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Response of Different Fish Species to Highly Saline Water under Desert Climate Condition – Finding Options for Local Food Security

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Fresh water shortage is indeed a global issue that affects many areas of the world, including desert regions like the Thar Desert of Pakistan. Recurring droughts have badly affected the marginal communities of these areas. The desert has wide spread lenses of saline groundwater. There is a pressing need for exploring ways to use saline groundwater and identifying alternative sources of livelihood under the prevailing conditions. Therefore, a research study on saline aquaculture was conducted. Twenty fish fingerlings (40-50 g) of the varieties namely rahu labeo (locally kurh'rho), silver carp, mrigal carp (morakhi) and grass carp were stocked into the earthen fish pond. Saline

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groundwater having electrical conductivity (EC) between 8.5 - 9.0 dS/m was used to fill the pond. The overall yield of silver carp was the highest (1275 g/fish) followed by grass (1093 g/fish), mrigal carp (965 g/fish) and rahu labeo (610 g/fish). However, meal yield of grass variety was the highest followed by mrigal carp, silver and lowest of rahu labeo. Silver carp varieties had 330 g/fish of egg in their bodies. Hence, for the massive fingerling development, silver carp is recommended for saline aquaculture. However, for meal production and high economic return, grass carp should be selected for saline aqua-culturing.

Keywords: Thar desert; saline water; aquaculture; rahu labeo; carp.

1. INTRODUCTION

Thar is the largest desert of Pakistan. It is located in Tharparkar district, which is Southeastern district of Sindh Province. It is the densest Desert of the world with the population density of 91.1 person/ km^2 [1]. Livestock is the primary source of earning and food followed by rain-fed agriculture during summer season. Agriculture is wholly dependent on the rainfall as the primary source of water for crops. The region receives very little rainfall and most of the time it is of very erratic nature. The rainy season prevails between early June to mid of July. Any rainfall deficit during the rainy months severely impacts the socio-economy of the region [2]. Due to arid climate, it is vulnerable to frequent droughts, which have led to widespread water scarcity, food insecurity, and livestock losses. According to various reports, it has been officially declared a drought calamity area at least 15 times since 1968, with the most recent declarations made in 2013, 2014, and 2018 [3].

Global warming, climate change and rapid growing population have put tremendous pressure on the available resources for food production. In 2017, the population of the area was estimated as 1.647 million, which has been increasing at an annual growth rate of 1.80% and currently expected to be 1.80 million. Recurring drought has badly affected the peasant communities of these areas. As a result, many people are forced to migrate to urban areas and near metropolitan cities in search of work and better livelihood opportunities. In most parts of the desert, groundwater is saline to highly saline (≥ 2.5 dS/m). Therefore, there is a pressing need for exploring ways to use saline groundwater and identifying alternate livelihood options, which can be farmed with such water. This requires a scientific study to investigate the technical viability of saline fish farming under prevailing land, water and climatic conditions. Thar Desert has wide spread lenses of saline groundwater, which can be utilized for saline fish farming [4].

Aquaculture is a relatively new concept in Pakistan; however, it has great potential for development and growth. Aquaculture involves the farming of fish, shrimp, and other aquatic species in controlled environments, such as ponds, tanks, and cages [5,6]. Saline aquaculture is one of the profitable options for income generation by utilization of saline groundwater [7]. It has been identified as an alternative livelihood source for many rural farming households living in areas with brackish groundwater. However, there is still limited research and understanding of the constraints and development opportunities for small-holder saline aquaculture farmers in marginalized saline areas, particularly Desert area of Pakistan [6,8].

