Technological Advancements in Brunei’s Local Agriculture and Fisheries Companies: An Exploratory Study Based on Field Observations

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Abstract

This exploratory study, through seven field observations and interviews, investigates the technological advancements transforming Brunei’s agricultural landscape in pursuit of local production augmentation and self-sufficiency. It confronts challenges with emerging technologies like aquaponics, hydroponics, fertigation systems, closed-house poultry systems, and UV lighting, which hold promise for enhanced farming practices. The research provides a comprehensive assessment of current practices, including livestock management advancements, underscoring their potential to boost productivity, optimize resource use, and promote sustainable agriculture. Furthermore, it discusses the broader implications for industry standards, job employability, and alignment with Brunei’s vision 2035. The findings contribute invaluable insights, advocating for strategic policy reforms, capacity building, and continued research to strengthen and future-proof Brunei’s agricultural sector.

Keywords: Agricultural innovations, Sustainable farming, Technological advancement, Resource efficiency, Livestock management

1. Introduction

Brunei’s agricultural sector, integral to the nation’s economic fabric, confronts the dual challenges of amplifying local production and reaching self-sufficiency (Musa et al., 2020). Amidst these challenges, the advent of technological advancements shines as a beacon of promise, offering innovative solutions to bolster and refine agricultural practices. This study delves into the technological panorama of Brunei’s agriculture, placing particular emphasis on breakthrough innovations such as aquaponics, hydroponics, fertigation systems, closed-house ventilated poultry, and UV lighting systems. While these technologies herald a new dawn with their promise of enhanced productivity, resource optimization, and sustainability, the barriers to their widespread adoption must be recognized and addressed (Mobarak & Saldanha, 2022).

By immersing in field observations and engaging with key stakeholders in agriculture, this research offers a comprehensive perspective on the...
technological fabric of Brunei’s farming practices. More than just an enumeration of technologies, this study delves into the nuances of current agricultural conditions, dominant practices, and looming challenges. It seeks to understand the far-reaching implications of these technological advancements, especially their impact on productivity, produce quality, and sustainability. As solutions emerge, the research underscores the imperative for strategic initiatives — be it policy shifts, intensified research and development, or capacity-building measures — to address the prevailing challenges.

The significance of Brunei’s agricultural sector is underscored by its contribution to 0.54% of the national GDP (Pehin Dato Musa & Basir, 2021). Despite strides in progress, the sector grapples with increasing local production to satiate domestic demand and realize self-sufficiency. Compounding these challenges are the limited availability of arable land, water scarcity issues (Suhaili, 2023), a dearth of skilled labour, and infrastructural constraints that can potentially dampen its competitive edge. While Brunei’s advancements in agricultural technology are commendable, it’s imperative to position these achievements in an Association of Southeast Asian Nations (ASEAN) region. Comparative data with neighbouring countries or regions provides valuable insights, revealing areas where Brunei is pioneering and where there is room for growth. This not only benchmarks Brunei’s progress but also paves the way for collaboration, learning and alignment with the nation’s vision, Wawasan 2035.

2. Methodology

The research methodology for this study encompassed an integrated approach, blending hands-on field trips with informal discussions to holistically understand Brunei’s agricultural and fisheries sectors. A total of seven field trips, each lasting approximately 4 h, were systematically planned and executed to traverse various agriculture and fisheries locales across Brunei. The primary author in collaboration with agrotechnology students from Universiti Teknologi Brunei (UTB), undertook these visits. Rather than being merely observational, each trip was an immersive experience aimed at comprehending the intricacies of employed technologies, inherent challenges, and potential innovative avenues. Informal discussions were integral to these visits. These were not structured interviews but were tailored around the modules’ objectives, providing a richer depth of understanding. The interactions encompassed dialogues with multiple representatives from the enterprises, ensuring a well-rounded perspective on practical applications, technological successes, and limitations (Vimal et al., 2023).

The dual approach of field trips combined with discussion had a two-fold rationale. For UTB agrotechnology students, it was a unique opportunity for hands-on learning, translating theoretical concepts into real-world applications. For the primary author, it presented an invaluable chance to gather firsthand insights, which is indispensable for an exploratory study like this. The sites for the field visits were strategically selected in alignment with specific modules of the UTB agrotechnology programme. Such meticulous selection ensured both a comprehensive grasp of the subject and its congruence with the academic curriculum. The key modules encompassed are:

1) Smart water and Irrigation management
2) Principles of Agriculture Technology
3) Ecology, Farmland and soil management
4) Smart Greenhouse and Aqua farming technologies
5) Livestock, welfare and slaughtering

Given the applied nature of these modules, the field trips were indispensable. They offered students and researchers a tangible touchpoint, linking classroom theories to the evolving realities of agricultural technology in Brunei.

