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Enhancing Postharvest Quality and Market Access: Adopting Integrated Ozone-Cold Storage Technology for Smallholder Farmers' Hygienic Produce

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ABSTRACT

Background: This community service program addresses the critical agricultural challenges of post-harvest loss in Asmorobangun Village, Kediri, specifically rapid product spoilage, inadequate storage, and unstable market prices. The focus is on introducing accessible technological solutions to farmers for hygienic post-harvest handling.

Purpose of the Study: The purpose of this program is to implement and evaluate the effectiveness of ozone technology combined with cold storage in reducing post-harvest losses. The objectives are to extend the shelf life of horticultural products, improve their market quality, and empower farmers through participatory training and application.

Methods: The implementation used a participatory approach, actively involving farmers in all stages: problem identification, socialisation, design and assembly of a corona discharge-type ozone generator and cold storage units, equipment testing, technical training, and field assistance.

Results: The combined use of ozone and cold storage significantly extended product shelf life by 2–3 days at room temperature and up to 3–4 weeks with cold storage. The technology effectively maintained freshness, colour, and texture while being user-friendly and eco-friendly. Farmers responded positively due to its economic benefits and improved product marketability. The program successfully established a replicable model for sustainable post-harvest management in similar farming communities.

Keywords

Ozon Technology; Cold Storage; Post-Harvest Preservation; Sustainable Agriculture; Farmer Empowerment

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Introduction

As an agrarian country with abundant agricultural potential, Indonesia produces agricultural products that are integral to daily life and play a vital role in providing food for society. These products contain rich sources of vitamins and minerals, which are essential for human health and thereby significantly contribute to improved well-being. Besides their nutritional value, agricultural products also play a crucial role in supporting economic and ecological sustainability and fostering Indonesia's food self-sufficiency.

The program's partner farmers' group, namely "Perkumpulan Rembulan Asmoro Bangun", operates under a centralised distribution system. It collectively manages the production, marketing, and sales of its members' agricultural commodities. The benefit of this model is reducing dependence on intermediaries who typically suppress farm-gate prices by 20 to 30 per cent below market value (Badan Pusat Statistik, 2023). Through this collective marketing, farmers can gain greater bargaining power and potentially access regional markets. However, post-harvest losses and fluctuating market prices remained challenges for the group, reducing the benefits.

Based on the Indonesian Ministry of Agriculture report in 2022, post-harvest losses are one of the most significant obstacles in Indonesia's horticultural sector. Inadequate post-harvest handling, poor storage facilities, and microbial decay are primarily causes of the losses for perishable commodities such as chilli, tomato, and leafy vegetables, which range from 20 to 35 per cent of total production (Kementerian Pertanian Republik Indonesia, 2022). These losses amount to approximately IDR 15 to 20 million per month for the Rembulan farmer group, which produces about 8 to 10 tons of vegetables. Vegetable spoilage generally occurs within 2 to 3 days after harvesting, reducing vegetable quality and often forcing farmers to sell their product at low prices or even dispose of unsold products.

The farmers already tried to reduce such losses by accelerating the harvest and delivery process, beginning as early as 5:00 to 6:00 a.m. to reach urban markets in Kediri and Malang. However, this approach raises labour costs by approximately 25 per cent due to higher early-hour wages. Rushed handling and transportation also contribute to an estimated 10 to 15 per cent of additional physical damage. In several instances, the urgency of delivery has also resulted in traffic accidents, demonstrating the unsustainable nature of current practices.

Price volatility remains another critical issue. Prices of key horticultural products, such as chilli and tomato, can drop by 40 to 60 per cent during peak harvest seasons, forcing farmers to sell their product below production costs. Delaying sales when most members lack proper preservation or storage facilities is rarely feasible. Hence, unsold products quickly lose freshness and market value. These conditions create an urgent need for appropriate post-harvest innovations, particularly the adoption of affordable ozone-based sterilisation and cold storage technologies, to extend product shelf life, maintain price stability, and strengthen the economic resilience of farmers.

We propose a Community Service Program under the Community Entrepreneurship Development Scheme to assist these farmers by means the application of two technologies: ozone treatment and cold storage systems for post-harvest preservation. Ozone (O₃) is known as an effective oxidative agent for inactivating pathogenic microorganisms such as bacteria, fungi, and viruses in horticultural products (Hartoyo & Rachma, 2022; Farizha et al., 2022; Hidayah et al., 2021; Liu et al., 2021). Meanwhile, cold storage slows metabolic activity and product degradation, thereby maintaining freshness over a longer period (de Souza et al., 2018; Tetelepta et al., 2023). The combination of these two technologies is highly appropriate for extending shelf life, preserving quality, and increasing distribution flexibility in distribution.

