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Incentives and barriers of integrated roof top farming (IRF) in Dhaka City, Bangladesh

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ABSTRACT

Unprecedented economic growth and burgeoning population have triggered massive vertical and horizontal expansion of cities across the world in recent decades. Integrated rooftop garden (IRF) in high-density cities is an urban agricultural practice that ensures alternative and efficient use of space and offers a great deal of social, economic, health, and environmental benefits. Dhaka is a rapidly expanding city, and a large scale IRF practices can be implemented due to the nature and availability of the rooftop space. Given the context, this research aims to analyze the potential incentives and barriers to adopting IRF in Dhaka city. IRF is a unique farming method where fish, vegetables, and fruits can be grown on the rooftop in a planned way and on a small scale without affecting buildings' structure. Hence, the research adopted two approaches: a small experiment on rooftop fish farming to estimate the economic value and a survey on public perception regarding IRF in Dhaka city. A small-scale biofloc based rooftop fish farming system was implemented on a rooftop of a building in Dhaka, where 200 climbing perch fishes were grown. Besides, a public perception survey regarding the incentives and barriers to implementing IRF was conducted online, and 150 responses were recorded. Water quality and fish growth were measured regularly. Survey data was analyzed using SPSS, and the relative importance index method was employed to interpret results. The results indicate that fish mortality in such a system was very low (less than 7%), and considering the return on investment, IRF is a feasible option. Survey data analysis suggests that access to the respondents' rooftop is strongly associated ($p<0.05$) with house ownership type. The relative importance index of benefits reveals that IRF has microclimatic benefits like reduced temperature, increased air quality, and increased aesthetics. As identified, the critical challenges to IRF are lack of houseowners' interest, additional maintenance cost, and lack of social networking. The research addresses the need for advocacy initiatives to encourage IRF practices among residents to formalize urban agriculture concepts.

Key words : *Integrated rooftop farming, Urban green space,Dhaka.*

Introduction

Unprecedented urbanization and burgeoning population have put the world's cities at the epicenter of significant problems, including food security and global warming. According to several projections, the urban population will nearly double in size between 2010 and 2050, resulting in an overwhelming demand for resources, including necessary food supplies (Swilling *et al.,* 2018). In Bangladesh, the urban population is increasing at an annual rate of 3.33% over the last few years, and it is projected that

50% of the population will live in urban areas by 2047 (United Nations, 2019). Cities occupy only 3% of the earth's surface, but they consume up to 70% of all the food produced in the world (Food and Agriculture Organization, 2019). Urban food consumption is also accountable for a significant portion of the global greenhouse gas emissions contributing to global warming (Pang *et al.,* 2019). Urban areas often manifest issues like undernutrition, micronutrient deficiencies, obesity, and diet-related health diseases because they consume easily accessible and available processed foods with low nutritional values (Khor, 2002). It is widely argued that the urban population across the world will increasingly face the food security problem. Hence, there has been a growing demand for spatial restructuring of urban areas by promoting resource-efficient buildings and behavioral change. Integrated rooftop farming in high-density urban areas can be a potential solution to food security and global warming (Yang, *et al*., 2008). Integrated rooftop farming can mitigate the urban heat island effects and bring locally produced fresh food to the consumers by reducing food miles (Severson, 2006; Wong and Yu, 2005). It is estimated in a study that rooftop farming in Singapore can meet 35% of the daily needs of vegetables and reduce Singapore's carbon emission by 9052 tons annually (Safayet *et al*., 2017).

Dhaka, one of the oldest cities in South Asia, has continued to urbanize and is now the primary city of Bangladesh. In recent decades, the rate of urbanization in Dhaka has become rapid, and the city authority has embraced massive outward expansion by converting agricultural lands to cater to the growing needs (Ahmed and Bramley, 2015). Given this situation, urban agriculture in Dhaka can ensure fresh food, a better diet, and a more sustainable environment. Dhaka city's rooftops are usually flat and suitable for integrated rooftop farming (Chowdhury, *et al.,* 2020). According to a study by an organization called Green Savers, out of 1,800,000 Katha of roof space in Dhaka, 810,000 Katha is usable for IRF (Amin, 2019). It is important to note that most of Dhaka's rooftops are made from reinforced concrete coarse and suitable for integrated rooftop farming (Hossain, *et al*., 2019). With little or no interventions, the existing rooftop space in Dhaka can quickly be brought under IRF by which 10% of the city's current vegetable demand can be met. Integrated rooftop farming (IRF) can be soil-based or hydroponic, and it can include vegetables, high-density fish farming, and poultry (Thomaier, *et al*., 2014).