3. Findings and observations

In our exploration of the agricultural and fisheries sector across Brunei, we encountered a range of innovative practices and technologies reshaping the industry’s landscape. The findings from each visit are summarized in Table 1 below, offering a snapshot of the technological advancements, practices, and produce associated with each company. These observations present a mosaic of Brunei’s commitment to modernizing its agricultural and fisheries sector, capturing both the traditional and emerging techniques. Let’s delve into the specifics of each location and their notable contributions.

During our study, there were a few constraints or limitations faced. Some companies, for reasons ranging from proprietary concerns to operational schedules, did not permit full access to certain areas or specific insights. While we endeavoured to capture a holistic understanding, these limitations should be kept in mind when interpreting the data and observations.

3.1. Significance of the findings

Aquaculture and Advanced Agri-tech Synergy: represents the zenith of merging traditional and
modern agricultural practices. IAMFood, as showcased in Fig. 1, stands as a testament to this fusion. This enterprise intricately intertwines traditional aquaculture with avant-grade agri-tech solutions such as aquaponics, fertigation, and hydroponics. Not only do these innovations significantly bolster crop yields, but they also champion the cause of water conservation – a resource fast depleting in our contemporary era. IAMFood's extensive product range, from leafy vegetables to the exclusive golden rock melons, speaks volumes about the enterprise's versatility and ability to cater to diverse market needs. Their unique approach of combining multiple farming techniques enables them to produce a vast array of products, setting them apart in Brunei's agricultural landscape.

Integrated Farming Approach: In the agricultural landscape of Kampong Masin, Ladang Zaías stands out as a testimony to the evolution of arming methods and their socio-economic implications. The farm's growth trajectory has been significantly influenced by the dual challenges of profitability

Table 1. Field observations.

<table>
<thead>
<tr>
<th>Section</th>
<th>Location</th>
<th>Key Insights – Technologies employed</th>
<th>Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>IAMFood Enterprise – kg Tungku Argo Farm</td>
<td>Aquaponics, fertigation, hydroponics system, Natural farming, IoT system for controlling and optimizing crop planting</td>
<td>Royale melons, Lettuces, Kale, Bak Choy, Xiao Bai Cai, Kang Kong, Kailan, etc.</td>
</tr>
<tr>
<td>1.2</td>
<td>Ladang Zaías – kg Mulaut</td>
<td>Conventional farming – Incorporating Hydroponics</td>
<td>Lettuces, Bak Choy, Basil, Mints, Chillies etc.</td>
</tr>
<tr>
<td>1.3</td>
<td>Ladang Hua Ho Agricultural Farm – kg Masin</td>
<td>Use of Polytunnel-Protected and semi-protected houses, Irrigation and sprinkler system, Closed-house system</td>
<td>A large variety of vegetables, Fruits and Poultry.</td>
</tr>
<tr>
<td>1.4</td>
<td>Helif Aquaculture Sdn Bhd – kg Mentiri</td>
<td>Use of Auto feeder &amp; Paddle Wheel for oxygen dissolution</td>
<td>Shrimp &amp; White Leg Shrimp</td>
</tr>
<tr>
<td>1.5</td>
<td>Barramundi Group Company Sdn Bhd – kg Serasa</td>
<td>Recirculating Aquaculture system (RAS), water filtration, UV light sterilizers, oxygen pump tanks &amp; Biofiltration</td>
<td>Seabass</td>
</tr>
<tr>
<td>1.6</td>
<td>Brugoat Sdn Bhd – kg Sg Liang, KB</td>
<td>Advanced animal feeding store</td>
<td>MEAT: Boer goats and Dorper Sheep</td>
</tr>
<tr>
<td>1.7</td>
<td>Syarikat Md Norfaidzal bin Hj Zaínuddin – Jln Mulaut Lampaki</td>
<td>Modern Slaughtering processes house i.e., Boning room or Cooling Hall</td>
<td>MEAT: Cows, Cattle, Buffalos, goats, sheep,</td>
</tr>
</tbody>
</table>

Fig. 1. Micro-Irrigation system (Top-left) & Mainline of the System (Top-Right), Golden Rock Melon produced and marketed (Bottom).
and sustainability. Initially, predominant reliance on conventional farming was driven by its higher profitability margins. However, as the broader agricultural industry gravitated towards sustainable practices, Ladang Zaias too felt the pull. This led to their tentative foray into hydroponic farming, a step that was both progressive and challenging. The juxtaposition of their hydroponic system alongside traditional soil-based farming, as illustrated in Fig. 2, speaks volumes about their commitment to innovation while still valuing conventional wisdom.

