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Trout Farming: A Comprehensive Analysis of the Current Landscape and Future Opportunities

Ishfaq Hamid, Zaheer Abass, Adnan Abubakr, Ishtiyaq Ahmad, Adnan Amin, Imtiyaz Qayoom, Monisa M. Malik, Ubaid Shakeel, Rinkesh Nemichand Wanjari*

Sher-e-Kashmir University of Agricultural Science and Technology of Kashmir, Shalimar, J&K

Abstract

Trout farming has seen experienced significant global growth, driven by sustainable aquaculture practices and technological advancements. In northern India, it has emerged as an economically vital industry, supporting livelihoods and contributing to protein production, while aligning with conservation efforts to safeguard local ecosystems. This industry's positive trajectory is fuelled by increasing consumer demand for sustainability and innovation. This paper examines the thriving trout farming sectors in Jammu and Kashmir and Himachal Pradesh, where favourable climatic conditions, well-established hatcheries, and feed mills have contributed to its success. Despite on-going challenges, the Himalayan region offers substantial opportunities for expansion by leveraging local feed formulations and available resources. This paper provides a comprehensive analysis of the current state of trout farming, including its global reach, key production centers and economic implications. The analysis concludes with strategies to enhance cost efficiency through locally sourced feed and highlights the region's strong potential for further growth in trout farming.

Keywords:
Trout farming, Himalayan region, Hatcheries, Feed mills, Climatic conditions

***Corresponding author:**
rinkeshwanjari0712@gmail.com

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Introduction

Trout farming in India is primarily limited to the upper Himalayan region and the Western Ghats due to climatic constraints. The Kashmir valley, in particular, plays a significant role in trout production in the country. Besides Jammu and Kashmir, trout can also be found in other states such as Himachal Pradesh, Tamil Nadu (Nilgiris), Uttarakhand, Sikkim, and Arunachal Pradesh (Ayyappan *et al*., 2006). However, Jammu and Kashmir and Himachal Pradesh are at the forefront of pioneering trout culture. Trout farming is well-suited for the sustainable use of water resources in the mountainous regions of Kashmir, as both surface and underground water in the area are suitable for fish culture, especially for trout. In regions where employment opportunities are limited, trout farming offers promise in terms of providing stable incomes and employment (Woynarovich *et al*., 2011; Asimi *et al*., 2022; D'Agaro *et al*., 2022). The successful introduction of this cold-water species from Europe in the early 20th century led to the recognition of trout fishery as a commercial and recreational venture in the Union Territory of Kashmir. Due to their exceptional genetics and superior health profile compared to trout from other Indian states, Kashmiri trout are in high demand, particularly for their eggs (Shah *et al*., 2023). As a result, nearly 700,000 trout eggs were transported to the North-Eastern states of India in 2021 alone (Shah *et al*., 2023). The presence of trout in water bodies has also made Kashmir one of the world's major angling destinations. Currently, the Union Territory of Kashmir has 583 private and state-aided trout farms that collectively produce 650 tonnes of trout, making trout farming a substantial industry in the landlocked valley (Hassan and Pandey, 2012). Kashmir Province is blessed with 486 kilometers of rivers, 447 kilometers of streams and 157 square kilometers of lakes, which provide an ideal habitat for breeding, rearing, and promoting trout fish (Sodhi *et al*., 2013). The topography and climate of Jammu and Kashmir are well-suited for trout, with snow and glacier-fed streams, mountains, lakes and springs contributing to the overall health of the fish. Trout thrive in cold, clear, fast-flowing streams and transparent, high-altitude lakes. These water bodies offer high oxygen levels, minimal vegetation, and temperatures ranging from 0 °C to 20 °C, with an optimal range of 5 °C to 15 °C for trout survival.

The Rainbow trout, scientifically known as *Oncorhynchus mykiss* (Walbaum, 1792), is the most extensively distributed and farmed species worldwide. It enjoys immense popularity as a sought-after sport fish and a commonly used experimental subject (Ortega and Valladares, 2017). Rainbow trout is originally endemic to the drainages of the Pacific and North America, inhabiting regions from Alaska down to Mexico. Except for Antarctica, it has been bringing into waterways for aquaculture and sport fishing on every continent. Trout fisheries are conserved or culture practised, across the highland catchments of various tropical and subtropical regions in South America, East Africa, and Asia. While certain local strains have been selectively domesticated, others have developed through cross-breeding and mass selection to enhance desirable aquaculture traits. Norway, Iran, Chile, Japan, Peru, North America, and Australia are among the largest trout fish-producing centres. FAO estimates that inland aquaculture accounted for all 739.5 thousand tonnes of trout production in 2020 (SOFIA, 2022). Brown trout and rainbow trout are the primary species cultivated worldwide, distinguishable based on their physical characteristics. Brown trout have orange spots on the body and red-tipped adipose fin edges, whereas small star-shaped black spots are on rainbow trout (Shahmiri, 2012). The body of rainbow trout is laterally compressed with an adipose fin proximate to the caudal peduncle. Scales are silvery to yellow-green on top of the back with a red-pink band along the lateral line. The male adult rainbow trout has a distinctive rose-coloured iridescent band on its flanks, which is more reflective during reproduction (Rust, 2002). The far-extending distribution of rainbow trout is due to its capability to adapt to different aquatic environments, including cultural conditions. Rainbow trout can be artificially propagated and grow fast, making it essential for fish food production (Halverson, 2010; Hoitsy *et al*., 2012; Stanković *et al*., 2015). In addition to the production, trout farming could ensure higher income and provide employment opportunities through angling tourism, restaurants and related services (Woynarovich *et al*., 2011; Singh, 2015). This study aims to comprehensively analyze the current landscape of trout farming, focusing on the Himalayan region in India, identifying the key factors contributing to successful trout farming, exploring the economic implications, and proposing strategies to enhance cost efficiency through the utilization of local feed formulations while highlighting the substantial potential for the expansion of trout farming in this region.