The objectives of this program are to enhance farmers' knowledge and skills in applying ozone and cold storage technologies, extend the shelf life and maintain the quality of agricultural

products, and improve post-harvest management through technology-based solutions that reduce costs and increase farmers' income.

Method

This community engagement program employed a participatory approach in collaboration with the Rembulan Farmers' Group of Asmorobangun Village, Kediri. The implementation comprised four main stages: dissemination and problem identification, design and fabrication of technology, technical testing and implementation, and training with evaluation. The workflow of the community service activities conducted by the team is presented in Figure 1 below.

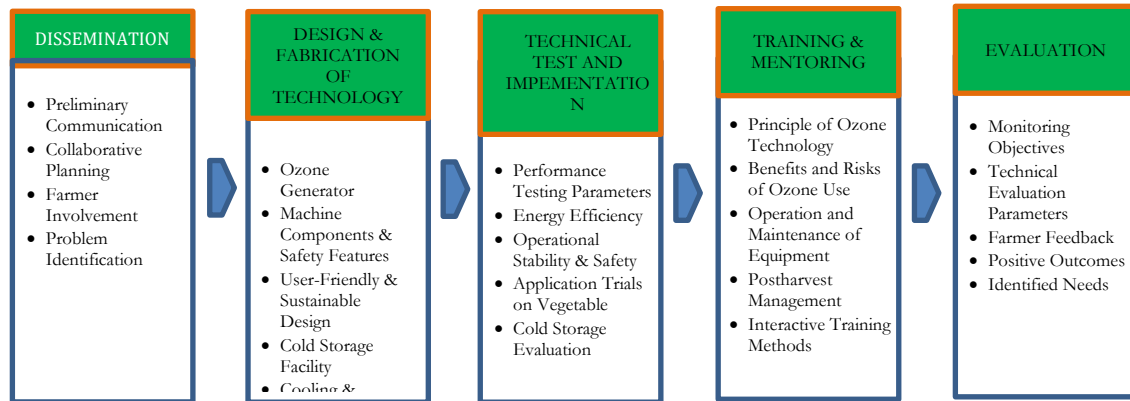


Figure 1. The Workflow of Community Service Activities

At the preliminary stage, communication was established with the farmer group, Perkumpulan Rembulan Asmoro Bangun, to build collaboration and mutual understanding of the objectives, benefits, and implementation of the proposed community service program. An initial data collection process to identify needs is provided during this engagement, assess existing resources and weaknesses, and determine suitable activity models. The active discussions and joint planning between the community service team and the partner group involved in participatory approach. Thus, it strengthened the farmers' sense of ownership and commitment to the program's success.

The primary issue affecting farmers' economic outcomes was the limited shelf life of horticultural products, according to the problem identification. The perishable nature of their produce often led to high postharvest losses, forcing farmers to accelerate harvesting and distribution to prevent spoilage. This practice increased labour requirements, raised operational costs, and frequently caused physical damage during handling and transport. Moreover, early-morning harvesting to reach markets at optimal hours added further costs, while unstable and fluctuating prices weakened farmers' bargaining positions. These challenges emphasised the need for an appropriate preservation technology to extend product shelf life and improve market flexibility.

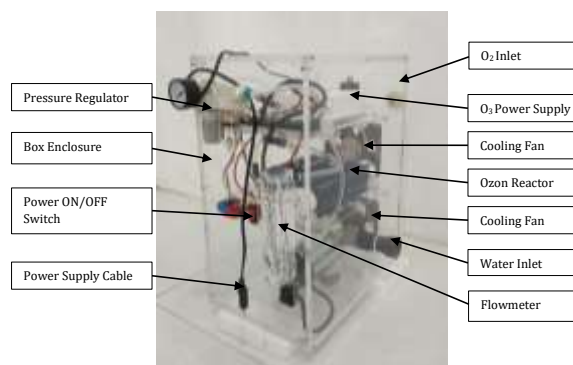


Figure 2. Micro-bubble Ozone Machine Generator

To address these problems, two practical technologies were designed and fabricated: a corona discharge ozone generator, as shown in Figure 2, and a low-cost cold storage chamber, as illustrated in Figure 3. The Micro-bubble ozone generator with venturi injection was constructed with a capacity of 10,000 mg/hour to ensure effective sterilisation of horticultural products (Farizha et al., 2022; Liu et al., 2021; Zhu, 2018). It works by applying a high-voltage charge to air or oxygen, converting oxygen molecules into ozone, which acts as an oxidising agent that inactivates microorganisms responsible for spoilage.

