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The economic viability of commercial-scale hydroponics: Nigeria as a case study

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ABSTRACT

The use of hydroponics to cultivate economic crops is an emerging agricultural practice in Nigeria. There is, however, a paucity of information on the economic viability and valuation of the production systems. This study investigated hydroponics' profitability and economic viability under small- and medium-scale production systems. The economic viability of ten hydroponic farms were evaluated using the financial metrics: net present value (NPV), internal rate of return (IRR), benefit-cost ratio (BCR), and sensitivity analysis. Sensitivity analysis based on positive and negative changes in the running cost and gross annual revenue was adopted to measure the robustness of the production method. The positive NPVs of the small-scale farmer (€42,895) and medium-scale farmer (€331,465) at a 15% discount rate show that both production scales are economically viable. The ten-year IRR of both production scales was about 83%. Similarly, the BCR showed that both the small-scale farmers (5.07) and the medium-scale farmers (4.91) are significantly profitable. In the sensitivity analysis, the small-scale farmers were more sensitive to recurrent 5% changes in the running cost at the 13% threshold. On the other hand, medium-scale farmers were less sensitive with a threshold value of 58.4%. Similarly, small-scale farmers are more sensitive to a 15% reduction in the gross annual revenue, with a negative net return of -€956. It is imperative to state that, though starting an investment in hydroponics requires a high initial investment, medium-scale farmers would be less sensitive to changes in the running cost of production in the face of uncertainties.

1. Introduction

Climate change and the covid-19 pandemic are intensifying poverty and food insecurity in sub-Saharan Africa [1]. In Nigeria, where there are several reports of insufficient supply of protein in 13% of infants [2], adequate nutrition remains a major concern. Hence, there are needs for consensus efforts to improve the availability of cheap and readily available healthy food supplies. The traditional field production that supports the production of crops and fodder and assists a range of ecosystem activities has recently been characterized by land degradation [3,4]. Moreover, the increasing Nigerian population, which is expected to reach 230 million by 2050, has continued to reduce the availability of arable lands and water for conventional agriculture [1,5]. Hence, the need to meet

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food demands in the face of limited natural resources means having production techniques that enable higher efficiency in using the available natural resources (land and water) [6]. Therefore, there are increasing efforts to promote innovative and sustainable urban farming systems as a solution to food insecurity.

Hydroponics is the growing of plants in a soilless medium where nutrient solutions containing required nutrients are artificially supplied for plant growth [7]. Hydroponics uses only 5% of the water used in conventional agriculture [8]. Hence, it is considered "self-sustainable" and environmentally friendly [9]. Apart from environmental sustainability, hydroponics cropping of vegetables has been reported to contribute to communities' social and economic development by generating employment and reducing rural-urban migration [10].

The use of hydroponics to cultivate economic crops and vegetables is an emerging agricultural practice in Nigeria [11]. Recent studies have delved into the variability of hydroponics system designs and technologies in Nigeria [12–14,14]. Other studies have focused on integrating hydroponics with other production systems such as aquaculture (e.g., aquaponics), the quality of its output, and the use of different growth substrates [1,15,16]. However, despite the recent developments, some parameters may prevent the commercial adoption of hydroponics in the country. These parameters include high initial investment, high energy expenditure, specific technical knowledge, and knowledge gap in the viability of hydroponics.

Hydroponics has been presumed to have enormous potential in Nigeria [11], but there is a paucity of information on the economic viability and valuation of the food production system in the short and long run. Different regional studies have investigated and established the profitability and viability of different hydroponics systems in Brazil and the United States, among others [17–19]. However, the differences in the economic status and climatic conditions have limited the usability of such information in different regions. Hence, this study sought to investigate hydroponics' profitability, economic viability, and robustness under small- and medium-scale production systems. It is expected that the results of this study will provide a guide and support to hydroponic farming under two common production scales in Nigeria. In addition, it is presumed that this study can encourage hydroponics practices and support legislation and public policies.