History of trout culture in India

Trout culture in the region of Jammu and Kashmir is closely linked to the pioneering efforts of Mr F.J. Mitchell, a Scotsman who was involved in the carpet industry in Srinagar in the late 19th century. Captivated by the allure of Kashmir, he recognised that the cold waters of the area were suitable for trout farming (Singh and Lakra, 2011). Mitchell believed introducing trout to the streams would enhance recreational fisheries and tourism in the region (Jhingran and Sehgal, 1978; Singh and Lakra, 2011). In pursuit of this idea, he procured a shipment of trout ova from Scotland in 1898. Unfortunately, this first endeavour was unsuccessful. Undeterred, Mitchell made a second attempt in 1900, choosing Harwan near the famous Shalamar Garden due to its consistent supply of clear, cold running water. This time, his efforts were met with success, marking the inception of trout culture in India. By 1908, Brown trout had become well-established in the region, and several angling locations were formed along the streams. In 1912, eyed-ova of *Salmo gairdneri* (Rainbow trout) were imported from Bristol Water Works England, and nearly 1000 alevins (advanced fry) were successfully hatched. To further promote trout culture, a hatchery was constructed at Achabal in the Anantnag District in 1908, from where eyed-ova were distributed throughout Kashmir. Following the prosperous introduction of Brown and Rainbow trout, the Department of Fisheries, Jammu and Kashmir imported eyed-ova (seed) of eastern brook trout (*Salvelinus fontinalis*) from Canada and land-locked salmon (*Salmo salar*) from the USA. They also introduced splake, a hybrid of brook trout and lake trout from Canada. This marked the expansion of Brown trout in the Himalayan region and beyond. The species was introduced to various regions, including Jammu, Himachal Pradesh, Gilgit Uttar Pradesh, North Bengal, Arunachal Pradesh, Meghalaya, and Nagaland. Additionally, trout species found their way to the Nilgiris and Kodia Hills in Tamil Nadu and Munnar High ranges in Kerala. Among the two trout species, brown trout has been successfully domesticated in culture systems, streams, and lakes, forming self-sustaining populations in the Himalayas. In contrast, rainbow trout remains largely confined to pond culture and is relatively uncommon in Indian streams and rivers.

Despite its expansion, trout culture has encountered challenges such as habitat degradation, pollution and competition from non-native fish species (Shah *et al*., 2023). To address these issues, conservation and initiatives were launched to preserve the Himalayan region's pristine aquatic ecosystems and safeguard native fish species. Trout culture became an important economic activity, contributing to the livelihoods of local communities in the hilly regions of northern India. It provided both a source of employment and a sustainable source of high-quality protein for the region. Trout farming continues to grow in India, with a focus on improving sustainable practices and addressing environmental concerns. The industry has also benefited from increased awareness of the health benefits of consuming trout as a lean source of protein-rich in omega-3 fatty acids. The trout culture in India has evolved over the years from its introduction during the colonial period to becoming an important part of the economy and culture of the Himalayan region. Efforts are ongoing to ensure the sustainability of trout farming while preserving the unique and fragile ecosystems in which these fish thrive.

Global and national production scenario of rainbow trout

Global scenario

Rainbow trout holds a prominent position in the aquaculture industry worldwide due to its adaptability, high market demand, and favourable culinary attributes (Ahmed and Ahmad, 2020; D'Agaro *et al*., 2022). This overview explores the global scenario of rainbow trout, encompassing production trends, geographical distribution, challenges, and the industry's future outlook. Rainbow trout production has witnessed substantial growth on a global scale. According to the Food and Agriculture Organization (FAO), the global production of rainbow trout reached approximately 981,239 metric tons in 2018 (FAO, 2021). Notably, regions such as Europe, North America, and parts of Asia contribute significantly to this production, reflecting the trout's adaptability to diverse environmental conditions. Europe remains a key player in rainbow trout aquaculture, with countries like Norway, Denmark, and France leading in production (Tacon and Metian, 2008). North America, particularly the United States and Canada, also boasts a robust rainbow trout industry, both in freshwater and marine environments (Bartley, 2020). Furthermore, rainbow trout farming has expanded in Asia, with countries like Iran and Turkey contributing to the global production landscape (FAO, 2021). While the industry flourishes, rainbow trout farming faces challenges, including disease outbreaks and environmental concerns. Infectious hematopoietic necrosis virus (IHNV) and bacterial infections pose risks to production (WOAH-OIE, 2019). Sustainable practices such as responsible water management and disease control are essential for overcoming these challenges and ensuring the industry's long-term viability.

The leading trout-producing nations, including Iran, EU-27, Chile, Turkey, and Peru, accounted for a major percentage of global production (Table 1). Over the past decade (2011-2020), there has been a remarkable surge in rainbow trout production in Iran, Turkey, Peru, China, and Russia federation, with increases ranging from 36 to 171 per cent (EUMOFA, 2023). These advancements may be attributed to effective governance and the optimal utilization of available natural resources (Singh *et al*., 2015). For instance, Iran's yearly trout production increased dramatically from less than 1,000 tonnes in 1993 to around 197 thousand tonnes in 2020. This increase was accompanied by an even more remarkable jump in productivity from less than 10 kg to 40 kg per square metre of pond area. Among India's neighbouring countries, China, Nepal, and Afghanistan (with respective annual trout production figures of 28,991, 180, and 150 tons in 2013) are included in the FAO's list of rainbow trout-producing nations (FAO-Fish stat, 2013). The future of rainbow trout farming appears bright, as seen by the growing output volumes fuelled by rising demand in many nations.

The future of rainbow trout farming holds promises as the industry continues to adapt to emerging trends. Consumer preferences for sustainably sourced and eco-friendly products provide opportunities for rainbow trout producers to differentiate themselves in the market. Innovations in aquaculture technologies, including recirculating aquaculture systems (RAS) and precision aquaculture, are likely to enhance production efficiency and environmental sustainability (Liao *et al*., 2020).

Table 1. Countries leading in rainbow trout production (Source: SOFIA, 2022).

Rank	Country	2011	2020	% Shift
1	Iran	106409	197370	+85
2	EU-27	173929	187936	+8
3	Turkey	107936	146594	+36
4	Norway	58545	96263	+64
5	Chile	224448	87724	-61
6	Peru	19962	54188	+171
7	Russian Federation	21180	50917	+140
8	China	18575	37841	+140
9	Others	80766	122406	+52
Total		**811750**	**981239**	**+21**