Apart from marine fisheries, inland fisheries (rivers, ponds, etc.) are also important sources of cheaper animal protein with high biological value (96%) and protein efficiency ratio (3.55) [9]. In Pakistan, the annual consumption of fish is very low i.e. 1.7 kg per capita. Only 26% of total production of fish is consumed domestically, 19% is exported and 55% used for fishmeal [10]. The fisheries sector as a whole contributes to about 1% to the country's gross domestic product (GDP) and provides jobs for about 1% of the country's labour force [11]. It is necessary to utilize all the available resources to develop fish industry through simple saline aquaculture practice. Among the new trends in fish culture, integrated semi-intensive system is more acceptable because, livestock dung can be utilized as a cost-effective source of fish feed [12]. Tharparkar has huge resources of the livestock - the census 2006 indicates 5 million populations of livestock's. Hence, there is abundance of animal dung available locally in the desert.

Mrigal carp (*Cirrhinus cirrhosus*) locally called as *Morakhi* is one of the most important commercial carps in Sindh, Pakistan [13,14]. It has high salinity tolerance even at 13.86 dS/m, mrigal carp show no mortality [15,16]. Silver carp (*Hypophthalmichthys Molitrix*) also has high tolerance against the salinity as can tolerate salinities up to 20.13 dS/m [17,18]. Rahu labeo (*Labeo rohita*) commonly known as *Kurh'rho* in the Sindh province is much liked in the food fish. It is rich in vitamin A, B and C. It is also rich in vitamin D, a vitamin which is richest in only a few fish species [19,20]. It can tolerate salinity up to 17.02 dS/m in inland saline water, but it is expected to perform well in salinities ≤ 10.61 dS/m [21]. Grass carp (*Ctenopharyngodon Idella*) could survive at the salinity level of ≤13.86 dS/m, however, it show good adaptability to low salinity equivalent to 4 dS/m [22]. It is good tolerant of the high temperature and spawn at 20°C to 30°C temperature [23].

These fish species has high salt tolerance limit and good market value. Hence, could eliminate the food insecurity in the Thar Desert. The aqua farming of these fishes could also play significant role to improve the socio-economic status of the region. However, these have not been farmed in the region with saline water. There is a need to examine the fish growth rate, net production, economics and problems of saline aquaculture to convince and educate the farmers for the promoting their interest in saline aquaculture. Therefore, this study has been designed to investigate the potential of different fish species using highly saline water under the prevailing climatic conditions of Thar Desert, Sindh, Pakistan.

2. MATERIALS AND METHODS

2.1 Experimental Site and Weather Conditions

The experiment on saline aquaculture was carried out at Research and Demonstration Center of Pakistan Council of Research in Water Resources (PCRWR) located at Mithi, Tharparkar. The study area is located at Chilhar – Mithi bypass road, 12 km away from the Mithi city. It lies on 24°49.522' N latitude and 69°49.635' E longitude. Fig. 1 shows the location map of study area. The annual maximum temperature varies from 34.7 °C to 36.9 °C with an average value of 35.5 °C. Months of the May and June are the hottest months of the year, with temperatures rising upto 48 °C. Annual minimum temperature varies from 17.5 °C to 19.9 °C with an average value of 18.6 °C. December and January are the coldest months of the year, with fall of temperatures upto 1 °C. Mean annual rainfall in the Thar Desert is 376 mm, with a maximum in August. The rainy season commences in early June to mid-July. Wind speed varies from 4.8 knot/hr to 7.3 knot/hr. May, June and July is the high wind speed months (9.5 knot/hr to 10.3 knot/hr). Dust storm and dust raising winds are common in these months.