2. Methodology

2.1. Research area

The study area was Ogun state, southwest Nigeria. The state comprises twenty local governments (Fig. 1). Most of the inhabitants

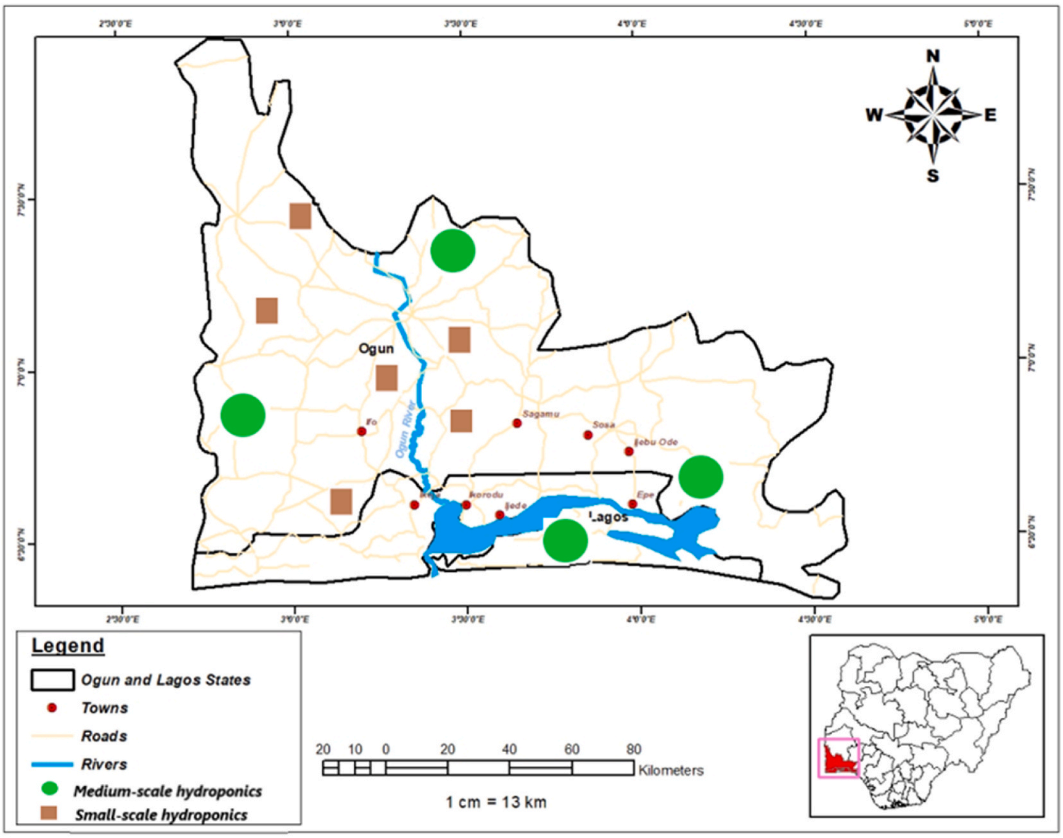

Fig. 1. Map of Ogun state showing the locations of the small and medium-scale hydroponic farms.

(693,100) of the state live in Abeokuta, the capital [20]. The state has a tropical climate with two less distinct seasons, wet and dry. The annual rainfall usually ranges between 1400 mm and 1500 mm, with an average relative humidity of 81% and a temperature of 30 °C [21].

2.2. Data collection

Data from ten hydroponics farms of different sizes and investment levels were used. The cost data are actual data collected from the interview. In order to exclude hobbyists and hydroponic enthusiasts from the data collection, the list comprised hydroponics entities that possessed farm with a minimum area of 100 m^2, and have been in operation for at least three consecutive years. In addition, from the total of nineteen farms that were contacted, only ten that were voluntarily willing to be participate were interviewed. Also, only CEOs or managers who have been in charge of the operations of the farm for at least two years were interviewed. The data were collected via personal interviews and online surveys between September and November 2021. The data collected include capital investments, production costs, selling prices, production, and infrastructure. The operating cost used in this study were running costs incurred under one year of operation. Other questions reflected in the survey also included general information such as farm size, type of culture/cultivation systems, sales per year, and cost details such as electricity and water supply, nutrients, transportation, staff, cooperatives, and investment cost. There was a variation in the data; hence, the data were further categorized into two categories (small-scale and medium-scale) based on literature using the parameters listed in Table 1. Six of the ten hydroponics farms were considered small-scales, while the rest were considered medium-scales based on these criteria. These criteria were primarily supported by studies [18,22].

The small-scale farms, which were majorly located within the city axis, operated with media bed and Kratky methods. On the other hand, medium-scale farms were situated around the city outskirts and mainly used nutrient film techniques (NFT) and deep-water culture (DWC) systems. The small-scale farmers relied primarily on the national electricity grid, which is mainly unstable [23]. In contrast, medium-scale farmers carried out their operations using power generators, while the national grid's electricity was used sparingly. Further information on the production scales is presented in Table 1 in the supplementary material.