National Scenario

The states of Himachal Pradesh, Jammu and Kashmir, Sikkim, Arunachal Pradesh, Uttarakhand, and Tamil Nadu are home to 660 private trout production units and 62 government trout farms (Mir *et al*., 2020). Breeding and rearing procedures are well-established. Due to the natural abundance of highly oxygenated cold freshwater in India's hilly regions, which is ideal for rainbow trout, it was imported in the early 20th century during British rule control to establish sport fisheries (Singh and Lakra, 2011). The top states for both public and private trout farming are Sikkim, Jammu and Kashmir, and Himachal Pradesh. During 2015-16, Himachal Pradesh was the largest trout producer in the country, standing at 417.23 tonnes, followed by Jammu and Kashmir (265 tonnes), Sikkim (120 tonnes) and Uttarakhand and Arunachal Pradesh (40 tonnes) (Chettri, 2021). Jammu & Kashmir and Himachal Pradesh, located in the northwest Himalayan area, continue to be India's primary trout-producing regions. These two states contribute the bulk of India's trout production of about 81% (50% from Himachal Pradesh and 31% from Jammu and Kashmir), Sikkim contributes 14%, and other states contribute 5% of total production in India. This is because trout farming in India was initially started in the states of Jammu and Kashmir, and Himachal Pradesh, which has more water resources and trout growers. Jammu and Kashmir and Himachal Pradesh are the hubs of cold-water fishery resources and fish species. Sikkim, another Himalayan state of India situated in the northeastern region, also performs well in trout farming and occupies the third position, leaving behind Uttarakhand and Arunachal Pradesh. In 2015–2016, the nation produced a total of 842 tonnes of trout, while the demand was approximately 1000 tonnes (Mir *et al.*, 2020). Currently, demand continues to exceed supply. According to data from the state fisheries departments Jammu and Kashmir led trout in 2022-2023 with 1990 tonnes, followed by Himachal Pradesh with 849.7 tonnes and Sikkim with 340 tonnes. These figures highlight the potential for expanding trout farming in India (India Trout Market Research Report and Industry Forecast 2025-2033).

Trout farming

Raceway construction and site selection

When choosing a location, two fundamental factors are crucial: (a) an adequate supply of pristine water, and (b) the water temperature should stay between 10-16°C. Building well-designed raceways is one of the most crucial things that make trout farming successful. For trout farming, a minimum structure dimension of 17 x 2 x 1.5 metres should be cemented entirely (Shah *et al.*, 2023).

Density of stocking and water flow

Water flow requirements

The water flow needed in a raceway is determined by the number of fish being reared. For conventional raceways, a water supply of 300 liters per minute is generally required to support one tonne of fish. When the water temperature is below 15°C, the flow rate can be reduced to 180 liters per minute per tonne of fish. If sufficient water is available, a standard raceway with a water volume of 51 m³ can accommodate approximately 2,000 trout fingerlings (Mir *et al.*, 2020).

Stocking density

The stocking density for trout depends on several factors, including the source and quality of water, water temperature, and the type of feed provided. When water temperatures exceed 20°C, it is recommended to lower the stocking density below standard levels to reduce stress on the fish. Typically, trout fry and fingerlings weighing between 5 to 50 grams are stocked at a density of 20 kilograms per cubic meter of water (Ellis *et al.*, 2002).

Physico-chemical requirements of water for trout farming

Temperature, dissolved oxygen, pH, and turbidity are the physico-chemical factors that determine whether trout may be successfully cultivated.

a) Temperature: The fish can withstand water temperatures up to 25°C without experiencing any death; however, it grows best in temperatures between 5 and 18 °C—however, the temperature range of 10 to 18 yields the maximum growth (Shah *et al.*, 2023).

b) Dissolved oxygen: The oxygen concentration in the water typically falls within the range of 5.8 to 9.5 mg/l. Increasing the water flow is particularly beneficial when the oxygen concentration is as low as five mg/l (Mir *et al.*, 2020).

c) pH: For trout, maintaining a neutral or slightly alkaline pH level is most favourable. Their acceptable pH range spans from a minimum of 4.5 to a maximum of 9.2. However, the most optimal pH range for their growth falls within 7 to 8

d) Turbidity: To maintain optimal conditions, it is essential to have pristine, uncontaminated water with a maximum turbidity of 25 cm, as measured by a Secchi disc for transparency (Jha, 2015).

Nutritional requirements, feeding strategies, and feed management

Rainbow trout's nutritional requirements are more comprehensively documented than other farmed fish species. However, it is important to note that most research on dietary requirements has focused on fingerlings or juvenile fish (NRC, 2011). However, as fry (young fish) and post-juvenile rainbow trout have similar digestive capacities, larger fish probably need similar diets for most nutrients. The exclusions may mostly relate to the ideal ratio of protein to energy and possibly certain dietary mineral needs related to skeletal development, which may differ for juvenile fish (Cho and Cowey, 1991; Hardy, 2002).

All known fish species, including rainbow trout, share a common requirement for ten essential amino acids. For the most part, we have established the precise dietary needs for these essential amino acids. However, some evidence suggests that the reported lysine requirement underestimates the actual requirement by approximately 15% (Hardy, 2002). In that order, when reducing fishmeal levels and incorporating more plant-based protein sources into rainbow trout feeds, lysine, methionine, and arginine (or threonine) emerge as the most limiting amino acids. It is worth noting that fish require amino acids rather than protein per se. However, minimum dietary protein levels must be met to maximise trout performance. For most fish species, the ideal protein content in their diet depends on factors such as dietary energy content and the ratio of essential to non-essential (or indispensable to dispensable) amino acids. A ratio of 55:45 is optimal for rainbow trout (Green *et al*., 2002). Rainbow trout efficiently utilise dietary lipids and necessitate dietary sources of n-3 fatty acids. The most effective way to meet the n-3 fatty acid requirements of rainbow trout is by providing eicosapentaenoic acid (EPA) (20:5n-3) and docosahexaenoic acid (DHA) (22:6n-3) in their diet. These specific fatty acids are essential for their nutritional needs. Trout need 1.0% of their diet to 20% of their dietary lipid to meet their n-3 fatty acid requirements (NRC, 1993). Poor growth, a high feed conversion ratio, and a shock syndrome that resembles fainting are indicators of an n-3 scarcity. In rainbow trout, the buildup of C20:3n-6 in polar lipids indicates a deficit in critical fatty acids. Carbohydrates are unnecessary for rainbow trout to thrive; they can flourish on diets low in carbohydrates. However, when conventional feed ingredients are employed, some carbohydrates are inevitable in practical feed and helpful to trout, as shown by better feed conversion ratios when some carbohydrate is included in the diet. Flow-through trout farming systems lack natural feeding sources, making rainbow trout farming mostly intensive. Hence, all necessary nutrients, including vitamins, must be included in the feed. Although rainbow trout can get part of their mineral needs directly from rearing water, just as other fish species, the dietary mineral requirements of rainbow trout are fairly well-quantified. The one major exception is phosphorus. While fish can get phosphorus from rearing water, freshwater has insufficient free phosphorus to meet fish demands. The majority of the minerals needed by trout were determined by particular clinical indicators of deficiency, which were caused by either insufficient food intake or antagonistic interactions in feeds that decreased the bioavailability of minerals to the point where deficiency developed.