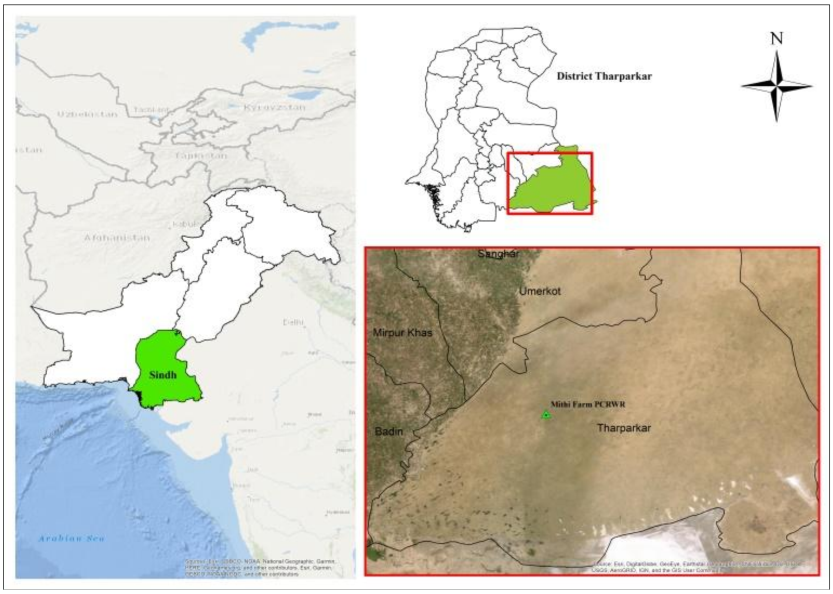

Fig. 1. Location map of the study area

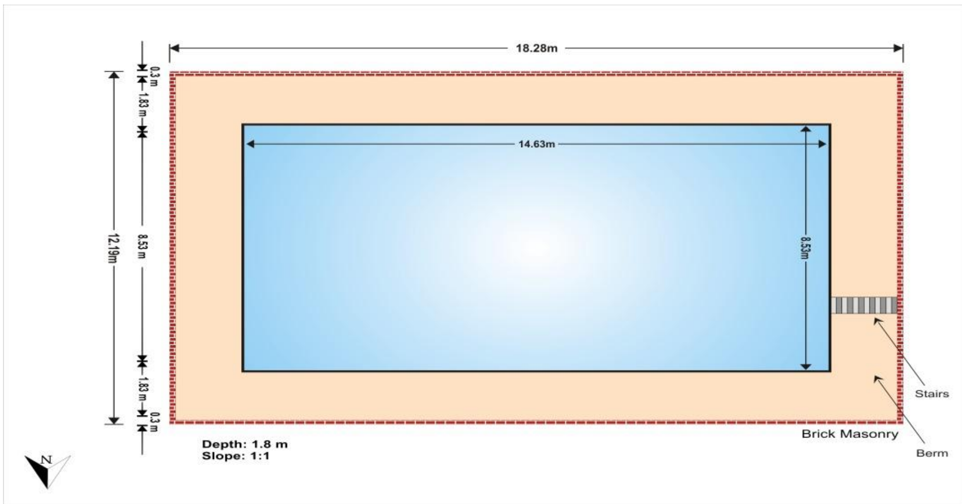

Fig. 2. Schematic diagram of fish pond

2.2 Construction of Pond

An ideal site was selected near to the tubewell water source. An excavator machine was used to excavate the land upto 3.05 m by depth, 24.38 m by length and 18.28 m by width. The side slope was maintained at 1:1. After necessary excavation work, pond dimension was set having Length = 18.28 m, Width = 12.19 m and Depth = 1.82 m. Hence, an area of 223 m^2 (18.28 m × 12.19 m) was occupied by the pond. Plastic sheet was first spread on the inner side of the ponds to avoid the massive seepage of water from the pond. Thereafter, bricks of the size 22.9 cm × 15.2 cm were laid upon the plastic sheet which was spread on the inner side of the ponds. Paste of the sludge made up of clayey soil was then applied about 2.54 cm thick over the bricks.

The Desert falls in arid and hot climatic zone, where evaporation losses are dominant. Thus to minimize evaporation losses, the green net was provided over the pond supported with the iron stand. Pond was provided with the pipeline network attached with the solar powered tube well. A flow meter was installed with the pipeline at 2 m distance from the pond. Fig. 2 shows the schematic diagram of the pond.