2.3. Sensitivity analysis

The sensitivity analysis conducted in this study measures the robustness of small- and medium-scale hydroponics businesses in Nigeria. This was performed using [24] approach. We created two scenarios; changes in the running cost ('income as usual'), and changes in the revenue ('cost as usual') which were to account for variations in the costs of inputs and market prices of hydroponics goods respectively. For the 'income as usual' scenario, we varied the running costs from a positive 35% increase in the running cost to a negative 35% decrease in the running cost. An interval of 5% variation upwards and downwards till the net return became negative envisaged the robustness of the business. An analogous analysis was conducted under the 'cost as usual' scenario, wherein revenue values were altered.

2.4. Cost-benefit analysis

We assumed that the annual revenue does not significantly change ('income as usual'), and we conducted economic analysis on production scales by calculating financial indices like internal rate of return (IRR), net present value (NVP), payback period, and benefit-cost ratio (BCR) considering a 15% annual discount rate for ten years. These indices allowed us to investigate the effects of changes in the production inputs on the farmers' cash flow.

2.4.1. Net present value (NPV)

NPV is defined as the value of benefits less the sum of current costs (Equation (1)) [25]. An investment with NPV values above zero indicates a minimum recovery of the capital investment. NPV was calculated from the following formula:

Table 1
Characteristics of the hydroponic systems' small- and medium-production scales. The values of the hydroponic area, number of staff, and yield/year are presented in Mean ± SD. The mean values were generated from the normal distribution averages from each category (small and medium scales). Other qualitative data were collected directly from the interview (in the two categories).

	Small-scale	Medium-scale
Area (approximate)	212 ± 89 m^2	1124 ± 279 m^2
Hydroponics types	MFB, Kratky, and NFT	Dripping, DWC, and NFT systems
Number of staffs	2 ± 0.98	12 ± 4.74
Power source	National electric grid	Power generators and the national electric grid.
Yield (tonnes)	11.5 ± 2.75	73.7 ± 20.85
Destination of products	Local and supermarkets	Supermarkets
Vegetables	Tomatoes, basils, lettuce, and kales	Tomatoes (Prophyta and Padma), bell peppers, cucumbers, lettuce, and basils

Note: DWC, Deep water culture; NFT, Nutrient film technique; and MFB, Media filled bed.

$$NPV = \sum_{t=t_o}^{T} \left(\frac{(B_t - C_t)}{(1+r)^{t-t_o}} \right) \tag{1}$$

Where B_t is total benefits per year, C_t is the total cost per year, T is the number of years (t is 1), t-t_o is the number of years between the present and future cash flow, and r is the discount rate. According to the [26], Nigeria's current discount rate (r) is 11.5%. However, discount rates in the country have been unstable due to recessions, insurgencies, and other economic crises. Hence, discount rates of 5 to 25% were used in this study.

2.4.2. Internal rate of return (IRR)

IRR is the interest rate where the total costs equal the benefits obtained during a certain period of business operation [26]. Hydroponics is considered financially viable when the IRR is equal to, or higher than, the interest rate (15%) that could be received from other financial investments (Equation (2)) [26].

IRR was calculated using the formula

$$\sum_{t=t_o}^{T} \left(\frac{(B_t - C_t)}{(1+IRR)^{t-t_o}} \right) = 0 \tag{2}$$

Where B_t is the benefit at time t, C_t is the cost at period t, T is the evaluated year, and IRR is the internal rate of return.

2.4.3. Benefit-cost ratio (BCR)

The benefit-Cost Ratio (BCR) is the ratio of the present value of revenues to the present value of costs at a given discount rate (Equation (3)) [27]. The ratio of BCR greater than one indicates a feasible project, and lower than one indicates a non-profitable project. The most viable project is the one with the highest BCR ratio. The benefit-cost ratio was calculated with the following formula:

$$BCR = \sum_{t-t_o}^{T} \frac{B_t/(1+r)^{t-t_o}}{C_t/(1+r)^{t-t_o}} \tag{3}$$

Where B_t is total benefits per year, C_t is the total cost per year, T is the number of years (t is 1), t-t_o is the number of years between the present and future cash flow, and r is the discount rate. The discount rate (r) used in this study is 11.5% [28].

3. Results

In the investment cost analysis, the small-scale farmers spent an average of €6.11 per m^2 on land (Table 2). Conversely, the medium-scale farmers were operating on the leased lands, costing €16.5 per m^2.