A plethora of research has been done on rooftop farming systems in different countries of the world. However, the potential benefits and challenges of a small-scale integrated farming system in the context of Dhaka city have not been explored. Therefore, this research is an effort to analyze incentives and barriers to adopting IRF (vegetables and fish) in Dhaka city. This research's primary objective is to explore the economic and social benefits of a small scale IRF. The study also intends to look at the inherent challenges of such farming in the context of Dhaka.

Materials and Methods

This research adopted two approaches to achieve its objectives: a small experiment on biofloc based small-scale rooftop fish farming to identify incentives and operational challenges, and a survey on public perception regarding IRF in Dhaka city.

Experiment: Design and Monitoring

The research started with a tarpaulin tank with500 liters of water set up on a five-storied building rooftop in Dhaka. The growth and survival of 200 pieces of climbing perch fishes in the tank were observed for 120 days. While setting up the tank, a slope was made at the bottom toward the center of the tank to accumulate sludge and water discharge. The tarpaulin was safely placed in rectangular concrete dice and cleaned thoroughly with soap water, and then filled with tap water. A 15-watt air pump was installed with three outlets of air diffusers into the Biofloc tank to ensure proper oxygen supply and the agitation of water is maintained. For this fish farming, the biofloc method was adopted where heterotrophic bacterial growth was stimulated by adding carbohydrates and the absorption of nitrogen by developing microbial proteins (Crab *et al.,* 2012). This encouraged the absorption of nitrogen by bacterial growth decreases the concentration of ammonium faster than nitrification. 50 mL of activated probiotic water was poured into the Biofloc system the day before the fishes were released into the tank after disinfection. Maintaining carbon to nitrogen ratio favors the heterotrophic bacteria to reduce ammonia level and determine total suspended solids (TSS). The optimum carbon to nitrogen ratio for a feed that contains 30 to 35 protein percentages is found to be 10:1 (Hargreaves, 2006). The fishes were fed 5% of their total body weight, at growth stage maintaining 5% standard feeding method for Climbing Perch fish, the fishes were fed in two intervals at 9:00AM and 3:00PM every day, and amount of feed was recorded, a 10:1 C/N ratio was maintained. Water quality monitoring and maintenance is essential to ensure optimal water condition and fish growth. Temperature, pH, SS (Suspended Solids), Total Ammonia Nitrogen (TAN), DO, Nitrate, and feeding schedules were monitored regularly.

Data Collection and Analysis

Sample water from the tank was collected daily to measure pH, temperature, and ammonia levels. Temperature below 13 degrees Celsius is lethal but suitable for cold species fishes, so 28 to 31 degrees Celsius is recommended for tropical fishes. A home-made settling cone was made with a measuring tube of 50 mL attached at the cone's bottom. One liter of water was taken from the tank after ten days, the sample water in the settling cones was left alone for 20 min for the settlement of solids, and the amount was recorded. Ten fishes were randomly caught using a fishnet every ten days and were weighed using a digital electric balance machine to observe and record their growth. The fishes' total weight was taken and divided by 10 to find the average weight of a single fish, which is then multiplied with the number of surviving fishes to get an approximate total fish weight. This entire process was repeated five times, and the mean value was taken. Collected data were then stored in MS Excel and plotted in graphs.