Feeding schedule

Feeding schedules for rainbow trout evolve with their growth stages. Newly hatched fry is typically fed almost continuously, employing manual feeding or mechanical feeders. However, it is crucial to exercise caution during this phase to uphold water quality and prevent bacterial gill issues, which can worsen due to excess suspended feed particles in the fry-rearing water. As soon as possible, transitioning trout fry to smaller feed particles is recommended, coupled with a reduction in feeding frequency to eight times daily. When the fish reach 1–2 grams, the feeding frequency can be reduced to four to five times daily, eventually decreasing to three times per day once they reach approximately 5 grams. During each feeding, the aim is to feed the trout until they appear satiated. It is essential to inspect the fry for signs of fullness visually. Any indications of thinness, such as "pinheads," are clear indicators of insufficient feeding frequency and inadequate amounts of food.

Trout fingerlings generally consume approximately 1% of their body weight per feeding (FAO, 2017). It is important to note that providing less feed at a single feeding can lead to increased size variations within a group of trout. To determine the ideal feeding frequency, it is advisable to calculate the total amount of feed that trout fry and fingerlings can consume daily, expressed as a percentage of the tank's biomass. This total should then be divided into an appropriate number of feedings, approximating around 1 per cent of their body weight per feeding. As the trout grows, feed is often administered using mechanical or demand feeders. Mechanical feeders can be set to dispense amounts in line with published recommendations for fish of a specific size range at a given water temperature. Demand feeders, on the other hand, automatically deliver the right amount of feed to promote efficient and rapid growth of the trout. Charts and guidelines are readily available from feed producers for precise and detailed feeding schedules tailored to specific fish sizes and environmental conditions. These resources can assist in optimising the feeding regimen for your trout.

Feeding method

Rainbow trout are typically fed in trout farming through manual feeding, mechanical feeders, or demand feeders. Mechanical and demand feeding methods are primarily used in developed countries, while the majority of the developing nations are still using manual feeding methods. In India, trout farming is practiced in Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Arunachal Pradesh, Assam, and Sikkim. They are also using this manual method of feeding, because the industry is still in infancy stage. Mechanical feeders are essential in commercial production in developed nations, mechanical feeders play a crucial role, as they can feed fry frequently, sometimes every ten to fifteen minutes. One such feeder is the belt feeder, which operates through a spring mechanism. It consists of a moving belt that gradually dispenses feed at a controlled rate into the tanks. In marine farming of rainbow trout, a different kind of mechanical feeder is used. This system employs tubes running from a central feed bin to each pen. A predetermined schedule is followed by controlled air pressure blowing precise amounts of feed into each pen. By ensuring consistent feeding, this method supports optimal fish health and growth.

Demand feeders provide several benefits throughout the feeding process, so they are commonly used in freshwater trout farming in the United States. The bottom of these feeders has a cone-shaped aperture where the feed is inserted. A plastic disc that is marginally smaller in diameter than the tapering cone is a plug to regulate the feed release, while a rod extends into the water inside the cone. A tiny amount of feed can fall into the water when fish swim around the rod in the water because the rod's movement changes the position of the disc. The feed quantity is regulated by moving the disc up or down the rod, which alters the clearance between the disc's edges and the cone's walls, dispensing more or less feed. Rainbow trout quickly learn to interact with the rod to obtain their feed, spending a significant portion of their day feeding. The utilisation of demand feeders offers numerous benefits:

1. *Efficient Self-Feeding*: Fish feed themselves, which reduces labour costs and minimises feed wastage, assuming the device is appropriately adjusted. Fish eat when they are hungry, allowing for more precise feeding.
2. *Continuous Feeding:* Water quality is constantly high since fish eat all day. There are no periods of low oxygen following feeding, which frequently occurs with intermittent hand or blower feeding. The quick movements of trout during feeding periods can lower the oxygen level of the water by as much as two or three parts per million.
3. *Feeding Hierarchy*: When it comes to feeding, fish take turns; the more aggressive fish eat first and then move away to make room for the less aggressive fish to eat (Newman, 1956). This results in efficient feeding minimizes size variability among the stock and ensures all fish have access to the necessary nutrition.

Production systems

The prevailing approach in rainbow trout culture is monoculture; in many cases, intensive systems are deemed essential to ensure the economic viability of the operation. Figure 1 depicts the production cycle of *O. mykiss.*

Development of broodstocks

Trout do not typically reproduce naturally within culture systems. Therefore, eggs are stripped artificially obtained from fully mature (ripe) good-quality brood fish. While trout as young as two years old may begin to spawn, it is uncommon to use females for reproduction until they reach the age of three or four years. Broodstock are chosen based on their rapid growth and early maturation, typically occurring within two years. A common strategy is using sex-reversed broodstock, consisting entirely of females, to promote accelerated growth in their offspring. Functional males are generated by orally administering the hormone 17-methyl testosterone via starter feeds during the fry stage. Typically, males and females are maintained separately, and a common practice is to maintain a sex ratio of one male to three females for the broodstock.

Stripping and fertilisation

The reproduction of rainbow trout is thoroughly understood with well-developed techniques. The most commonly employed method is the dry fertilisation approach, which does not involve mixing with water. Eggs are carefully extracted from the females, usually under anaesthesia. This is accomplished either via air spawning, which causes less stress for the fish and yields eggs that are cleaner and healthier, or by gently pressing on the vent area from the pelvic fins. When air