3.1. Operating cost

The medium-scale farmers spend an average of €324 (€0.003/kg) annually on hydroponics insurance (Table 3), which covers farms against physical losses, extreme weather events, and pest and disease outbreaks [29]. In contrast, the small-scale farmers were not insuring the hydroponic produces. Additionally, the small-scale farms spent more (per unit area) on labour welfare, transport, plant seeds, electricity, and nutrient fertilizers. The small-scale farmers relied entirely on the national electricity grid for electricity supply. On the other hand, the medium-scale farmers have standby generators and the national electricity grid to complement the electricity supply. The cost of electricity for business outlets per KWh is €0.08 [30], indicating that an average small-scale farmer uses about 11, 538 kWh while a medium-scale farmer consumes about 32,388 kWh annually.

Table 2
The average investment costs for small- and medium-scale hydroponic systems. The values are presented in Mean ± SD. The mean values were generated from the normal distribution averages from small-scale (n = 6) and medium-scale (n = 4). The values are cost values incurred by farmers during system constructions. The numbers in the brackets represent cost per unit area (m^2).

Items	Small-scale	Medium-scale
	Cost (€)	Cost (€)
Greenhouse	1,080 ± 408.32 (5.09)[a]	43,182 ± 15067 (38.4)[a]
Grow beds	540 ± 338 (2.55)[a]	4,318 ± 4300 (3.84)[a]
Plumbing	212 ± 19.81 (1)[a]	324 ± 73.21 (0.29)[a]
Water pump	173 ± 41.66 (0.82)[a]	864 ± 293 (0.77)[a]
Farm wears	–	21.6 ± 23.44 (0.02)[a]
Land	1,295 ± 251.79 (6.11)[a]	–
Testing kit	216 ± 21.59 (1.02)[a]	648 ± 205.12 (0.58)[a]
Total	**3,515 (16.6)[a]**	**49,358 (43.9)[a]**

*[a] indicates cost per unit area (m^2).

Table 3
Operational cost in EUR for a small- and medium-scale hydroponic system. The values are presented in Mean ± SD. The mean values were generated from the normal distribution averages from small-scale (n = 6) and medium-scale (n = 4). The values are average operational cost values incurred by farmers in the last 12 months of operation. The numbers in the brackets represent cost per unit area (m^2).

Items	Small-scale	Medium-scale
	Cost (€)	Cost (€)
Electricity	982 ± 355.67 (4.63)[a]	2,591 ± 1070.99 (2.31)[a]
Labour	1,036 ± 334.48 (4.89)[a]	10,364 ± 4282.12 (9.22)[a]
Insurance	–	324 ± 87.26 (0.29)[a]
Nutrient/Fertilizer	1,241 ± 1039.57 (5.85)[a]	3,239 ± 3766.56 (2.88)[a]
Labour welfare	1,090 ± 1007.11 (5.14)[a]	3,886 ± 1244.32 (3.45)[a]
Pest and disease	896 ± 83.44 (4.23)[a]	8,636 + 4537.51 (7.68)[a]
pH buffer	147 ± 48.23 (0.69)[a]	147 ± 122.56 (0.13)[a]
Water	972 ± 297.22 (4.58)[a]	97 ± 220.56 (0.08)[a]
Land rent	–	18,568 ± 6520.39 (16.5)[a]
Fuel	–	5,182 ± 3269.72 (4.6)[a]
Transportation	3,239 ± 1064.48 (15.27)[a]	1,296 ± 774.46 (1.15)[a]
Seed	335 ± 282.45 (1.58)[a]	460 ± 337.03 (0.41)[a]
Total	**9,938 (46.88)[a]**	**54,780 (48.74)[a]**

*[a] indicates cost per unit area (m^2).

Hence, the medium-scale farmers spend about €5,182 (on an annual basis) on petrol and diesel to power the generators. Other variable costs such as labor, nutrient supplements, pest, and disease treatments dominate the operational costs of the two scales' production. The small-scale farmers have approximately two staff working an average of 10 h per day. However, this varies with the type of engagement, which varies during the productive process and depends on the general hydroponics operation (cleaning and maintenance, transplanting and harvesting vegetables). On the other hand, medium-scale farms use up to 12 laborers, working approximately the same hours per day. At both scales, the average labor approximately earns €43 per month.

At this input level, a small-scale farm annually produces approximately 11,500 kg (54.2 kg/m^2) biomass, worth €11,227 (€52/m^2) (Table 4). Medium-scale farmers, on the other hand, given this level of input, annually produce 73,700 kg (65.6 kg/m^2) of vegetables, worth €86,797 (€77.2/m^2).