Their product range, encompassing hydroponically grown lettuces, bak choy, basil, and mints, alongside soil-grown chillies and other vegetables, showcases their diverse farming practices. A noteworthy addition to their portfolio is the melons cultivated via fertigation, slated to be harvested in the imminent months. Ladang Zaias doesn't merely focus on farming practices; it is also an educational hub. Their holistic approach was evident during a recent visit, where the majority of the time was dedicated to enlightening visitors on the intricacies of establishing a farm, tapping into governmental and private sector resources, and the larger vision of agricultural self-sufficiency for Brunei. Such initiatives underscore the farm's pivotal role in shaping Brunei's future in food security and its potential as an agricultural exporter.

Diverse Agriculture Techniques: Ladang Hua Ho, a key player in Brunei's agricultural landscape, reflects the significance of innovative farming methods. One of the farm's technological marvels is the automated seedling machine, which is a testament to its commitment to efficiency as depicted in Fig. 3 below. Imported from Japan and Taiwan, this machinery optimized the planting process. With the capacity to insert seeds into 98 small pots in a single tray, this equipment drastically amplifies worker productivity. Once the trays are populated with seeds, they are transported to another greenhouse.
Effective farm management is indispensable. This involves maintaining soil quality, an efficient irrigation system, and ensuring the well-being of the workers. A lapse in any of these can result in substantial losses, as evidenced by past incidents like the unintentional flooding caused by an open water pipe. Fig. 4 shows below, that Huaho’s open greenhouses, such as the one housing Bok Choy, Pai Choy and Siew Choy, are designed with accessibility in mind. These structured pathways simplify the manual watering process, ensuring each plant receives the required attention. Different crop necessities distinct irrigation systems, such as drip and sprinkler systems, based on their water requirements.

Post-harvest, the farm emphasizes the importance of maintaining the quality of their produce. In a dedicated room, crops are sorted, weighted and packaged under optimum conditions to ensure they retain their freshness. This room, designed to keep pests at bay and maintain a cool temperature, houses various crops ready for distribution to different Huaho branches. The post-harvest process is a meticulous operation, aiming to extend the shelf life of the produce and mitigate any potential damage or wilting before reaching the consumers, as visualized in Fig. 5 below.

Marine Innovation at the Forefront: In the dynamic realms of aquaculture, the technologies employed by Helif Aquaculture and Barramundi Group reveal a forward-thinking aquaculture sector to ensure sustainability and efficiency. Their efforts, as depicted in Fig. 6, highlight a commitment to eco-friendly marine farming.

Helif Aquaculture’s approach to prawn farming is a commendable blend of traditional open-pond systems and cutting-edge technology. The ponds, sourced from the Brunei River and managed with a water depth of around 1 m, showcase a dedication to maintaining optimal health conditions for prawn cultivation. Critical to this operation is the ‘auto-feeder’ shown below, a device that significantly outperforms manual feeding by delivering feed effectively and rapidly, thus promoting better growth rates and health of the prawns. To sustain a healthy ecosystem, Helif rigorously monitors and adjusts pond water conditions, including pH levels (7.5–8.5), salinity (14–15 ppt) and dissolved oxygen DO (5 mg/L). Such precision is maintained through daily checks and calculated interventions, like the periodic addition of Sodium bicarbonate to maintain alkalinity and regular water exchanges to prevent algae blooms. These algae can have detrimental effects on water quality and prawn health by consuming oxygen and blocking sunlight, crucial for the pond’s ecological balance.

The use of paddlewheel aerators below is a strategic choice to maintain DO levels. These devices circulate oxygen-rich water throughout the pond, vital for the prawn’s survival and growth. Helif’s resourcefulness extends beyond aquaculture as they repurpose pond sludge, rich in nitrogen and phosphorus, as fertilizer for agriculture areas, thereby adopting a circular approach to waste management.