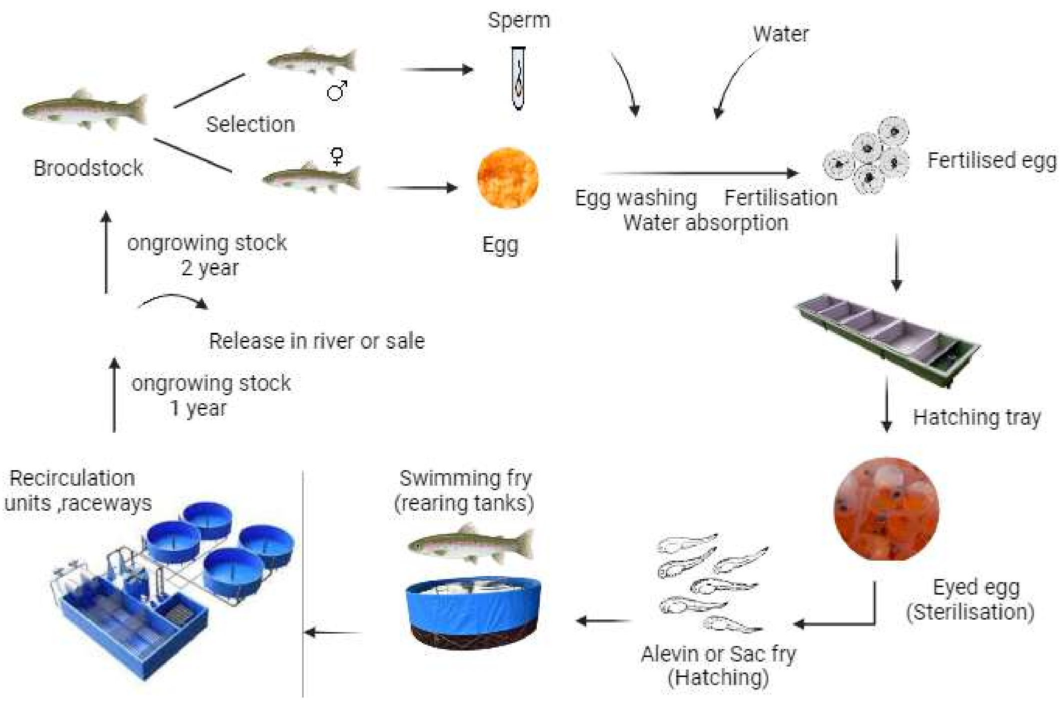

Fig. 1. Production cycle of rainbow trout, *Oncorhynchus mykiss*

spawning occurs, the eggs are released using air pressure at 2 psi after a hypodermic needle is placed about 10 mm into the body cavity close to the pelvic fins. The fish's sides are then gently massaged to release the remaining air from its body cavity. Up to 2,000 eggs can be collected using this dry method for every kilogram of body weight. The fertilisation process is aided by keeping the eggs in a dry container. The preparation of males is the same as that of females; their milt is gathered in a different container to avoid contaminating water or urine. The eggs are combined with milt from many males to guarantee sufficient fertilisation. This procedure facilitates adequate fertilisation. Water is added to start the fertilisation process, causing the sperm to become active and the eggs to enlarge by about 20%. Filling the perivitelline gap between the eggshell and yolk causes this growth, known as "water-hardening." Fertilised eggs can be moved for transportation up to 48 hours after fertilisation, but only until the point at which the eyes show through the shell (referred to as the "eyed stage"). This movement can occur 20 minutes after fertilisation. It's important to avoid direct exposure to light at all stages of development, as this can be detrimental to the embryos' survival.

Hatchery production

To get to the eyed stage, eggs are incubated in hatching jars, hatching troughs, or vertical flow incubators without being handled. The hatching and raising troughs have standard dimensions of 40–50 cm in width, 20 cm in depth, and up to 4 m in length. These troughs hold two layers of eggs, which are arranged in California trays, or wire baskets or screened trays. The trays are positioned 5 cm above the bottom of the trough, allowing water to flow through them at a rate of 3-4 litres per minute. As the eggs hatch over 4-14 weeks, the fry naturally drops through the mesh of the trays and collects in a lower trough. An alternative method involves the use of vertical flow incubators, often referred to as Heath incubators. Up to 16 trays can be stacked on top of one another in these incubators. A single water source in this system raises the eggs by 3–4 litres per minute. After that, the water overflows into the tray below, aerating itself in the process. This design allows for hatching many eggs in a relatively compact space with minimal water usage. The sac fry, which is newly hatched fish with yolk sacs still attached, can be kept in these trays until they are ready to swim up, which typically occurs around 10 to 14 days after hatching. The hatching time can vary depending on water temperature, with hatching taking approximately 100 days at 3.9 °C and around 21 days at 14.4 °C. This hatching time is measured in degree days, with higher temperatures accelerating the process. The hatching process for a batch of eggs typically spans 2 to 3 days. During this time, it is essential to regularly remove all eggshells and any dead or deformed fry to maintain a healthy and clean environment. Once hatching is complete, the egg shells are removed from the rearing troughs. Following hatching, the incubation trays are taken out and the rearing troughs' water depth is kept at a shallow level, often between 8 and 10 cm. Up until the fry reaches the "swim-up" stage, the water flow is decreased. At this point, the fry absorbs the yolk sac and starts actively looking for food.

Rearing fry

Fry is traditionally raised in fibreglass or concrete tanks; circular designs are preferred because they guarantee a steady water flow and even fry distribution. However, square tanks are also utilised for this purpose. These tanks typically have a diameter of around 2 meters or are square with dimensions of 2 meters by 2 meters. The depths of these tanks usually range between 50 to 60 centimetres. In tanks, water is introduced from the side using an elbow pipe or a spray bar to create a circulating water flow. The tank's central area contains a drain protected by a mesh screen. Placing the drain in this manner is intentional, as it promotes the formation of a vortex in the water, facilitating waste collection in the centre for convenient removal. The sump or drain pipe is linked to an elbow pipe on the tank's side, enabling the water level adjustment. Fry are nourished with specially formulated starter feeds through automatic feeders, generally commencing when around 50 per cent of the fry have reached the swim-up stage. Once most of the fish are actively feeding, it is recommended to introduce a daily feed amount equivalent to 10 per cent of the fish's total weight for 2 to 3 weeks. Continuous feeding using clockwork belt feeders is preferred during this time to ensure a steady food supply. Automatic feeders offer convenience, but it is advisable to hand-feed in the early stages to prevent overfeeding. As the fish grow more prominent, demand feeders become more efficient. Continuously monitoring dissolved oxygen levels is essential as the fish continues to grow. When necessary, fish can be transferred to larger tanks to reduce population density, ensuring their well-being and optimal growth.

Grow out ponds/Raceways

The fry is moved to outdoor grow-out facilities after they reach a length of around 8–10 cm, which typically equates to a stocking density of about 250 fish per kilogramme. Concrete raceways, flow-through Danish ponds, or cages are a few examples of these facilities. The average size of a raceway or pond is two to three metres wide, twelve to thirty metres long, and one to two metres deep. Raceways benefit from providing well-oxygenated water, and by raising the flow rates, the water quality can be enhanced. It is imperative to acknowledge that fish raised in raceways are susceptible to external factors affecting water quality, and the ambient temperature has a substantial impact on their growth rates.

Exploring the wellness advantages of trout fish

Nutritional Composition: Trout is a semi-fatty fish with fewer calories compared to salmon. A 100g serving holds only 149 calories versus salmon's 160 calories. It's rich in protein, providing 20.77g/100g (37% of RDI) with a complete profile of essential amino acids (USDA Food Data Central, 2024).

Heart Health Benefits: Seafood consumption, including trout, has been associated with decreased risks of heart attack, stroke, obesity, and hypertension due to its low saturated fat and high polyunsaturated fat content, especially omega-3 fatty acids (Mozaffarian and Rimm, 2006).

Omega-3 Fatty Acids: Trout is rich in long-chain omega-3 fatty acids (PUFA) like EPA, DPA, and DHA. These fatty acids play crucial roles in neural system development, cardiovascular health, reducing blood pressure, and lowering the risk of abnormal heartbeats (Simopoulos, 2002; Rizos *et al*., 2012).