3.2. Cost-benefit analysis

NPV values were positive in the cost-benefit analysis in both production scales under all the assumed discount rates, 5–20%. The positive NPVs of the small-scale farmer (€42,894.8) and medium-scale farmer (€331,464.9) at a 15% discount rate show that both production scales are economically viable for at least ten years. The ten-year internal rate of return (IRR) of both production scales was about 83% (Table 5). Similarly, the benefit-cost ratio (BCR) showed that small-scale farmers (5.07) are more profitable after ten years compared with the BCR of medium-scale farmers (4.91).

3.3. Sensitivity analysis

Small-scale farmers were more sensitive to the concurrent 5% changes in the running cost with a 13% threshold. Conversely, medium-scale farmers were less sensitive to the concurrent 5% changes in the running cost, with a threshold value of 58.4% (Table 5). Also investigated was the influence of the changes in the prices of the vegetables on the farmers' cashflow (Table 7). With a 10% decrease in the total revenue, both production scales will still have a positive net return. However, small-scale farmers showed more sensitivity at a further 15% decrease in the total revenue resulting from vegetable prices with a negative net return of -€956. On the other hand, medium-scale farmers will still maintain a positive net return even at a further 20% reduction in the total vegetable price.

4. Discussion

Field crop production plays an integral role in food security in the development of Nigeria [31]. However, with 48% of soils

Table 4
Annual revenue for small- and medium-scale hydroponic systems. The net returns, revenues, and yields are Mean ± SD values of small-scale (n=6) and medium-scale (n=4) farmers over a period of 12 months. The numbers in the brackets represent yield/value per unit area (m^2).

Produces	Yield (Kg)	Income: Revenue (€)	Income: Net return (€)
Small-scale	11,500 ± 1801.76 (54.2)[a]	11,227.4 ± 1685.56 (53)[a]	1,289 ± 852.26 (6.1)[a]
Medium-scale	73,700 ± 22,201.87 (65.6)[a]	86,796.6 ± 19305.49 (77)[a]	32,007 ± 27091.5 (28.5)[a]

*[a] indicates yield/value per unit area (m^2).

Table 5
Economic evaluation criteria showing net present values (NPV), internal rate of return (IRR), benefit-cost ratio (BCR), and payback period for the small-scale and medium-scale hydroponics systems for a period of ten years at different discount rates.

Discount rate	Net present values after ten years	
	Small-scale (€)	Medium-scale (€)
5%	73,242	566,073
10%	55,535	429,180
15%	42,895	331,465
20%	33,618	259,745
IRR (%) 10 years	83%	83%
BCR (10 years)	5.07	4.91
Payback period	1.2	1.02

Table 6
Sensitivity analysis showing the effects of varying running costs on the cash flow of the small and medium-scale hydroponics systems.

Parameters	Small-scale				Medium-scale			
	Percentage	Running cost	Total revenue	Net return	Percentage	Running cost	Total revenue	Net return
	−35%	6,460	11,227	4,768	*−35%*	35,613	86,797	51,183
	−30%	6,957	11,227	4,271	*−30%*	38,353	86,797	48,444
Running cost	−25%	7,453	11,227	3,774	*−25%*	41,092	86,797	45,704
	−20%	7,950	11,227	3,277	*−20%*	43,832	86,797	42,965
	−15%	8,447	11,227	2,780	*−15%*	46,571	86,797	40,225
	−10%	8,944	11,227	2,283	*−10%*	49,311	86,797	37,486
	−5%	9,441	11,227	1,786	*−5%*	52,050	86,797	34,746
	Baseline	9,938	11,227	1,289	Baseline	54,790	86,797	32,007
	5%	10,435	11,227	793	*5%*	57,529	86,797	29,267
	10%	10,932	11,227	296	*10%*	60,269	86,797	26,528
Threshold	**13%**	***11,227***	***11,227***	***0.00***				
	15%	11,429	11,227	−201	*15%*	63,008	86,797	23,788
	20%	11,926	11,227	−698	*20%*	65,748	86,797	21,049
	25%	12,423	11,227	−1,195	*25%*	68,487	86,797	18,309
	30%	12,920	11,227	−1,692	*30%*	71,227	86,797	15,569
	35%	13,416	11,227	−2,189	*35%*	73,966	86,797	12,830
Threshold					***58.4%***	***86,796.6***	***86,796.6***	***0.00***
					60%	87,664	86,796	−867

Table 7
Sensitivity analysis showing the effects of the variation vegetable prices on the cashflow of the small and medium-scale farms.