The Barramundi Group, a leader in Barramundi farming, underscores the importance of sustainable practices combined with commercial viability. Their operations utilize the Serasa beach’s natural resources within a Recirculating Aquaculture System (RAS), as shown above, mechanical filter, to minimize costs and environmental impact. The RAS system is a testament to their innovative spirit, employing a series of processes to ensure water quality. This includes filtration to remove impurities and regulate salinity, UV light treatment to eliminate microbial contaminants, biofiltration to process waste, and oxygenation to ensure the water is conducive to the fish’s growth. Safety and biosecurity are of paramount importance are meticulous steps taken to ensure the health of the fish population. Procedures such as shoe water baths for
disinfection, and vaccination of each fish underscores their meticulous approach to aquaculture.

Comprehensive Livestock and Meat Production practice, Brunei: The transformation of livestock management in Brunei is markedly observed in the innovative approaches of Brugoat farming and trading and Syarikat Md Norfaisal abattoir, particularly in their advanced feeding methods and modern slaughtering processes. These practices reflect a commitment to efficiency, animal welfare, and adherence to halal standards, which are intrinsic to the nation’s values.

Brugoat farming & trading has established itself as a vanguard in Brunei’s livestock industry since its inception in 2015. Operating on 3 ha of land, the farm began by breeding high-quality Dorper sheep and Boer goats imported from Australia, with a mission to supply locally reared meat to the Bruneian market.

The farm operates with state-of-the-art open-concept shelters that allow ample sunlight, essential for the animals’ well-being. These shelters, elevated above ground level, facilitate efficient manure management, showcasing Brugoat’s commitment to cleanliness and sustainability. By integrating the manure into the cultivation of Napier grass—a staple in the livestock’s diet—the farm exhibits a circular approach to resource usage, as shown in Fig. 7 below. Additionally, innovative feeding practices that include the incorporation of molasses and mineral blocks underscore Brugoat’s dedication to animal health and productivity. During the mating season, meticulous records and tagging systems prevent inbreeding and ensure the traceability of each animal. Post-mating, the farm employs ultrasound technology to monitor pregnancies, providing specialized care throughout the gestation period.
Norfaidzal’s halal slaughtering expertise upholds halal principles, ensuring that the slaughtering process is carried out humanely and efficiently. The guidelines for halal slaughter prioritize rapid and complete bloodletting while minimizing the animal’s pain, showcasing a humane approach to meat processing. Norfaidzal which was first started in 2005 and is located in a rural area at Jalan Mulaut, Lampaki, is a family-owned business that provides and sells fresh meat which can be found in their ship and local supermarkets. The business also owns cowsheds capable of holding 1500 to 2000 cows and buffalos. The animals used for their meat product such as goats, sheep, cows, buffalos, and bulls are imported from Australia when they are approximately two years old, taking into account the welfare of the animals and adhering to slaughter regulations. The facility plays a critical role in safeguarding public health by monitoring, treating, and eliminating potential foodborne hazards. Additionally, they provide services for the Islamic ritual animal sacrifice, known as ‘Majlis Korban’.

In Brunei, the slaughtering of animals is a process that is meticulously regulated to ensure compliance with Islamic dietary laws, food safety, and public health standards. The Department of Agriculture and Agri-food (DoAA) oversees the adherence to these standards, which are further reinforced by the Public Health (Food) Act, the Wholesome Meat Order, and the Halal Meat Act. These acts and orders establish strict requirements for the humane handling of animals, the conditions of slaughterhouses, and the processing and distribution of meat products. The halal slaughtering process shown in Table 2 below, is executed with precision and care to avoid causing unnecessary pain to the animals. For instance, before the slaughtering process begins, a thorough inspection ensures that the animals selected for slaughter

<table>
<thead>
<tr>
<th>Kill box</th>
<th>Lainage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skinning</td>
<td>Excoriation</td>
</tr>
<tr>
<td>Post-mortem inspection</td>
<td>Quartering</td>
</tr>
<tr>
<td>Meat cutting session</td>
<td>Meat store</td>
</tr>
</tbody>
</table>

Table 2. Whole Slaughtering process..
are in good health and not pregnant or injured. The slaughtering is carried out by skilled workers who follow strict guidelines to perform a swift and humane kill, which includes reciting a prayer, using a sharp knife, and ensuring quick bloodletting. After the animal is slaughtered, it goes through a process of bleeding, skinning, and evisceration, where the internal organs are inspected for any signs of disease. This careful inspection is crucial to determine the safety of the meat for consumption. The meat is then chilled immediately to prevent spoilage and to maintain its quality, with strict temperature controls in place during the cutting and storage processes.

