Development of Aquaponics in Lithuania Through Pilot System Implementation and Key Outcomes

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Annotation

This study presents prototype aquaponics systems implemented on ten Lithuanian farms during 2021–2022. Results show stable fish growth, safe vegetable production, and controlled indoor conditions. Performance is comparable to that of established European systems, highlighting aquaponics as an innovative and sustainable farming approach, while also identifying the key technical challenges that remain.
Keywords: *Aquaponics, sustainable agriculture, fish–plant integration*

Anotacija

Šiame tyrime pristatomos 2021–2022 m. dešimtyje Lietuvos ūkių įdiegtos bandomosios akvaponikos sistemos. Rezultatai rodo stabilų žuvų augimą, saugią daržovių produkciją ir kontroliuojamas vidaus sąlygas. Našumas yra panašus į pripažintų Europos sistemų našumą, o tai parodo, kad akvaponika yra novatoriškas ir tvarus žemės ūkio metodas, tačiau taip pat nurodo pagrindines technines problemas, kurias dar reikia išspręsti.
Raktažodžiai: *akvaponika, tvari žemdirbystė, žuvų ir augalų integracija.*

Introduction

Aquaponics integrates recirculating aquaculture systems (RAS) with hydroponic plant cultivation, creating a closed-loop system in which fish waste is biologically converted into nutrients available for plant uptake. This process enables efficient recycling of nitrogen, phosphorus, potassium, and micronutrients, reduces water consumption, and supports sustainable food production (Goddek et al., 2019; FAO, 2014). Despite its potential, aquaponics faces challenges related to nutrient balance, system stability, species compatibility, and environmental control, which limit wider adoption, particularly in regions with colder climates.

International studies demonstrate that successful aquaponic performance depends on optimal biofiltration, microbial activity, water quality parameters (pH, dissolved oxygen, temperature), and the biological compatibility between fish and plant species (Nozzi et al., 2018; Ibrahim, 2023; Rakocy et al., 2006). Nitrogen transformation processes, driven by nitrifying bacteria, are critical for converting toxic ammonia into plant-available nitrate, while deficiencies in iron, potassium, and calcium often require system-specific management strategies (Lennard & Goddek, 2019; Lenz et al., 2021). European research reports variable fish growth and plant yields depending on stocking density, feeding regimes, and environmental control technologies (Bordignon et al., 2020; Siikavuopio et al., 2019).

Water quality management is most important for system performance. Nitrogen dynamics are particularly critical, as fish excrete ammonia, which is toxic in its un-ionized form (NH_3). Through microbial nitrification, total ammonia nitrogen is converted into nitrate, a less toxic and plant-available form of nitrogen (Hu et al., 2015). Maintaining appropriate levels of ammonia, nitrite, and nitrate is essential to prevent toxicity while ensuring sufficient nutrients for plants. pH regulation represents a key operational compromise. Plants generally prefer slightly acidic conditions (pH 5.0–7.0), nitrifying bacteria perform best at neutral to slightly alkaline pH (7.5–8.0), and fish tolerate a broader range (6.5–9.5). As a result, most aquaponic systems operate at a compromise pH of approximately 6.8–7.0 to support all components simultaneously (Sallenave, 2016). Temperature and dissolved oxygen are also tightly linked and difficult to optimize. Fish, plants, and nitrifying bacteria each have distinct optimal temperature ranges, typically between 10°C and 34°C depending on species. Higher temperatures reduce oxygen solubility, increasing the risk of hypoxia, while low

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temperatures slow metabolic and biological processes. Adequate dissolved oxygen is essential, as fish generally require >5 mg/L and nitrifying bacteria require 4–8 mg/L for efficient ammonia oxidation (Somerville et al., 2014).

Environmental factors such as air temperature, light intensity, humidity, and CO_2 concentration strongly affect plant growth. Excessive heat or light can induce bolting and reduce crop quality, while insufficient light limits productivity. Sensitivity to photosynthetically active radiation varies among plant species, making crop selection and environmental control critical (Yanes et al., 2020; Somerville et al., 2014).

System success also relies on balancing fish density, plant density, and microbial capacity to convert waste into plant-available nutrients without toxic accumulation. Leafy greens and herbs are particularly well suited to aquaponics due to their rapid growth and high nitrogen demand (Yep and Zheng, 2019). Tilapia is the most widely used fish species because of its tolerance to variable water conditions, with carp and catfish also commonly employed (Yep and Zheng, 2019).

In Lithuania, agricultural policy increasingly emphasizes sustainability, circular economy principles, and bioeconomy development (Ministry of Agriculture of Lithuania, 2022), aligning well with aquaponics concepts. However, scientific studies on aquaponics under Lithuanian conditions remain scarce. Previous research has mainly focused on controlled-environment agriculture, highlighting its potential to mitigate climate-related risks and enable year-round production (Petrauskas et al., 2020). The lack of locally adapted aquaponics data represents a significant knowledge gap for system design and practical implementation.

The aim of this study is to evaluate the development of aquaponics in Lithuania through the implementation of a pilot system, assessing fish and plant performance, nutrient dynamics, and key technical outcomes under controlled conditions.