A comprehensive survey was conducted in this research to capture public perception regarding incentives and barriers of integrated rooftop farming. The survey was done online using a Google form due to the current COVID-19 pandemic situation. The form was circulated on various platforms on social media and emailed to acquaintances, and a total of 150 responses were recorded. Regarding the incentives and barriers, the respondents were asked to provide their answers based on a five-degree Likert scale, such as "strongly disagree" to "disagree," "neutral," to "agree," and "strongly agree." Relative Important Index (RII) was used to evaluate the level of agreement or disagreement regarding incentives and barriers to implement IRF using the following Equation.

$$RII = \frac{\sum_1^5 w_i x_i}{\sum_1^5 x_i}$$

In this Equation, *i* = 5, 4, 3, 2, and 1 for strongly agree, agree, somewhat agree, disagree, and strongly

Disagree, W_i is the weight given to the *i*th response and X_i is the frequency of the *i*th response.

Results and Discussion

Water Quality and Fish Growth

The water's pH was initially greater than 7.5, and the graph shows that the pH was getting lower slowly with time (Figure 1). Throughout the study, the highest pH amount of 7.7, and the lowest 6.8 was recorded. For healthy fish growth at the optimum level, the pH should be between 6.5 to 8 (Bhatnagar and Devi, 2013). The total dissolved solids (TDS) of the water gradually increased with time. To increase water density, the TDS of the water was gradually increased by adding sodium chloride (Raw Salt). Maintaining a TDS of 600-700ppt in biofloc tanks helps to keep organic matter suspended. So, the TDS was gradually increased and

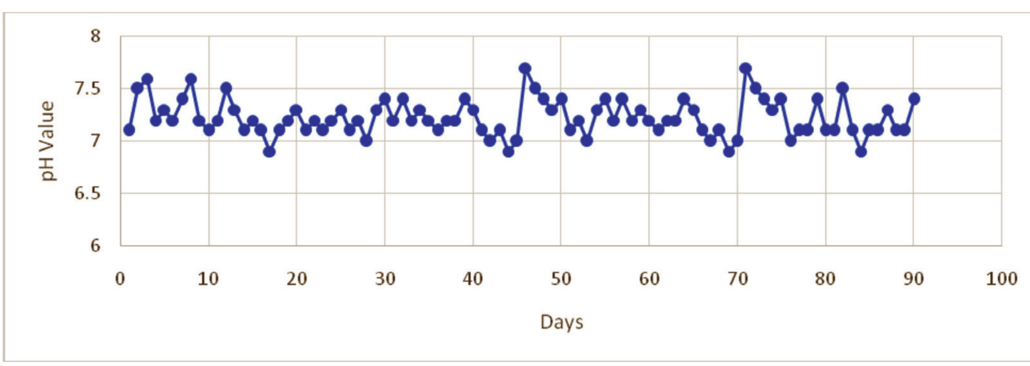

Fig. 1. Day to day changes in pH value

maintained at 700ppt.

A rising trend in the temperature was observed throughout the study, with the highest recorded temperature of 29 °C and the lowest 22 °C. As fish is a cold-blooded species, its body temperature changes as the environment influence its metabolism and physiology and eventually influences development. The temperature of less than 20° C and more than 35 °C is dangerous for fishes' survival and growth in such a system (Bhatnagar and Devi, 2013). From various research, it is identified that the temperature of Dhaka city in February stays close to 20 °C, and there has been an increasing trend since 1995 (Mohiuddin *et al.*, 2014). Considering the temperature condition, the experiment started at the end of February 2020.

The highest amount of Total Ammonia Nitrogen (TAN) 1 mg/L was recorded on day two, and the lowest was 0.25 mg/L. Ammonia is the by-product of protein digestion excreted by fish and organic bacterial decomposition such as waste food, fecal, and dead planktons. At every ten days interval, random ten fishes were caught from the tank and weighed. This process was performed at least five times, and the average weight of 10 fishes was taken and multiplied with the total number of fishes to get the overall fish weight. The fishes' initial total weight was 152 g before rearing in the biofloc tank, and the total final weight measured in 90 days was 9741 g at the end of the experiment. A total of 10 fishes died over 90 days, and hence, the fish survival rate was 93%.