The combined practices of Brugoat and Syarikat Md Norfaidzal illustrate a synergistic approach to livestock management that prioritizes animal welfare and product quality. Brugoat’s focus on diet and breeding, along with Syarikat Md Norfaidzal’s commitment to ethical slaughtering and meat handling, set a precedent for the industry that could influence nationwide practices in the future. The Authors and Agrotechnology students from Universiti Teknologi Brunei (UTB) observed both Brugoat’s advanced feeding operations and Syarikat Md Norfaidzal’s meticulous slaughtering processes. These observations provide students with invaluable insights into the practical aspects of animal husbandry and meat production, linking classroom knowledge with real-world applications.

3.2. Implications for the broader agricultural industry

From our field observations, it becomes evident that these sites hold considerable promise in establishing industry standards. More than just operational entities, they exemplify cutting-edge practices that can guide and inspire others in the sector. For instance, IamFood Enterprise stands out with its seamless integration of aquaponics, fertigation, and hydroponics. Their approach provides a model for other agricultural endeavours aiming to harness the benefits of these sophisticated farming methods. The prospect of amplifying export potential emerges as another crucial takeaway. The assortment and calibre of produce, from the succulent Royale melons to the enticing Seabass, speak volumes about Brunei’s agricultural prowess. This level of excellence suggests Brunei’s potential to distinguish itself on the global stage. By employing effective marketing and robust supply chain management, Brunei can emerge as a top-tier supplier of such premium products. Our field assessments also spotlighted Brunei’s commendable commitment to environmental sustainability. The widespread adoption of eco-friendly farming practices not only reduces environmental impact but resonates deeply in a market where sustainability is increasingly valued (Jiang et al., 2022; Muhie, 2022). This dedication to sustainable agriculture might attract eco-sensitive investors and partners, seeking alignment with nations that uphold environmental preservation (Shah & Wu, 2019).

Lastly, as Brunei’s agricultural landscape evolves, integrating contemporary technologies and strategies, there emerges a clear indication towards skill enhancement and job generation. The gravitation towards tech-centric methodologies demands a workforce proficient in managing such advancements. This evolution highlights the pressing need for comprehensive, tailored training initiatives. Ensuring the Bruneian workforce is armed with the necessary skills will not only reinforce the nation’s agricultural sector but also pave the way for fruitful employment prospects.

3.3. Comparative analysis

In the dynamically evolving landscape of agriculture, the integration of technology stands as a hallmark of progress and innovation. Southeast Asia (SEA), with its rich agrarian history with diverse ecological tapestry, is no exception to this trend. The region, brimming with potential, witnessed the countries at different stages of technological assimilation, each carving a unique trajectory in modernizing they’re of three pivotal nations within their region: Malaysia, Indonesia and Brunei. By examining their distinct approaches, innovations, and challenges, we aim to offer a holistic overview of their endeavours and the implications of these on the future of SEA agriculture.

Malaysia has made notable strides, with the implementation of drones providing pivotal real-time data and potentially elevating yields by 5% through a precision farming system (Ab Rahman et al., 2019; Spalević et al., 2018). The nation’s embrace of precision farming and mechanization technologies, coupled with advancements in information technology like artificial intelligence and satellites, underscores its commitment to modernizing agriculture (Aslan et al., 2022). This multifaceted approach not only assures optimum health and productivity levels for both crops and soil but also forecasts significant market growth, potentially reaching $3.2 trillion by 2025 (Karunathilake et al., 2023; United Nations Conference on Trade and Development (UNCTAD), 2021).

Conversely, Indonesia’s focus is prominently on digital transformation and smart farming
technology, addressing crucial aspects such as food security and waste reduction (Shamin et al., 2019; Soma, 2017; Sutardi et al., 2023). The creation of an Innovation Hub exemplifies the nation’s determination to consolidate multiple stakeholders in the agriculture value chain, aiming for synergistic advancements in sustainable farming and addressing climate crises (Sutardi et al., 2023). Investment in data and innovation ecosystems is paving the way for agriculture-specific digital solutions, reflecting a holistic transformation of Indonesia’s agriculture sector, impacting supply chain and data management, market access and digital information (United Nations Conference on Trade and Development (UNCTAD), 2021).