Materials and Methods

The pilot project was conducted in two stages: from summer 2021 to winter 2022 (Stage 1) and from spring 2022 onward (Stage 2). Ten Lithuanian farms were equipped with prototype aquaponic systems. One prototype aquaponics system was installed on a farm in Pakruojis District Municipality, and nine systems were installed on farms in the Klaipėda region: five in Klaipėda District Municipality, two in Šilutė District Municipality, and one each in Skuodas and Kretinga District Municipalities. Project funding covered not only the installation of prototype aquaponics systems but also the purchase of fish, feed, biofilter media, nitrifying bacteria, water quality test kits (Salifert Profi Test Kits), polystyrene boards, hydroponic pots and substrates, as well as the planting of various vegetable seedlings in each farm. The prototype systems were installed indoors. The aquaponics system (see Fig. 1) consists of the following components: (1) a fish tank with a volume of 1.5 m^3; (2) a sediment trap combined with a reserve water tank (200 L); (3) a biofilter (200 L); (4) a plant growing tank with a capacity of 250 L; (5) an artificial lighting system; and (6) aeration and water circulation equipment, including an air blower, manifold, air hoses, diffusers, check valves, PVC piping, and connecting components. Fish species included Arctic char (*Salvelinus alpinus*), Siberian sturgeon (*Acipenser baerii*), Rainbow trout (*Oncorhynchus mykiss*), and Tench (*Tinca tinca*). Fish were fed 1% of biomass per day under good water quality. Initial fish weight averaged 600 g. Plants included lettuce, spinach, chard, leeks, dill, strawberries, peas, and medicinal herbs (mint, basil, celery, oregano). Water quality parameters, nitrate levels in plants (ECO6 BL Nitrate Tester), and yields were monitored periodically. Systems were located indoors to maintain stable air and water temperature.

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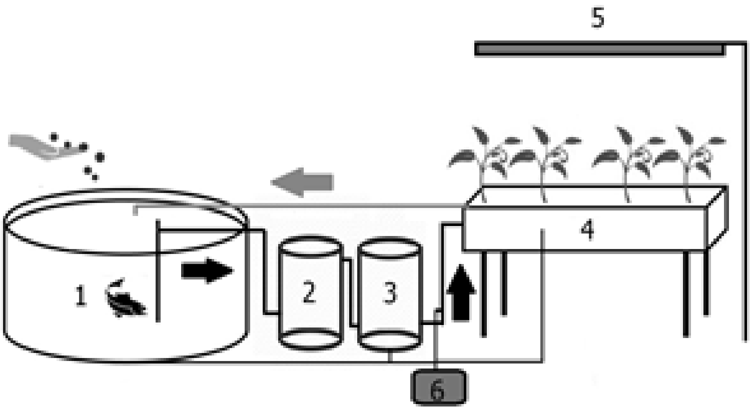

Fig. 1: 1 - fish tank, 1.5 m^3; 2 - sediment trap, reserve water tank, 200 l; 3 - biofilter, 200 l; 4 - plant growing tank, 250 l; 5 - lighting; 6 - air blower, manifold, air hoses, diffusers, check valves, PVC piping and connecting parts

Results and discussion

The results of the study were obtained as the average of the production growth of all farms. Table 1 summarizes the growth results of four cultured fish species during the observation period. The initial body weight was approximately 600 g for most species. Final mean weights differed among species: Arctic char reached about 1100 g, Siberian sturgeon 1500 g, rainbow trout 1100 g, and tench 1200 g. The recorded weight ranges indicate greater individual variability in Siberian sturgeon and rainbow trout, moderate variability in Arctic char, and comparatively lower variability in tench, reflecting species-specific growth patterns and different responses to culture conditions.

Table 1. Cultured fish growth outcomes

Species	Initial weight (g)	Final weight (g)	Range (g)
Arctic char	600	1100	800-1150
Siberian sturgeon	600	1500	1200-2200
Rainbow trout	500	1100	900-1300
Tench	600	1200	950–1350

The most common fish farmed during the project was the Siberian sturgeon. This choice was determined by the fact that sturgeons are hardy fish that can tolerate various conditions, grow relatively quickly, and are edible and nutritious. In successfully balanced systems, 10 kg of fish were started to be farmed, and after a 6-month cycle, about 27-30 kg of fish were harvested. With a small amount of fish, it is easier to ensure water quality, but at the end of the cycle this became difficult. The average nitrate level in the water was 100 mg/l.

The biggest problems on farms arise when it comes to properly mastering plant cultivation.