2.3 Water Feeding Arrangement

A deep tube well has been installed to a depth of 131 m. However, submersible pump and motor alongwith abstraction pipe is laid at 70 m, whereas groundwater table in the area lies at 58 m. The highly saline groundwater having salt concentration of 8.5 – 9.0 dS/m was pumped to cater water requirements of the farm. However, a major portion of this water was also been provided to the community for livestock drinking purpose. This well was used as source of water for maintain water level inside fish pond having 1.82 m depth. However, pond was filled upto 1.52 m and 0.30 m depth was left as free board. Annual evapotranspiration in this region varies between 2,500 mm to 2,800 mm. Any water deficit in the pond due to the high evapotranspiration was compensated by refilling the pond to its previous level (1.52 m). The daily water application to the pond was measured through a flow meter installed with the pipe about 2 m away from the pond.

2.4 Selection of Fish Varieties and Feeding

Four varieties of fish fingerlings mrigal carp locally called morakhi, silver carp, grass carp and rahu labeo locally called kurh’rho were selected for the study. The selection criteria were fishes should have high salinity tolerance, high consumption compared to other fishes and good market value [7]. Twenty fish fingerlings of these varieties each of having 40-50 g weight was experimented in the pond during April 2021. However, twelve were survived and remaining left breath. This may be due to the fact that fingerlings brought from farmer pond were raised in good quality water. The shifting and stocking of fingerlings (raised in good quality water) in highly saline water led to mortality. Similar results were found by Hoque et al. [16]. In case of Catla, mortality started at salinity above 8.96 dS/m, and reached to 100% at salinity level of 13.86 dS/m. Jayanti rohu showed no mortality up to 10.61

dS/m salinity, though the survivability got reduced to 40% in salinity of 13.86 dS/m. In case of Mrigal, no mortality was recorded at salinity level up to 13.86 dS/m to 30 days post experiment. The farm yard manure and dry meal was applied in the pond to feed the fish fingerlings. About 6,000 kg/ha of farm yard manure and 1793 kg/ha of dry meal was applied [9]. Feeding was done on fortnightly basis. The cumulative per month application of feeds such as farm yard manure was 7.4 kg/month and dry meal 2.25 kg/month. The fish was then harvested in September, 2022.

2.5 Economic Analysis

The cost incurred, gross income and net return was estimated. These were further used to calculate Benefit-cost ratio (BCR) to analyze economically the performance of fish species. BCR is the ratio of gross income to the total production cost. BCR is an assessment that how much money could be earned by spending a single rupee.

3. RESULTS AND DISCUSSION

In this study, different fish species has been used to produce marketable sized fish. However, there are many factors that affect productivity and cost of fish production. Water quality, stocking rate and the quality and quantity of food are most important factors that influence fish growth rate and production [8]. This study provides a base line for the profitable use of saline groundwater for aqua-farming. The data regarding the yield and yield traits, water measurement, economic analysis and lesson learnt are given in the subsequent sections.

3.1 Yield and Yield Traits

By weight, overall performance of silver carp (*Hypophthalmichthys Molitrix*) fish variety was better as it produced high yield (1275 g/fish) followed by grass carp (*Ctenopharyngodon Idella*) (1093 g/fish), mrigal carp (*Cirrhinus cirrhosus*) (965 g/fish) and rahu labeo (*Labeo rohita*) (610 g/fish). This indicates that pond water salinity coupled with the arid weather condition was a key factor in controlling growth of the rahu labeo that showed poor performance in high saline water. The regression analysis showed a significant difference (R^2 = 0.2739) in single fish yield among different fish species (Fig. 3).

The silver carp had 330 g/fish of egg in their body. Hence, the meal weight of grass carp was maximum (1093 g/fish), followed by mrigal carp (965 g/fish), silver carp (945 g/fish) and lowest of rahu labeo (610 g/fish). Egg production trait was not seen in other varieties. This indicates silver carp was much tolerant to saline water coupled with the arid weather condition and could produces massive numbers of fingerlings. The findings also highlights that quality of ponded water coupling with the arid weather condition was a key factor towards production of the eggs particularly for rahu labeo, mrigal carp and grass carp species. The regression analysis shows a significant difference (R^2 = 0.8459) in single fish meal weight of different fish species (Fig. 4).