Brunei, while similar in comparison, is forging path with strategic technological integrations. The incorporation of varied technologies such as fertigation systems, hydroponics, and aquaponics, manifests Brunei’s commitment to enhancing agricultural productivity (Azffri et al., 2022). The nation’s venture into smart farm technologies and vertical farming indicates a targeted optimization, focusing on deriving enhanced results from agricultural practices (Suhaili, 2023). Moreover, the government’s emphasis on technology adoption for improving self-sufficiency in paddy plantations and the exploration of IoT-based smart aquaculture for shrimp farming is indicative of a responsive and adaptive approach to agricultural needs and demands (Musa et al., 2020; Suhaili, 2023).

3.4. Job Employability and Wawasan 2035

In the context of Brunei’s Vision 2035, the agricultural advancements observed not only enhance the sector’s production capacity and sustainability but also contribute significantly to the nation’s broader goals of fostering a highly skilled and accomplished workforce.

1) Skills diversification and Specialization – with the introduction of smart technologies such as hydroponic farming, precision agriculture and IoT-driven aquaculture, there’s an increasing demand for specialized skills. It’s no longer about traditional farming methods; the agricultural workforce now requires proficiency in managing digital tools, analyzing data, and optimizing advanced farming systems. As such, there’s a significant potential to diversify the job market and introduce specialized roles – from hydroponic system managers to agricultural data analysts.

2) Training and education initiatives – to harness the full potential of these technologies and meet the standard set by Brunei Vision 2035, tailored educational and training initiatives are paramount. Collaboration with educational institutes to introduce agricultural tech programs can arm the future workforce with the necessary skills. Such initiatives directly align with Vision 2035’s emphasis on cultivating an educated populace, ensuring that the nation’s agricultural workforce is not only competent but also at the forefront of global agricultural advancements.

3) Enhancing economic resilience and self-reliance – as the agricultural sector grows and diversifies, there’s potential for increased job creation. From research roles to operational jobs in new farming facilities, the sector can contribute significantly to reducing unemployment rates. A robust agricultural sector, equipped with modern technologies and practices, can foster economic resilience, aligning with Brunei’s Vision 2035’s goal of a self-reliant nation with a steady income.

4) The path to sustainable employment – the observed emphasis on sustainable farming practices goes hand-in-hand with the creation of sustainable employment opportunities. As global markets move towards eco-friendly products, Brunei’s commitment to sustainable agriculture can position it as a leading exporter, driving economic growth and creating long-term job opportunities. Such a focus not only ensures that Brunei’s agricultural sector remains profitable but also that jobs created within the sector are stable and long-lasting.

4. Future research

One of the predominant trends observed during our field visits was the inclination towards hydroponic farming. Given its prominence, there’s an imperative need for focused research tailored to Brunei’s unique conditions. Comparative studies, contrasting hydroponic methods with traditional farming in terms of yield, resource use, and sustainability would be beneficial (Ali et al., 2022; Buyeye et al., 2022). As more farms, such as Ladang Zaias, incorporate hydroponics, understanding its nuances and potential challenges in the Bruneian context becomes paramount.

Animal welfare stands out as a significant facet that warrants comprehensive investigation. Observations at sites like Syarikat Md Norfaiszal bin Hj Zainuddin and Brugoat Sdn Bhd highlight the advancements in livestock management. Delving deep
into research that evaluates and ensures the highest standards of animal welfare is both an opportunity and a responsibility (Olmos Antillón et al., 2021). This research could also influence consumer perceptions, positioning Bruneian products favourably in markets that value the ethical treatment of livestock. In an era where sustainability is paramount, policymakers must be equipped with concrete data. While observational data offers a qualitative understanding, dedicated studies to quantify the environmental benefits of sustainable practices are essential (Ekins & Zenghelis, 2021). Such sustainability metrics validate Brunei’s commitment to eco-friendly agriculture and can be a selling point for Bruneian agriculture on global platforms, enticing both consumers and investors.