Vitamins: Trout contains essential vitamins like A, D, B6, B12, E, niacin, thiamin, and riboflavin, contributing to healthy skin, mucosa, and calcium metabolism (USDA Food Data Central, 2024).

Minerals: Trout is a rich source of minerals such as calcium, zinc, potassium, phosphorus, magnesium, and iodine (USDA Food Data Central, 2024).

Pregnancy Recommendation: The FDA recommends that pregnant women consume 8-12 ounces of low-mercury seafood, like trout, weekly to benefit from its nutritional value without adverse effects (Park and Johnson, 2006; Silbernagel *et al*., 2011; Hellberg *et al*., 2012).

Managing common diseases: effective remedies and solutions

The onset of any disease in stocked fish typically manifests as alterations in behaviour or bodily functions. Among Skin's most prevalent diseases affecting farmed trout, fungal and bacterial diseases are common culprits. Saprolegniasisis the primary fungal disease primarily caused by the Saprolegnia species, often called "water moulds." The most common diseases in trout farming are presented in Figure 2. Recognition of this ailment often begins with observing fluffy, cotton-like growths, ranging from white to shades of grey and brown, appearing on the skin, fins, gills, or fish eggs. Saprolegnia infections are frequently linked to suboptimal water conditions, such as low circulation, reduced dissolved oxygen, high ammonia levels, and high organic loads.

Common treatments for Saprolegniasis include:

a) Bath treatment with $KMnO_4$ (Potassium Permanganate): Use 1g of $KMnO_4$ per 100 litres of water for 30-90 minutes.

b) Malachite Green: Utilizing a 1:15,000 solution of Malachite Green for short dips lasting 10 to 60 seconds, administered in two or three treatments.

c) Salt bath: Employing a 3% salt solution for effective treatment, typically for 10-15 minutes.

The most effective approach to managing common diseases is prevention through sound management practices. These practices include maintaining the following:

a) Good Water Quality and Circulation: Providing and maintaining high-quality water conditions with adequate oxygen levels and efficient circulation helps reduce the risk of disease outbreaks.

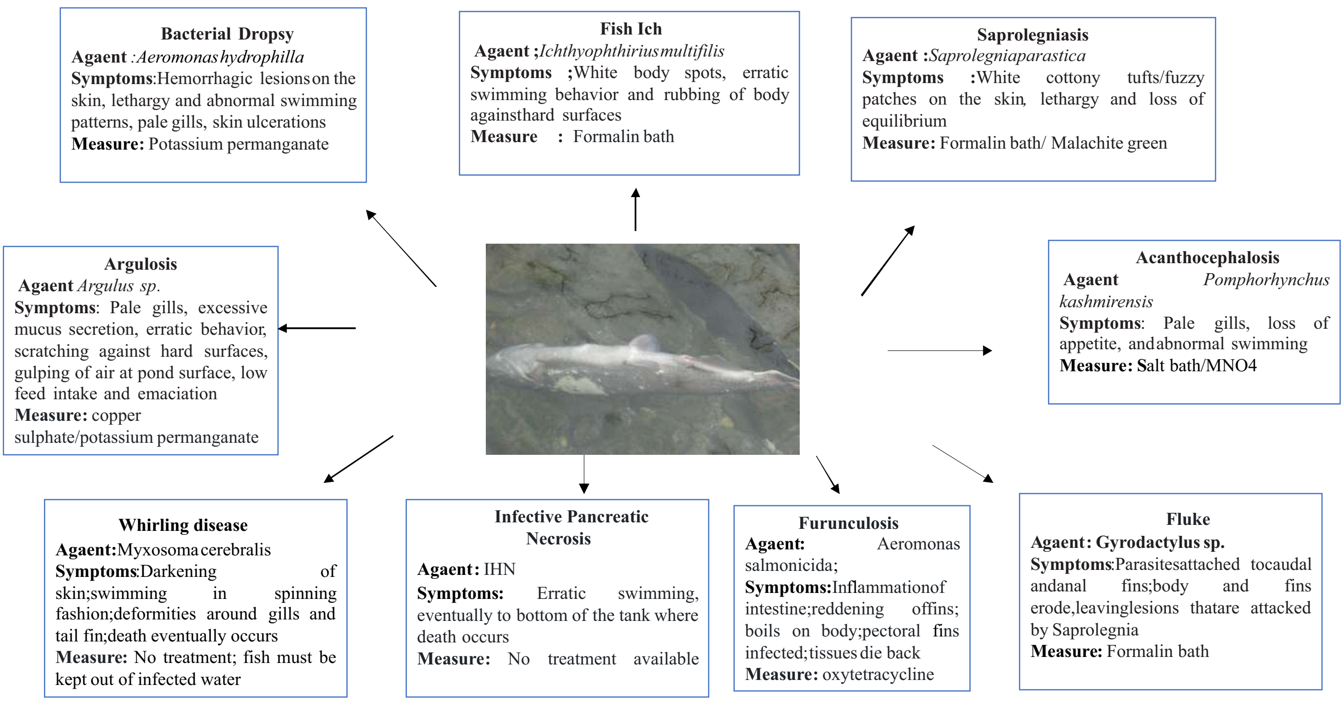

Figure 2. Common diseases of rainbow trout, *Oncorhynchus mykiss*

b) Avoidance of Crowding: Minimizing fish crowding is crucial to prevent injuries and reduce stress among the fish population, as crowded conditions can promote the spread of diseases.

c) Nutrition: It is crucial to provide fish with a well-balanced and nutritious diet to promote their overall health and bolster their immune systems, reducing their susceptibility to diseases.

d) Regular Cleaning: Consistent and thorough cleaning of raceways, tanks, or aquaculture systems is essential to remove potential sources of contamination and pathogens. A 3% salt solution can be an effective method for cleaning and disinfection.

Navigating challenges and expanding horizons

They are unlocking the potential of untapped water resources for fisheries development in India's Hilly Regions. India has abundant untapped water resources, particularly in virgin and unutilised areas. The Himalayan region, renowned for its perennial springs and streams, presents a remarkable opportunity for fisheries development. However, several challenges hinder the full utilisation of these resources, particularly in states like Jammu, Kashmir, and Sikkim. The fisheries sector in these states faces numerous obstacles, including poor accessibility due to rugged, hilly terrain, inadequate transportation infrastructure, improper marketing channels, and limited aquaculture infrastructure. Consequently, the region has yet to flourish to its full potential. Trout farmers, in particular, encounter significant issues such as delayed availability of fish feeds, high feed costs, and inadequate supply of required fish seeds (Pandey and Pandey, 2023). Despite these challenges, the hilly states hold tremendous prospects for fisheries and fish farming, and their production levels can be substantially enhanced by implementing the following strategies:

1. The available water resources could be brought into fish farming and aquaculture development by utilizing these resources efficiently and adequately rather than going to waste.