% variation	Small-scale			Medium-scale		
	Revenue (€)	Running cost (€)	Net return (€)	Revenue (€)	Running cost (€)	Net return (€)
−20%	8,982	9,938	−956	69,437	54,790	14,647
−15%	9,543	9,938	−395	73,777	54,790	18,987
−10%	10,105	9,938	167	78,117	54,790	23,327
−5%	10,666	9,938	728	82,457	54,790	27,667
Baseline	11,227	9,938	1,289	86,797	54,790	32,007
5%	11,789	9,938	1,851	91,137	54,790	36,347
10%	12,350	9,938	2,412	95,476	54,790	40,686
15%	12,912	9,938	2,974	99,816	54,790	45,026
20%	13,473	9,938	3,535	104,156	54,790	49,366

reported to have low productivity and soil management issues such as soil erosion, salinization; flooding; and organic matter degradation, promoting hydroponics systems as a sustainable food production system has become a great deal for food security [32]. Hydroponics production of economic crops in Nigeria is an emerging aspect of agriculture. This study investigated the economic viability of hydroponics in Nigeria under small and medium production scales.

4.1. Profitability and economic viability of the production scales

This study investigated the profitability of hydroponics under two production scales, small- and medium-scales. At both production scales, hydroponic systems were found to be largely profitable. Small-scale farmers had a net return of €6.1/m^2, while medium-scale farmers had a net return of €28.5/m^2 annually. Using the data displayed in Tables 4 and it is evident that the revenue-to-yield ratio for small-scale farms (0.97) is comparable to that of medium-scale farms (1.2). However, there is a notable distinction between the net-return-to-yield ratio of small-scale farms (0.11) and that of medium-scale farms (0.43). Furthermore, despite both production scales having a similar operational cost per unit area, medium-scale farms are considerably more profitable. This could be associated with more costs incurred per unit area by the small-scale farms. For example, small-scale farms spent more (per unit area) on labour welfare, transportation, plant seeds, electricity, and nutrients. This result is in line with other studies [17,22]. The authors investigated the economic viability of the hydroponic system in Mato Grosso do Sul (Brazil) as a distinguished approach to treating investment risk [17]. The authors reported an average of $41.5/m^2 in hydroponics of vegetables such as lettuce, winter cress, and kale, among others. In another study [22], authors reported a net return of $22/m^2 in lettuce grown in the DWC hydroponic section of aquaponics. In the U. S., a study [33] also reported $14.2/m^2 and $15.6/m^2 net return on lettuce and basil grown in the NFT section of aquaponics. These two studies reported a significantly lower net return (to the cultivation area), despite relying on wastewater from aquaponics as a source of the nutrient. The discrepancies could be associated with the high cost of regulating power during winter seasons and the high labor cost, contributing significantly to the increased cost of production in the U.S. Similarly, the percentage proportion of labor in the total annual cost of lettuce, basil, and tomato in NFT in the U.S. ranged between 63.8 and 83.8% [33–35].

Though the direct effects of the lack of interest of small-scale farmers in insuring hydroponics produce were not investigated in this study, it could be partly accountable for reduced yield. For example, in the advent of pest and disease outbreaks, a small-scale farmer could lose an entire hydroponics crop without indemnification. Conversely, a medium-scale farmer that insured his produce would have a lower risk.

4.2. Cost-benefit analysis

The positive NPVs of a small-scale farmer (€42,895) and medium-scale farmer (€331,465) at a 15% discount rate show that both production scales are economically viable for at least ten years. According to the principle of NPV, a positive NPV indicates that the hydroponic establishments will have a financial return greater than the initial investment cost. Thus, NPV with values greater than zero shows that the project should be accepted [36]. BCR of both scales was significantly higher than 1. When a BCR of a project is greater than 1, such project is considered feasible; hence, both production scales can be considered to be economically viable by this indicator. Like BCR, the IRR of both production scales was about 83%, confirming the profitability of hydroponics in this region (Table 5). A higher internal rate of return (IRR) indicates a superior investment return rate, without considering external factors. Since the IRR (83%) was higher than the interest rate (15%), which also represent the cost of borrowing, then investing in small and medium-scale hydroponics in Nigeria is profitable was considered cost-effective (Table 6). This result is in line with other studies [17,37]. In a survey analysis of hydroponics farms carried out in Nepal, authors pointed out a quick recovery of invested capital, with a BCR of 2.3, positive net present value (NPV), and an average internal rate of return (IRR) of 27% [37]. [17] researched the economic viability of hydroponic farms in Brazil using financial metrics. The viability was assessed using the following financial metrics; NPV (€16,8504), IRR (31%), and BCR (2.13). Higher BCR and IRR in our study could be attributed to the differences in the economic status and relatively cheap labor. In the present study, the annual labor cost per unit area (m^2) is 4.89 euros for small-scale farms and 9.22 euros for medium-scale farms. According to a hydroponics survey conducted in Brazil, the annual labor cost per unit area (m^2) was estimated at 40.84 USD [17]. In another financial feasibility study of hydroponics conducted in Italy, the labor cost per 5 m^2 area was calculated at 630 euros, indicating a cost of 125 euros per m^2 [24].