Further collaborations and partnerships with academic institutions, international organizations, and private entities can elevate research and development. These alliances can enhance the applicability and reach of research findings, ensuring that the advancements in Bruneian agriculture gain the recognition they deserve. Lastly, an infrastructure assessment holds significant value. While technological advancements have been observed across various sites, understanding the supporting infrastructure, from basic amenities to advanced agricultural facilities, is crucial (Wang et al., 2022; Zhong et al., 2022). This assessment would spotlight areas requiring investment, ensuring the sector’s technological growth remains sustainable. Strengthening ties with institutions adept at infrastructure research can also be pivotal, allowing for a more holistic perspective on the sector’s needs. By focusing on these research avenues, Brunei can fortify its agricultural sector, ensuring a future marked by innovation, sustainability, and global appeal.

5. Conclusion

The evolution of Brunei’s agricultural sector, as illuminated by this research, underscores a journey marked by both challenges and transformative potential. While the sector has its own set of hurdles to overcome, especially in terms of enhancing local production and achieving self-sufficiency, the introduction and adoption of cutting-edge technologies herald a future brimming with promise. A noticeable trend towards hydroponic farming is not just a mere shift in technique but reflects a broader inclination towards sustainable, efficient, and resource-saving methods. These advanced farming practices, if effectively harnessed and optimized, could very well position Brunei as a frontrunner in modern agriculture, carving a distinct niche on the global stage. The emergence of high-calibre production, evident from the Royale melons to the Seabass, attests to Brunei’s capabilities to deliver quality, meeting the demands of an ever-evolving international market.

Animal welfare, a facet traditionally overshadowed by productivity concerns, is now gaining prominence, aligning with global trends and ethical considerations. The marriage of advanced livestock management with humane treatment presents a unique selling proposition, differentiating Brunei in markets that increasingly value ethical and sustainable practices. Beyond techniques and production, the observed emphasis on sustainability resonates with a global shift towards ecological mindfulness. Brunei’s commitment is more than just surface-level adherence to global trends. With a deeper dive into quantifying these sustainable efforts, the nation could further solidify its reputation as a responsible and eco-conscious agricultural player. Infrastructure, the backbone of any sector’s growth, demands thorough evaluation. While advancements in farming techniques are commendable, their sustainability hinges on the robustness of underlying infrastructure. Addressing these foundational aspects can propel Brunei’s agricultural sector into a realm of consistent growth, resilience, and innovation.

In essence, Brunei’s agricultural landscape, illuminated through direct observations and interviews, showcases a sector in flux, moving from traditional methods towards a technologically driven, sustainable future. It reflects a narrative of hope, change, and ambition. With continued research, strategic interventions, and a commitment to both innovation and sustainability, Brunei’s agricultural sector stands poised to emerge as a beacon for others to emulate. The insights derived from this exploration not only elucidate the present but also draft partially a strategic blueprint. This blueprint, much like a roadmap, guides stakeholders, policymakers, and researchers alike, in shaping a resilient, productive, and sustainable agricultural future for Brunei.

Authors’ contributions

Muhammad Firdaus Mujibuddin Syah Mustafa was the principal investigator, developing the idea and plan for this research. He was also the main author of the paper. Fieldwork was a collaborative effort, with Fatnin Farhanah Alihan, Amni Sahilah Sahrullamzah, and Khairina Umairah Takiyauddin participating under the supervision of Dr. Hong Shyang Pei, the UTB lecturer. These authors also conducted data collection and interviews, with
Fatnin, Amni, and Khairina providing data verification and filtration. Dr. Namisivayam Navaranjan oversaw the entire research process, from the initial review to the final editorial stages. All authors, including Muhammad Firdaus Mujibuddin Syah Mustafa, Fatnin Farhanah Alihan, Amni Sahilah Sahrullamzah, Khairina Umaiarah Takiyyuddin, Dr. Hong Shyang Pei, and Dr. Namisivayam Navaranjan, have read and granted their approval for the final manuscript.

Ethical considerations

This research adheres to stringent ethical guidelines to ensure the privacy and confidentially of the entities involved. All companies referenced, whether by their actual names or pseudonyms, have been notified, and their explicit consent has been obtained. Furthermore, direct contact was made with the farmers involved in this study, and they have graciously provided their permission for the inclusion of specific details related to their operations. In cases where consent was not explicitly provided, names and identifiable details have been anonymized to protect the company's and individual confidentiality.

Declaration of Generative AI and AI-assisted technologies in the writing process

We declare that no Artificial Intelligence (AI) technologies or AI-assisted tools were utilized in any capacity during the writing and preparation of this article.

Conflict of interest

We declare that there is no conflict of interest in the publication of this article.

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