The experimental unit can produce 500 fishes, and with a 93% survival rate, 48kg of fishes can be harvested at once. Considering the amount invested (around 8,000 BDT) and the current market price of climbing perch fish (250 BDT/kg), the return on investment (ROI) stands at 5.81%, making it a good case. In economic analysis, Return on Investment, usually abbreviated as ROI, is a standard, widespread metric used to evaluate the forecasted profitability on different investments (Rajan *et al.*, 2007). Before any large-scale investment opportunities are even considered, ROI is a solid base from which to go forth. The results obtained indicate that small-scale IRF that includes fruits, vegetables, and fish on the urban rooftop is a feasible option. This generates money and provides scope for diversified use of rooftop, and offers nutrition for urban families (Mandel, 2013).

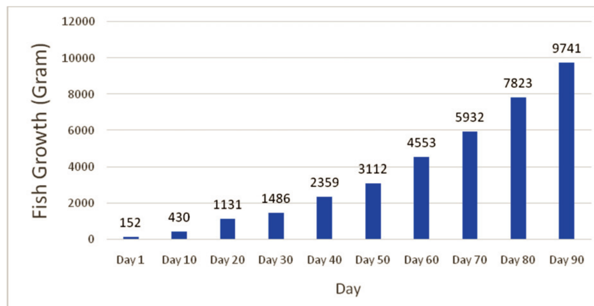

Fig. 3. Fish growth in the rooftop fish farming unit

Benefits and Challenges of IRF Implementation

Discussion about the perception of people about IRF is well-grounded in studies related to urban planning and city design. Public inclinations, likings, intentions, and attitudes are usually reflected in perception studies (Ingold, 2002). Table 1 shows respondents' house ownership types, accessibility to rooftops, rooftop utilization status, and their perception about the feasibility of implementing IRF. Most

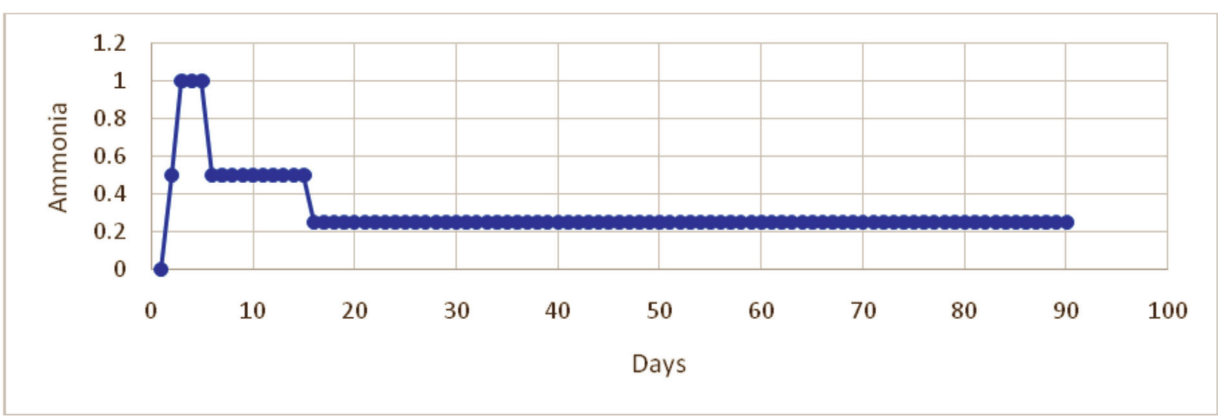

Fig. 2. Day to day ammonia level

of the respondents (86.7%) have access to their rooftops, while only 13.3% did not have access as they were mostly tenants. It was found in a study that less than 5% of the house owners in Dhaka city are willing to share the rooftop with tenants for gardening (Islam, 2002). From the Chi-square test, it is seen that access to the rooftop for the respondents is strongly associated ($p<0.05$) with house ownership type. 37.4% of respondents mentioned that their rooftops were not being utilized for any purposes. Only 28% were using their rooftops for fruits and vegetable farming, and another 16.6% were used for gardening, play area, and solar panels. It is essential to state that 73.3% of respondents believed that the implementation of IRF is feasible on their rooftops. The next part started by collecting information about the respondent's perceptions regarding the benefits of IRF. Respondents were asked about seven benefits of IRF, and based on the responses; benefits were ranked according to relative importance index (RII) values.