4.3. Operating cost

In the analysis of the annual running cost, the cost of transportation had the highest contribution (32.5%) to the annual running cost in small-scale farming. This could partly be associated with the cost incurred on poor motorable roads. Since the small-scale farms are located within the city axis, there is a concurrent cost on repairs of automobiles used to convey farm produce around the city and local markets. Also, it could be associated with the transportation cost of procuring fertilizers from foreign countries. Conversely, the percentage proportion of transportation costs in the total cost of medium-scale farmers was <2.5% (Table 3). This discrepancy could be associated with the fact that all the medium-scale farmers interviewed were situated on the outskirts of the city or at an interlink between two cities. Hence, the cost of automobile repairs may be insignificant due to relatively good highways.

However, the highest percentage contribution of the total operating cost in the medium-scale farm was labor and personnel welfare, amounting to ~35% of the total running cost. While the labor's monthly salary was the same as those offered in small-scale farming, the welfare activities such as meals, clothing, and socialization of medium-scale laborers amount to 15.6% of the cost of production. This result is in line with many studies [24,38,39]. The total running cost of producing lettuce in NFT in Australia was dominated by 42% of the percent proportion cost of labor and labor welfare [38]. Similarly, the running cost of producing Oregano and Rubin in Romania in the NFT section of aquaponics was dominated by 36.1% percentage cost of labor [39]. In contrast, the economic viability of hydroponics operations carried out in Brazil on a 2475 m^2 greenhouse, with fixed investment of $89,654, had a greenhouse structure corresponding to 32.4% countertop material to 24.1% of the total invested [17].

In our study, labor earns an average of €43 per month, which is less than the minimum wage of the country, €64.3. However, it is imperative to state that there is no law binding the compulsory obligation of this minimum wage by the private sector; thus, it is not considered illegal to pay less than the minimum wage [27].

Other significant discrepancies between the production scales are power and insurance. In most parts of the country, this electricity supply is usually distributed between communities, indicating an alternate availability of power supply in different communities [40]. Hence, relying on small-scale farmers' national electric power supply may affect the overall output of small-scale operations. However, small-scale farmers can reduce the risks of their farming activities being affected by power instability by cultivating less sensitive or more adaptive crops that can withstand the variations. Another alternative solution to the irregular power supply could be using grow substrates that can hold substantial moisture for the plant roots during the power outage. For this purpose, lightweight expanded clay aggregate (LECA) could be a better alternative because of the large gaps between the clay balls, allowing for better moisture dispersion around the plant roots for a more extended period. However, LECA may be considered a 'luxury' for small-scale start-ups in the country, but alternatives such as sedimentary rock-like material, which can be found in many parts of the country, could be a close alternative. In an aquaponics study conducted in Nigeria [1], media bed hydroponics operated with locally-sourced materials (such as rock-based grow beds) was ten times more profitable than the conventional-based counterpart.

On the other hand, medium-scale farmers relied on power generators while using national electricity as a backup. Though this could contribute significantly to the increased cost of production, its trade-off could be a rapid growth of hydroponics produces. Also, medium-scale farmers insure hydroponic products using commercial agricultural insurance bonds. This management practice can save farmers from unprecedented risks such as pest and disease attacks, fire outbreaks, and the like.