2. Awareness of the importance and role of fisheries and aquaculture for rural development and nutritional value can motivate the younger generations, which could result in greater participation of people in fish farming.

3. Fish is a highly perishable product; proper accessibility, cold storage, transportation and marketing facilities in rural areas could foster this sector so that local fish can be readily available in the market. The use of modern technology and training for farmers can increase the level of production and productivity.

4. The retail local fish shop should be started at the district level so that the local fish will be readily available in the market, and this will also encourage fish farmers to produce local fish.

5. Although water resources are plentiful, many problems need immediate attention from the government and the management teams to get better results in steady growth in production, productivity, profitability, sustainability, etc.

6. To minimize farmer's significant problems, such as the non-availability of feed on time and high feed cost, the government should frequently monitor or establish at least a feed mill plant within the state to redress such problems.

Constraints faced by trout farmers

Trout farming faces numerous challenges that hinder its growth and profitability, with the high cost of inputs - particularly feed and seed - emerging as the most pressing concern. The industry's heavy reliance on artificial feeding makes it vulnerable to feed price fluctuations, which were notably high during the study period, significantly affecting farmers' bottom lines. This situation is exacerbated by underutilized feed mills operating below capacity due to limited demand, creating a cycle of high prices. Similarly, trout seed costs remain substantially higher than carp seed, largely because government-run hatcheries aren't operating at full capacity. The study suggests that privatizing seed and feed production could help stabilize prices and improve availability. Transportation of fingerlings presents another major obstacle, as the process requires specialized knowledge to maintain proper oxygen levels during transit, with many farmers reporting difficulties in securing viable seed supplies. Marketing challenges further compound these issues, as farmers in the Trans-Himalayan region are largely limited to farm-gate sales despite strong demand in urban markets like Srinagar, due to inadequate distribution infrastructure. Additional constraints include limited access to clean water, lack of crop insurance, knowledge gaps in modern farming techniques, predation risks, credit accessibility issues, skilled labor shortages, disease outbreaks, and inconsistent seed quality. These factors collectively account for significant production challenges, with feed and seed alone constituting about 70% of total costs. The intensive nature of trout farming also increases disease susceptibility compared to wild populations, presenting sustainability concerns. To address these challenges, the Pradhan Mantri Matsya Sampada Yojana (PMMSY) provides crucial support through financial assistance for raceway construction, hatchery development, brood banks, and training programs, while also facilitating the import of genetically superior trout strains to enhance productivity and sustainability in the sector.

Conclusion

Over the past two decades, the cold-water fisheries in the Himalayas have shown consistent growth. Fish production has increased across all Himalayan Indian states, with a particular focus on the progressive development of rainbow trout farming. While production levels have experienced some fluctuations, the overall trend has been positive. In the Indian Himalayas, the production of rainbow trout has steadily increased over the last few decades. From a modest 147.0 tonnes in 2004-2005, the production escalated to 602.0 tonnes in 2013-2014, reaching 755 tonnes in 2014-2015 and 842 tonnes in 2015-2016. These figures indicate a significant rise in rainbow trout production, reflecting the sector's growth potential. However, it is noteworthy that the annual supply of trout in India stands at approximately 842 tonnes, while the demand exceeds this figure, reaching around 1000 tonnes. This supply-demand gap highlights the substantial scope and potential for further development in this sector. An analysis of the annual growth rate of trout production shows that it was 25.42% in 2014-2015 but declined to 11.52% in 2015-2016. Among the leading trout producers in India, Himachal Pradesh, Jammu and Kashmir, and Sikkim played prominent roles, contributing 50%, 30%, and 14% respectively to the total production in India during 2015-2016. Trout farming in India's Himalayan region has proven successful due to the species adaptability to local environmental conditions. However, sustaining this industry requires a cost-effective and reliable feed supply. Since formulated feeds are expensive, there is a need to develop local feed formulations using indigenous components to improve the cost-benefit ratio. The establishment of modern feed mills has significantly enhanced the availability of affordable feed, making trout farming an attractive livelihood opportunity, particularly for young entrepreneurs. Furthermore, the abundance of available resources in the Himalayan region presents ample opportunities for the expansion of trout farming. Overall, trout farming has become essential for both the local economy and the preservation of trout populations in the Trans-Himalayan region of India. These findings underscore the positive trajectory of cold-water fisheries in the Indian Himalayas, demonstrating the sector's growth and potential. Continued focus and investment in this area can bridge the supply-demand gap, promote sustainable production, and further contribute to the overall development of fisheries in the region.

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References

Ahmed I, Ahmad I. Effect of dietary protein levels on growth performance, hematological profile and biochemical composition of fingerlings rainbow trout, *Oncorhynchus mykiss* reared in Indian himalayan region. 2020. *Aquaculture Reports*.;16:100268. https://doi.org/10.1016/j.aqrep.2019.100268

Asimi OA, Khan IA, Baba SH, Javaid H. 2022. Status of Trout Culture in Kashmir, *India. Curr. j. appl.*; 41(46):29-32.

Ayyappan S, Jena JK, Gopalakrishnan A, Pandey, AK. 2006. Handbook of fisheries and aquaculture. *Indian Council of Agricultural Research*. New Delhi 100012 Bureau, D.P.

Bartley DM. 2020. World Aquaculture, A brief overview. In FAO Fisheries and Aquaculture Circular No. 1233; FAO: Rome, Italy,

Chettri KB. 2021. Current status of rainbow trout culture in Sikkim: A sustainable farming system in the hills. *Indian Journal of Hill Farming*,. 34(1), pp.126-133.

Cho CY, Cowey CB. Rainbow trout, *Oncorhynchus mykiss*. In Handbook of Nutrient Requirements of Finfish .CRC Press.1991;131-144.

D'Agaro E, Gibertoni P, Esposito S. 2022. Recent trends and economic aspects in the rainbow trout (*Oncorhynchus mykiss*) sector. *Appl. Sci*.; 12(17):8773. https://doi.org/10.3390/app12178773

Ellis, T., North, B., Scott, A. Á., Bromage, N. R., Porter, M., & Gadd, D. 2002. The relationships between stocking density and welfare in farmed rainbow trout. *Journal of fish biology*, *61*(3), 493-531.

