et al. (2020)

↑ symbol: Increase.
WG, weight gain (%); FE, feed efficiency (%); SGR, specific growth rate (%/day); PER, protein efficiency ratio (%); SOD, superoxide dismutase (% inhibition); MPO, myeloperoxidase (absorbance); LYZ, lysozyme (U mL^{-1}); NBT, nitroblue tetrazolium (absorbance); NT, not tested.

thors reported that the combination treatment produced some beneficial responses including improved growth performances and increased survival rate in response to a challenge with an exogenous pathogen. A study by Oncul et al. (2017) with feeding trials of fermented tuna by-product containing SGS in olive flounder (*P. olivaceus*) diet, revealed positive effects on non-specific immune responnses such as lysozyme, superoxide dismutase (SOD) and myeloperoxidase (MPO) activities; and enhanced resistance to bacterial infection. Also, Bae et al. (2020) conducted beneficial effects on growth and feed utilization performance, MPO and nitro-blue-tetrazolium (NBT) activity and survival of olive flounder (*P. olivaceus*) fed low-fishmeal (FM) diets.

These studies revealed a trend favoring enhancements of growth performances and disease resistance in response to SGS treatment, without definitively establishing a mechanism of action. These responses are comparable to enhancements seen in response to oxytetracycline (OTC), and for this reasons SGS is viewed as a possible replacement to antibiotic therapy. Beneficial antibiotic effects have tentatively been attributed to increased nutrient absorption in response to a thinning in the gastrointestinal lining, the decrease in harmful bacteria that otherwise would secrete harmful metabolic by-products, and/or a reduction in nutrient competitiveness between host animals and bacteria (Marshall & Levy, 2011). However, evidence of hazards associated with routine antibiotic use are leading to its elimination in large-scale aquaculture activities (Hernandez-Serrano, 2005; Marshall & Levy, 2011).

Conclusion

In conclusion, previous studies demonstrating that SGS may be a safe, effective, and affordable supplement for improving growth efficiency and resistance to pathogens in fresh water and marine fish and they suggest its further evaluation as a dietary replacement for the antibiotic, OTC. In order for these findings to be widely used in other fish species, further studies on the mass production, safety, and toxicity of SGS are needed.

Competing interests

No potential conflict of interest relevant to this article was reported.

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Availability of data and materials

Upon reasonable request, the datasets of this study can be available from the corresponding author.

Ethics approval and consent to participate

Institutional Review Board Statement: Fish handling and euthanizing were approved by the Animal Use and Care Committee of Pukyong National University (protocol number 554).

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