4.4. Sensitivity analysis

By varying the value of one parameter such as variable costs and revenue, fundamental linear parameter variation and its effect on an annual cash flow can be studied. We created two assumptions: positive and negative changes in the running cost ('income as usual') (1), and progressive and regressive changes in the revenue ('cost as usual') (2). Under our assumption 'income as usual,' where we assumed a steady positive and negative 5% changes in the running costs (Table 6), small-scale farmers were more sensitive to changes in the running cost. This means that during uncertainties such as the pandemic event when productions were halted in the majority of the manufacturing companies, if the cost of production expectedly increases beyond 13%, a small-scale farmer will have a negative net return. Conversely, the medium-scale farmer is less sensitive to changes in the running cost, with a 58.4% threshold. This means that the running cost would have to increase by 58.4% to deny the medium-scale farmer the chance to make a profit. On the other hand, both production scales have a payback period of about one year. Hence, both production scales will be economically safe over the calculated period. This could be associated with the relatively higher cost of investment of the medium-scale farmers, which 'back-'rolls' their revenue in the short run. They are, however, more financially stable in the long run.

In the sensitivity analysis involving the alternation of the farmers' annual gross revenue, small-scale farmers were more sensitive with a negative net return of -€956 at a 15% decrease in the annual gross revenue (Table 7). The findings indicate that small-scale farmers exhibit a slight, albeit insignificant, higher level of sensitivity to fluctuations in gross revenue compared to operational costs. For example, if the market price of a vegetable drops from 2.2 euro to 1.87 euro due to an increased supply (or other factors), a small-scale farmer may experience a negative return if the variable or operating cost remains unchanged. This result identifies the magnitude of the sensitivity of small-scale farmers to changes in revenue. Our result is in line with other studies [22,24]. In an hydroponics feasibility study [24], authors found that the net-return was still positive until an increase of 23% in running costs and a decrease of 19% in total revenue occurred. Though [22] concentrated on assessing the economic viability of aquaponics and did not differentiate the cash flow between the hydroponics unit and the fish section. Nevertheless, the study indicated that a decrease of 11% in revenue and an increase of 15% in operational costs led to a negative return for the farmers. Conversely, medium-scale farmers demonstrated considerably lower sensitivity to fluctuations or alterations on both ends. It is crucial to emphasize that the results of this study were derived from ten farms located in a single state out of the thirty-seven states (including the federal capital territory) in Nigeria. Therefore, these findings may not be a direct representation of the entire country.

4.5. Existing opportunities and challenges of hydroponics in Nigeria

Nigeria's favorable temperature and rainfall patterns assure hydroponic cultivation of several crops all year round. The total annual rainfall is about 2,000 mm in the coastal zone (in the Niger Delta, it averages over 3,550 mm); but ranges from only 500 to 750 mm in the north. The southern regions of the country are more suitable for hydroponics due to the high relative humidity (≥60%) during greater parts of the year, February – to November [41]. Hence, crops can be grown all year round under minimum energy input. However, freshwater scarcity has been severally reported in northern Nigeria [42]. Hence, using the limited available water for hydroponics may have competitive effects on other essential human activities. A sustainable alternative to water scarcity could be integrating hydroponics with existing aquaculture systems (aquaponics). The wastewater from fish can supply the majority of 'plants' essential nutrients, allowing for the fertilization of hydroponic crops with an organic solution instead of using commercial fertilizers originating from depleting natural resources [43]. Though there is no significant commercial aquaponics in Nigeria, it has been presumed to be highly successful in tropical regions due to favorable climatic conditions and cheap labor.

Another challenge limiting optimal hydroponics operations in Nigeria is an unstable electrical power supply. The national electrical grids are known to shed light among communities; power supplies are thus frequently interrupted without any schedule. Hence, since energy is an essential resource, contributing up to 20–30% of the total cost [44], potential farmers would have to prepare self-powering units (e.g., generator plants or solar systems) to run the hydroponics operation. Also, as mentioned above, using adaptable grow systems or substrates that would save humidity over more extended periods could be a cheaper alternative.

5. Conclusion

The hydroponic cultivation of leafy and fruity vegetables in southwest Nigeria shows good economic viability for potential small-scale and medium-scale farmers. The cost-benefit analysis of the production scales shows that the production scales are economically feasible in the short and long term. However, it is imperative to state that, though starting an investment in hydroponics requires a high initial investment, medium-scale farmers are less sensitive to changes in the running cost of production in the face of uncertainties. In addition, the relatively higher sensitivity of the small-scale farmers could result from the lack of insurance for their produces or the effects of the constantly interrupted power supplies. Hence, there are needs to innovate grow systems or substrates that are adapted and efficient to the available resources. Additionally, small-scale farmers could be oriented and fascinated by the benefits of agricultural insurance to reduce their risks of uncertain events.

Author contribution statement

Ewumi Azeez Folorunso: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Zala Schmautz; Radek Gebauer: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Jan Mráz: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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