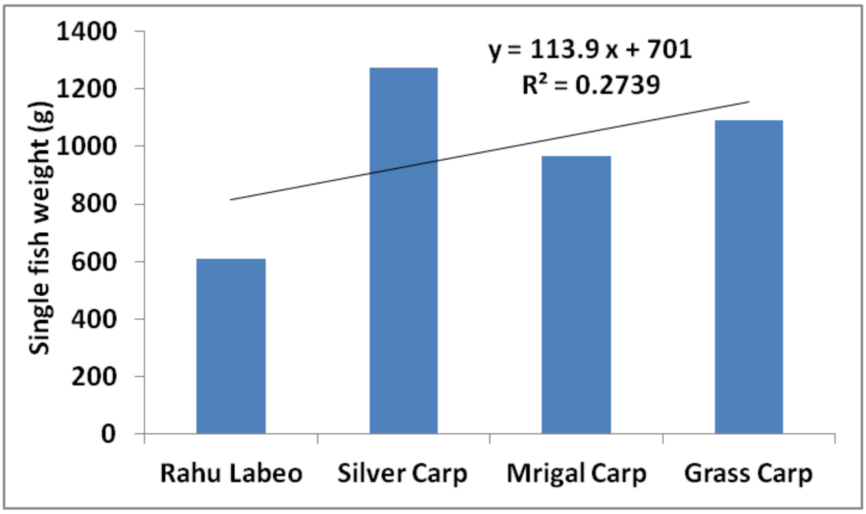

Fig. 3. Single fish weight of different fish species

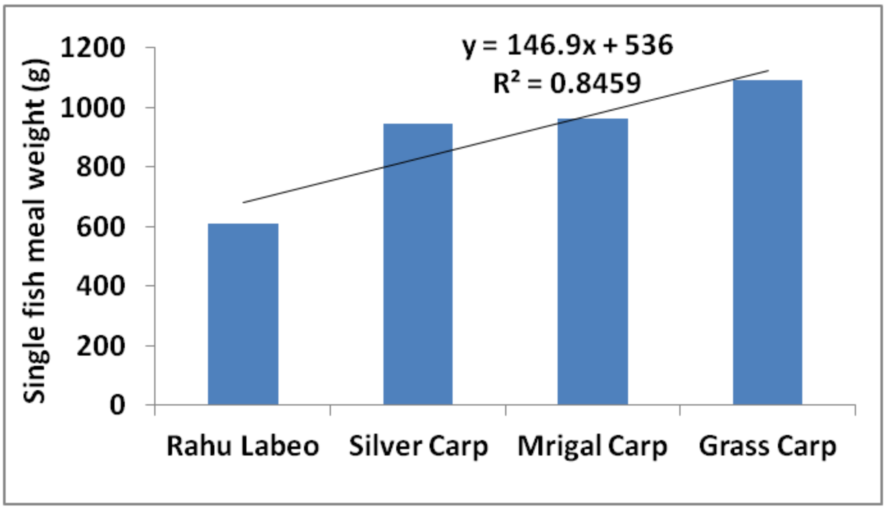

Fig. 4. Single fish meal weight of different fish species

Table 1. Yield and yield trait data of different fish

Parameters	**Fish varieties**			
	Rahu labeo	**Silver carp**	**Mrigal carp**	**Grass carp**
Total number of fish	01	02	06	03
Single fish weight (g)	610	1275	965	1093
Egg weight (g)	-	330	-	-
Fish meal weight (g)	610	945	965	1093
Fish yield (kg/ha)	1525	2363	2413	2733
Fish length (cm)	38	47	42	48
Fish girth (cm)	13	28	21	25
Water used	923094 US Gallon (3494 m^3)			

Grass carp attained highest length. The length of grass carp was 48 cm followed by 47 cm of silver carp, 42 cm of mrigal carp and shortest of rahu labeo was 38 cm. However, girth was maximum of the silver carp (28 cm) followed by grass carp (25 cm), mrigal carp (25 cm) and rahu labeo (13 cm). This implies girth is the most important aspect affecting the yield. Although, the silver carp fish had comparatively short length, however, it produced highest yield mainly because had highest girth.