EUMOFA. Blue Bioeconomy Report. The European Market Observatory for fisheries and aquaculture products. EUMOFA: Luxembourg. WWW.EUMOFA.EU 2023.doi:10.2771/279177

FAO. 2021."The State of World Fisheries and Aquaculture 2020." Food and Agriculture Organization of the United Nations. FAO. Food and Agriculture Organization of the United Nations. Aquaculture Feed and Fertilizer Resources Information System, 2017. https://www.fao.org/fishery/affris/species-profiles/rainbow-trout/feed-formulation/en/

FAO. 2013. Statistical Yearbook 2013, World Food and Agriculture, Food and Agriculture Organization of the United Nations, Rome.

FAO. 2020. World fisheries and aquaculture. Food and Agriculture Organization:1-244.

Green JA, Hardy RW, Brannon EL. 2002. The optimum dietary essential: nonessential amino acid ratio for rainbow trout (*Oncorhynchus mykiss*), which maximizes nitrogen retention and minimizes nitrogen excretion. Fish Physiol. Biochem.;27:109-15.https://doi.org/10.1023/B:FISH.0000021877.49848.8f

Halverson A. 2010. An entirely synthetic fish: how rainbow trout beguiled America and overran the world. Yale University Press.

Hardy RW. 2002. Rainbow trout, *Oncorhynchus mykiss*. In Nutrient requirements and feeding of finfish for aquaculture Wallingford UK: CABI Publishing; 184-202.

Hassan, N. U., & Pandey, D. N. 2012. Present status of trout fisheries in Jammu and Kashmir. *IOSR Journal of Pharmacy*, *2*(5), 35-37.

Hellberg RS, DeWitt CA, Morrissey MT. 2012. Risk benefit analysis of seafood consumption: A review. Comprehensive reviews in food science and food safety;(5):490-517.

Hoitsy G, Woynarovich A, Moth-Poulsen T.2012. Guide to the small scale artificial propagation of trout. Budapest: FAO;22.

India Trout Market Research Report and Industry Forecast(2025-2033): SR112025A9913

Jha. G. 2015. Trout Culture Practices. 10.13140/ RG.2.2.21337.31844.

Jhingran, VG, Sehgal, KL. 1978. Coldwater fisheries of India. *Coldwater fisheries of India.*

Mir, S. A., Gul, S., Mir, N. I., Qayoom, U., & Mushtaq, Z. 2020. Trout culture in Kashmir: An economical venture for young entrepreneurs. *Aqua Star Magazine National News*.

Mozaffarian D, Rimm EB. Fish intake, contaminants, and human health: evaluating the risks and the benefits. 2006. Jama.;296(15):1885-99.

National Research Council (NRC). 2011. Nutrient requirements of fish and shrimp. Washington DC: The National Academies Press.

National Research Council (NRC). 1993. Nutrient requirements of fish. Washington, D.C., National Academy Press, 114 pp. National Research Council (NRC).. *Nutrient requirements of fish.* Washington, D.C., National Academy Press, 114 pp.

Newman MA. 1956 Social behavior and interspecific competition in two trout species. Physiol. Zool.; 29(1):64-81.

Ortega C, Valladares B. 2017. Analysis on the development and current situation of rainbow trout (*Oncorhynchus mykiss*) farming in Mexico. Rev. Aquac.:194-202. https://doi.org/10.1111/raq.12133

Pandey, P. K., & Pandey, N. 2023. Fish and Fisheries of the Temperate Himalayas: An Overview and Way Forward. *Fisheries and Aquaculture of the Temperate Himalayas*, 1-10.

Park S, Johnson MA. 2006. Awareness of fish advisories and mercury exposure in women of childbearing age. *Nutr. Rev*.;64(5):250-6. https://doi.org/10.1111/j.1753-4887.2006.tb00207.x

Rizos EC, Ntzani EE, Bika E, Kostapanos MS, Elisaf MS. 2012. Association between omega-3 fatty acid supplementation and risk of major cardiovascular disease events: a systematic review and meta-analysis. Jama.; 308(10):1024-33. doi:10.1001/2012.jama.11374

Rust MB. 2003. Nutritional physiology. InFish nutrition .(pp. 367-452). Academic Press.

Shah FA, Maqbool H, Hafeez M, Bhat FA. 2023. History, Present Status and Strategies of Rainbow Trout (*Oncorhynchus mykiss*) Farming in Jammu and Kashmir, India-A Review. *Fish. Technol*.;60:149-56.

Shahmiri B. 2012.Propagation and breeding of rainbow trout. Adv. Environ. Biol.:836-43.

Silbernagel SM, Carpenter DO, Gilbert SG, Gochfeld M, Groth III E, Hightower JM, Schiavone FM. 2011. Recognizing and preventing overexposure to methylmercury from fish and seafood consumption: information for physicians. J. Toxicol..;983072. https://doi.org/10.1155/2011/983072

Simopoulos AP. 2002. The importance of the ratio of omega-6/omega-3 essential fatty acids. Biomedicine & pharmacotherapy.; 56(8):365-79.

Singh AK, Lakra WS. 2011. Risk and benefit assessment of alien fish species of the aquaculture and aquarium trade into India. Rev. Aquac; (1):3-18. https://doi.org/10.1111/j.1753-5131.2010.01039.x

Singh AK. 2015. Advances in Indian coldwater fisheries and aquaculture. *J Fish Sci*.;9(3):48.

Sodhi AS, Saroch JD, Verma J. 2013. Fisheries Resources of Kashmir: A case study of River Jhelum. *Journal of Chemical, Biological and Physical Sciences* (JCBPS).;3(2):1194.

SOFIA. 2022. State of World Fisheries and Aquaculture report. 266 p. https://www.fao.org/3/cc0461en/cc0461en.pdf

Stanković D, Crivelli AJ, Snoj A. 2015. Rainbow trout in Europe: introduction, naturalization, and impacts. Rev. Fish. Sci. Aquacult;23(1):39-71. https://doi.org/10.1080/23308249.2015.1024825

Tacon AG, Metian M. 2008. Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. Aquac.;285(1-4):146-58. https://doi.org/10.1016/j.aquaculture.2008.08.015

USDA. 2024. Food Data Central, Agricultural Research Service, Beltsville Human Nutrition Research Center. Food Data Central.. [Accessed 06 January 2024]. Available from https://fdc.nal.usda.gov/.\

World Organisation for Animal Health OIE. 2019. Aquatic Animal Health Code 2019, Chapter 2.3.10, Viral haemorrhagic septicaemia; Chapter 2.3.4, Infectious hematopoietic necrosis, Manual of Diagnostic Tests for Aquatic animals, OIE, Paris. Retrieved from http://www.oie.int/international-standard-setting/aquatic-manual/access-online

Woynarovich A, Hoitsy G, Moth-Poulsen T. Small-scale rainbow trout farming. 2011. FAO fisheries and aquaculture technical paper; (561):I.