Table 1. Basic information from the respondents

Item	No. of responses	Percentage
House ownership type		
Own a building	59	39.3
Own an apartment	42	28.0
Tenant	49	32.7
Access to rooftop		
Yes	130	86.7
No	20	13.3
Rooftop utilization		
No utilization	56	37.4
Fruits & vegetables gardening	42	28.0
Mixed use	40	26.6
Fish farming	3	2.0
Solar panel	3	2.0
Play area	5	3.3
Birds cage	1	0.7
Is the implementation of IRF feasible?		
Yes	110	73.3
No	6	4.0
Maybe	34	22.7

The relative importance index (RII) is a statistical method used widely to ascertain the ranking of different factors contributing to something (Kassem *et al.*, 2020). Five RI levels are estimated from RI values as high (H) ($0.8 \le RI \le 1$), high-medium (H–M) ($0.6 \le RI \le 0.8$), medium (M) ($0.4 \le RI \le 0.6$), medium-low (M-L) ($0.2 \le RI \le 0.4$) and low (L) ($0 \le RI \le 0.2$) (Rooshdi, *et al.*, 2018). The analysis of survey results in Table 2 depicts the RII values, RII rank, and RI levels for the benefits of IRF.

Most of the respondents agreed to the benefits of IRF in Dhaka city. The Cronbach's Alpha value (0.844) exemplifies the internal consistency of the responses regarding the benefits of IRF. Improving air quality was ranked top (RII = 0.840), followed by reducing temperature (RII = 0.817) as the benefits of IRF. Removal of air pollutants by green roofs in Chicago were quantified in research, and the result indicates that 19.8 ha of green roofs in the city removed 1675Kg of air pollutants in one year (Yang, *et al.*, 2008). Among the pollutants that were removed, 52% was O_3, 27% NO_2, 14% PM_{10} and 7%SO_2. In Dhaka, where land is scarce and air quality is low, rooftop gardening in the residential and commercial buildings can supplement air quality improvement initiatives. Due to the rapid expansion of Dhaka city, the urban heat island effect's magnification remains a serious concern (Yasumoto, *et al.*, 2019). Several studies also identified the microclimatic benefits of rooftop gardens in urban areas. An increase in leaf area index resulted in a temperature drop up to 0.4 °C at the pedestrian level and even more at the rooftop level (Berardi, 2016). This indicates the potential of green roofs to mitigate the urban heat island effects in cities like Dhaka. The other benefits that were subsequently ranked are increas-

Table 2. Incentives from IRF according to RII

Benefit	Mean	Std. Deviation	Cronbach's Alpha	RII	Rank	RI Level
Increases aesthetics	2.08	1.084	0.844	0.784	3	H-M
Reduces temperature	1.91	1.029		0.817	2	H
Improves rainwater discharge	2.21	0.879		0.757	4	H-M
Improves air quality	1.80	0.927		0.840	1	H
Improves building's energy efficiency	2.64	1.076		0.672	6	H-M
Adds value to the property	2.50	1.073		0.700	5	H-M
Reduces noise pollution	3.31	0.912		0.539	7	M-L

ing aesthetics (RII = 0.784), improves rainwater discharge (RII = 0.757), and adding value to the property (RII=0.700). Research indicates that the price of a property with green roofs is roughly 15% higher than a conventional property without any greenery (Weso³owska and Laska, 2019). The study also analyzed the adverse effects of IRF. Nearly 70% of respondents rejected that IRF is highly costly and around 65% disagreed that IRF dampens the building.

This study also tried to analyze the survey data on barriers to implementing IRF in a high-density city like Dhaka. Table 3 depicts the challenges of implementing IRF according to the respondents. A reliability test in SPSS (Cronbach's Alpha value=0.870) was carried out to test theresponses' internal consistency. Lack of house owner's interest and lack of knowledge about the benefits of IRF is the top-ranked challenges according to RII values. The absence of formal urban agricultural practices in Dhaka made scientific knowledge available at a minimal scale. Research conducted among food growers in Dhaka city revealed that house/building owners are unwilling to let their tenants use the rooftop for gardening (Momtaz, 2020). The time required for IRF maintenance and lack of skilled workforce are two successively ranked challenges. It is found in the literature that there is minimal scope for learning IRF in Dhaka city (Safayet *et al.*, 2017). However, the number of gardening service providers has increased in recent times, and many of them are providing services using digital platforms (Amin, 2019).