3.2 Water Measurement Data

Although, polythene sheet was provided on the inner side of the ponds to avoid the massive seepage of water from the pond followed by earthen bricks soiling and paste of the sludge. However, saline groundwater coupled with high temperature led to erode the pond structure and a massive amount of water was been deep percolated. Difficultly, about 0.60 m water depth was maintained in the pond by providing water on the daily basis. Since April 2021 to September 2022, 3494 m^3 of water was applied. Hence, it is a lesson learnt that while adopting the saline aquaculture in the Thar Desert, brick lined pond should be developed. Another option is the sludge of sodium bentonite clay made up of 50% sodium bentonite, 25% soil (sandy loam) and 25% chopped wheat straw should be applied about 2.54 cm thick over the bricks [24].

3.3 Economic Analysis

A proper saline aqua-culture practice produces a number of different kinds of fish species. Hence, stocking different kinds of fish will efficiently utilize the space as well as food material inside the pond. Throughout the world, several stocking rates were adopted. However, combination of four to five or more than five species of carps particularly labeo rohita was cultivated with stocking rate of 2500/ha with water storage depth of 1.82 m to 2.13 m [9]. Hence, a pond of 18.28 m in length and 12.19 m in width will have stocking capacity of 56 fish.

The economic analysis involves the total production cost, gross income and net return of different fish species (Table 2). The total expenditure incurred on saline aquaculture for all of the four varieties was Rs. 2,82,930/ha (1 US$ = 235.88 PKR on September 15, 2022). After harvesting, the fish were sold @ Rs. 300/kg. This led to income generation of Rs. 4,57,500/ha for rahu labeo, Rs. 7,08,900/ha for silver carp, Rs. 7,23,900/ha for mrigal carp and Rs. 8,19,900/ha for grass carp. The net income found for rahu labeo is Rs. 1,74,570/ha, Rs. 4,25,970/ha for silver carp, Rs. 4,40,970/ha for mrigal carp and Rs. 5,36,970/ha for grass carp. Net income of the grass carp is 18%, 21% and 67% higher than the mrigal carp, silver carp and rahu labeo, respectively.

Benefit-cost ratio (BCR) is an assessment that how much money could be earned by spending a single rupee. The BCR was also the highest in case of grass carp (2.90) followed by mrigal carp (2.56), silver carp (2.51) and rahu labeo (1.62). Hence, the most economic viable fish species for stocking in saline water and arid weather conditions is the grass carp. The regression analysis shows significant difference (R^2 = 0.8444) in BCR (Fig. 5).

Table 2. Economic analysis of different fish species

Parameters	**Fish varieties**							
	Rahu labeo		**Silver carp**		**Mrigal carp**		**Grass carp**	
	Rs./fish	**Rs./ha**	**Rs./fish**	**Rs./ha**	**Rs./fish**	**Rs./ha**	**Rs./fish**	**Rs./ha**
Generated income								
Gross income	183	4,57,500	284	7,08,900	290	7,23,900	328	8,19,900
Incurred expenditure								
Capital cost (pond construction): Rs. 4,35,000								
Fish seedlings	100	250000	100	250000	100	250000	100	250000
Farm yard manure	6	15000	6	15000	6	15000	6	15000
Dry meal	7	17930	7	17930	7	17930	7	17930
Total production cost	113	282930	113	282930	113	282930	113	282930
Net income	70	1,74,570	171	4,25,970	177	4,40,970	215	5,36,970
BCR (benefit-cost ratio)	1.62		2.51		2.56		2.90	