The main goal of aquaponics is to harvest crops. The main advantage of aquaponics is that it allows you to grow a wide variety of crops, including vegetables, herbs, and even fruit trees. Vegetable and herb seedlings can be grown on floating foam with or without embedded hydro pots (containing expanded clay). It is not recommended to grow plants from seeds in an aquaponics system, as this is a longer and more complicated process. Plant growth in different farms ranged from very good to average, with root development being particularly good. It has been found that not all plant varieties are suitable for growing in the system. Many plant species can be grown in aquaponics, but lettuce is the most common and popular. The most suitable lettuce varieties are: Black Seeded Simpson, Grand Rapids, Green Ice, Lollo Rosso, Ruby Red Leaf, etc. The most suitable tomato groups are cherry and plum tomatoes. Suitable varieties include Giulietta, Black Cherry, Tiny Tim, White Cherry tomatoes, Sungold, etc. Plant yield was increased by regulating light, turning off the lamp (lighting) at night. The height at which the lamp is hung is also very

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important so that all plants receive equal lighting. For example, the average weight of well-lit head lettuce 3 weeks after planting was 200–250 g. The yield of these vegetables growing on the edges, where lighting was insufficient, was 50–70% lower. Sticky traps were used for pest control. It should be emphasized that strict compliance with biosafety requirements is necessary for the prevention of plant diseases and pests. Vegetables performed from moderate to very good across farms. Nitrate levels remained below half of the permissible limits (280–350 mg/kg), confirming suitability for food consumption. Indoor installations allowed optimal control of temperature, enhancing vegetable growth consistency.

The results demonstrate that the implemented aquaponics systems were capable of achieving marketable fish growth and vegetable production comparable to those reported in European studies. Consistent indoor control of water and air temperature played a key role in stabilizing system performance, particularly under Lithuanian climatic conditions. This finding supports previous research indicating that controlled environments are essential for reliable aquaponic operation in temperate regions. Fish growth performance in Lithuanian farms was above the average values reported in the scientific literature for cold-water species such as rainbow trout and Arctic char. Studies conducted in other European systems indicate that trout growth can vary widely depending on stocking density and management practices, while Arctic char generally performs well in low-temperature, well-oxygenated systems (Bordignon et al., 2020; Siikavuopio et al., 2019). The comparatively strong growth observed in this study suggests that system design, water quality management, and feeding regimes were effectively adapted to local conditions. Vegetable production outcomes were consistent with findings from previous aquaponics research, where plant performance is strongly influenced by nutrient availability and system balance rather than by species alone. Earlier studies highlight that nitrate concentrations and leaf nitrate accumulation depend on nutrient dynamics and management strategies within the system (Nozzi et al., 2018; Lenz et al., 2021). Similar challenges were observed in the present study, particularly during the initial adaptation phase of plants.

Despite the positive production results, several challenges were identified. Plant adaptation to aquaponic conditions, maintaining balanced nutrient concentrations, and limited technical knowledge among participating farmers required ongoing support and system adjustments. These constraints align with commonly reported barriers in aquaponics adoption across Europe and emphasize the need for training, standardized guidelines, and long-term monitoring to ensure system stability and scalability.

The biggest challenge for the farms participating in the project was balancing the system (water quality parameters). Since the systems were experimental and did not have automatic quality control systems installed, farmers had to do this themselves using water quality tests. However, this required a great deal of care and time, and not all farmers participating in the project fully completed the work. As a result, some farms experienced problems such as slower plant and fish growth or even fish or plant mortality. A separate aquaponics system is like a unique ecosystem created by the farmer, and the farmer must have all the knowledge to understand all the processes involved in their work. This is the foundation for success.

Conclusions

The study confirms that aquaponics is a feasible, innovative, and sustainable farming approach in Lithuania. Successful management (balancing) of aquaponics processes requires multidisciplinary knowledge, i.e., an understanding of the environment and mechanical design, as well as botany related to aquatic plants, biology and biochemistry related to fish, which examines water quality and the processes taking place in it. Despite this prototype systems achieved fish and plant productivity comparable to European benchmarks. Indoor systems allowed environmental control, enhancing consistency and food safety. Future research should focus on long-term productivity, economic modeling, and further plant adaptation strategies.

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Akvaponikos plėtra Lietuvoje: bandomosios sistemos įgyvendinimas ir pagrindiniai rezultatai

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Santrauka

Šiame tyrime pristatomos 2021–2022 m. dešimtyje Lietuvos ūkių įdiegtos bandomosios akvaponikos sistemos. Akvaponika sujungia akvakultūrą ir hidroponiką į tvarią maisto gamybos sistemą. Tyrimo metu augintos žuvų rūšys: arktinis palijus (Salvelinus alpinus), sibirinis eršketas (Acipenser baerii), vaivorykštinis upėtakis (Oncorhynchus mykiss) ir lynas (Tinca tinca). Augintos daržovės: salotos, špinatai, mangoldai, porai, krapai, braškės, žirniai ir vaistiniai augalai. Vidaus patalpų įrengimas leido kontroliuoti vandens ir oro temperatūrą, užtikrinant rezultatus. Lyginamoji analizė su literatūros duomenimis rodo, kad Lietuvos akvaponikos sistemos prilygsta Europos tyrimams, demonstruodamos inovatyvumą ir tvarumą. Akvaponikos sistemos neapsieina be iššūkių, susijusių su augalų adaptacija, maistinių medžiagų valdymu ir techninių žinių stoka. Šis darbas pateikia praktinių įžvalgų ūkininkams ir sprendimų priėmėjams, siekiantiems tvarių ir inovatyvių ūkininkavimo sprendimų.

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