Lack of social cohesion is also identified as a challenge faced by many respondents. Spearman's correlation coefficient between accessibility level to the rooftop and lack of social cohesion as a barrier to implementing IRF is -0.084 with a significance level of 0.309. This indicates that house ownership that defines accessibility to a rooftop has no significant relationship with this barrier to implement IRF. It is argued in the literature that social relations stem from the way space is organized (Tonkiss, 2005). Hence, social cohesion and rooftop gardening are complementary to each other. In scholarly works, it is widely discussed that residents in Dhaka city have a little attitude to create internal networking, primarily through rooftop utilization (Munni, 2010). Some respondents also raised concerns about the additional cost associated with the design and construction of IRF and increased structural load. Similar concerns were also expressed in research on rooftop gardening in other cities (Xiao, *et al.*, 2014). During the experimental stage of this research, a few challenges were also identified. First, Maintaining the water quality parameters is essential for fish growth (Bhatnagar and Devi, 2013) and for the biofloc system to sustain. Water parameters are needed to be checked and maintained at regular intervals. A sudden fluctuation in the water quality can disrupt the whole system and can cause higher fish mortality. Second, commercial fish culture typically takes place outside Dhaka in big ponds. It is challenging to manage a small number of fish seeds for a small system. Dhaka is not a hub for fish culture/farming; hence, the necessary support system such as fish feed availability and medicine is minimal. Third, a constant supply of air and oxygen into the fish farming system is required.

Conclusion

A plethora of research identified that greening the rooftops in high-density city areas offers a host of social, environmental, health, and economic benefits. Integrated rooftop farming (IRF) is a unique

Table 3. Barriers to implementing IRF according to RII

Challenges of IRF Implementation	Mean	Std. Deviation	Cronbach's Alpha	RII	Ranks	RI Level
Lack of knowledge	2.12	0.983	0.870	0.781	2	H-M
Lack of owner/client's interest	2.03	0.944		0.799	1	H-M
Additional design and construction cost	2.50	1.002		0.705	6	H-M
Lack of incentive from the government	2.51	1.110		0.701	7	H-M
Increase in structural loading	2.83	0.999		0.635	9	H-M
Lack of skilled workforce	2.42	0.929		0.718	4	H-M
Increase in maintenance cost	2.53	1.041		0.700	8	H-M
Require regular maintenance	2.21	1.053		0.765	3	H-M
Lack of social cohesion	2.44	1.065		0.716	5	H-M

form of rooftop gardening that ensures a more diverse and planned utilization of rooftop spaces currently underutilized in many cities across the world Dhaka. This research attempted to explore the incentives and challenges of IRF by conducting a rooftop fish farming experiment using the biofloc method at a small scale. It also tried to investigate public perception regarding integrated rooftop farming through an online-based survey using Google forms. According to output from the small-scale experiment, it is evident that biofloc based microsystems for rooftop fish farming are an economically feasible option for cities like Dhaka. The result indicates that a rooftop-based microsystem of fish farming brings a 5.81% return on investment. Besides, it offers organically grown and nutritionally rich food for urban residents without occupying much space. In the public perception survey, respondents agreed that IRF could offer a wide range of benefits. It was found from the survey results that improved air quality, reduced local temperature, increased aesthetic value, improved rainwater discharge, and higher value of the property are some benefits of IRF. A very few respondents also identified some adverse effects of IRF, including increased cost of maintenance and structural change in building structure. Respondents also identified some barriers to implement IRF that include lack of house owner's interest to provide rooftop accessibility, lack of required knowledge, lack of time for maintenance, lack of skilled workforce, and lack of social cohesion. Some other barriers include cost involved in the construction and maintenance of IRF and lack of city administration incentives. This research provided a comprehensive understanding of incentives and barriers to IRF implementation in Dhaka city. The research findings may offer help and guidance for the relevant stakeholders to formalize the rooftop gardening practices in Dhaka. However, further research on encouraging IRF practices among urban residents is essential before addressing relevant policymaking findings.

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