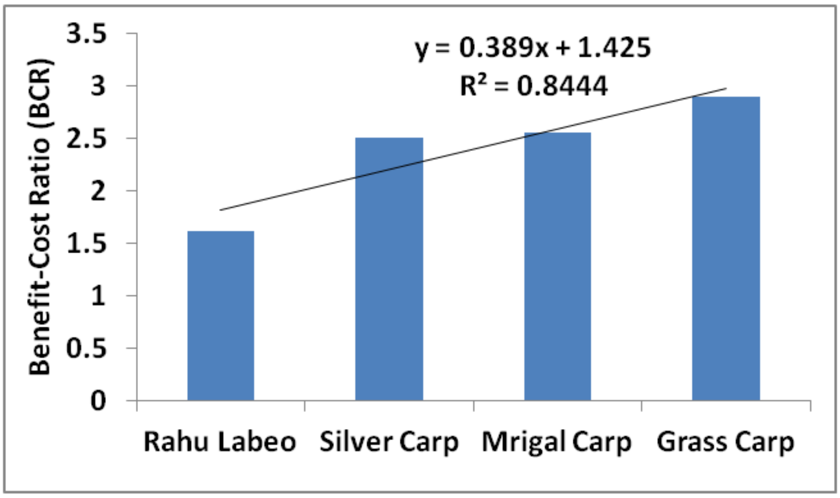

Fig. 5. Benefit-cost ratio of different fish species

3.4 Lesson Learned

The major constraints faced during the study period were the impact of high wind speed and saline soil water erosion. The area falls in arid and hot climatic zone, where evaporation losses are significant. Thus to minimize evaporation losses, the green net was provided over the pond supported with the iron stand. However, high wind speed during April, 2021 led to crash down green net along with the stand structure. Hence, while managing the pond in such areas, green net should not be installed over the pond as this will not contribute rather is a loss of the money. However, to avoid impact of hot climate on fish and evaporation loss, iron shed may be a good option that may be provided over the pond supported with the polls. Raising a wind barrier of Damas trees (Conocarpus lancifolius) with proper plant spacing can also minimize the wind impacts [25].

Plastic sheet was spread on the inner side of the ponds to avoid the massive seepage of water from the pond. Thereafter, earthen bricks of the size 22.9 cm × 15.2 cm were laid upon the plastic sheet which was spread on the inner side of the ponds. Paste of the sludge made up of clayey soil was then applied about 2.54 cm thick over the bricks. However, ponding of the highly saline water coupled with high temperature led to erode the pond structure and a massive amount of water was been deep percolated. Consequently, 0.60 m water ponding was maintained by providing water on the daily basis. Hence, lined pond should be developed rather than an earthen pond. Another option is the sludge of sodium bentonite clay made up of 50% sodium bentonite, 25% soil (sandy loam) and 25% chopped wheat straw should be applied about 2.54 cm thick over the bricks [24].

4. CONCLUSIONS

Highly saline water could be used successfully for saline aquaculture in the arid environment of the Thar Desert. All fish species stocked can comfortably live in 8.5 - 9.0 dS/m salinity waters. However, to get highest yield along with better egg production, silver carp is a good choice. It has good potential to produce the eggs and fingerlings. This variety has high tolerance against the high salt water and hot weather environment. Hence, for the massive fingerling development, silver carp is recommended for saline aquaculture. For the meal production and high economic return, grass carp may be selected for saline aqua-culturing.

There exists tremendous scope for further expansion of different fish species in highly saline water in the desert environment by managing levels of inputs and monitoring water quality. Consequently, this will give more yield and better returns. The study also identified several problems and constraints of saline fish culture which may be helpful in future for the fish farmers, policy makers and extension staff.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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