Complementing the ozone generator, a cold storage unit measuring $5 \times 3 \times 3$ meters was developed to suit the partner group's harvest volume and available space, as shown in Figure 3. Foam and aluminium foil are used to insulate the chamber, consisting of polyurethane to maintain low internal temperatures and minimise energy loss. To maintain temperatures between $5\text{--}15^{\circ}\text{C}$ and regulate humidity, it is supported by a 2-horsepower refrigeration unit which consists of a condensing system and electronic temperature control to preserve product freshness and nutritional quality. And to ensure accessibility, stability, and cost efficiency, the cold storage is also equipped with an airtight, insulated door, a pressure-balanced window, and energy-efficient LED lighting.

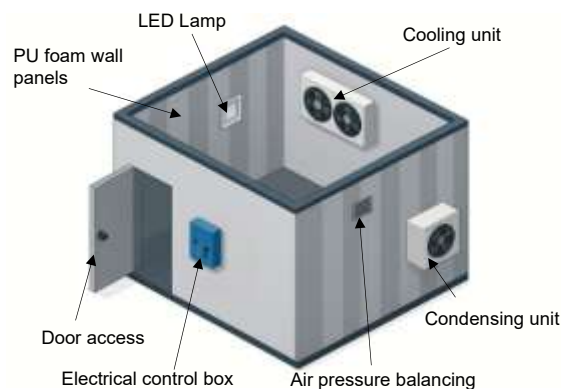


Figure 3. Design of A Low-cost Cold Storage

Moreover, training and mentoring sessions were conducted to enhance farmers' technical competence and understanding of how to use ozone and cold-storage technologies for agricultural products. The training covered the working principle of ozone sterilisation and the proper procedures for safe and effective operation. Participants were introduced to how the machine works, including its startup, adjustment, and turn-off procedures, according to standard operating guidelines. The framers were also trained in maintenance procedures, such as fixing leaking hoses, checking electrical connections, and monitoring pump performance. The sessions further emphasised postharvest management strategies to optimise storage, adjust harvest timing, and

reduce dependence on fluctuating market prices.

Evaluation and monitoring were carried out to assess the program's performance. Key indicators included the program outcomes throughout monitoring and technical objectives results. Moreover, farmers may provide feedback on the benefits and challenges experienced during the program. Nonetheless, continued mentoring and technical support remain essential, particularly in equipment maintenance and troubleshooting, to ensure sustainable long-term utilisation.

Result

Technological Innovation

The program results showed that the Microbubble ozone generator was successfully assembled and operated in accordance with the desired specifications. The assembly process involved the integration of several key components which ensuring user safety. After a series of performance tests, the machine was proven to operate stably, producing ozone at concentrations suitable for post-harvest applications. These findings highlight that the design of this relatively simple machine can be effectively realised within the context of empowering farmer groups.



Figure 4. Micro-bubble Ozone Machine Technical Trial

As shown in Figure 4, the ozone generator underwent technical testing to assess ozone concentration, power consumption, discharge stability, and electrical safety. The tests showed an ozone concentration of 15–25 ppm, sufficient for microbial suppression without damaging the produce (Papachristodoulou et al., 2018; Sarron et al., 2021; de Souza et al., 2018). Such stability further indicates that the discharge mechanism and airflow system within the machine function optimally. The controlled use of ozone is essential to ensure a balance between sterilisation efficacy and product safety, thereby reinforcing the feasibility of adopting this technology at the farmer-group level (Liu et al., 2021; Papachristodoulou et al., 2018; Sarron et al., 2021). Power consumption averaged around 80 watts, demonstrating high energy efficiency suitable for rural operation. Stability tests confirmed consistent performance over repeated use, and safety tests showed no electrical leakage, allowing for safe operation even by non-technical users. Application trials were conducted with fresh vegetables, including chilli peppers and long beans. For the treatment, the vegetables were immersed in ozonated water for 3 to 5 minutes, drained, and transferred into cold storage. The combination treatment between ozone sterilisation and cold storage significantly reduced spoilage, preserved product colour and texture, and effectively extended the storage period.

Meanwhile, the cold storage unit test demonstrated its effectiveness in maintaining a constant low temperature within the range of 5–15°C. This temperature range is sufficiently effective to slow down the physiological processes of fresh vegetables, thereby reducing respiration rates and suppressing microbial activity. Therefore, under these storage conditions, horticultural

products are expected to remain fresh for a longer period of time.



Figure 5. The cold storage facility was constructed for the farmers' group

Postharvest Application Test

The application trials were conducted on vegetables treated with ozone at room temperature. The results indicated that vegetables immersed in ozonated water exhibited greater resistance to deterioration compared to the untreated control samples. Visual changes that commonly appeared on the second or third day, such as wilting, leaf discoloration, or an unpleasant odour, were significantly suppressed in the ozone-treated samples. This finding confirms that ozone technology is effective in slowing down the spoilage process of horticultural products (Sari, Latuserimala, & Ansiska, 2023; Sari, Prawanto, et al., 2023; Wulandari et al., 2022; Yudiastuti et al., 2022).

Furthermore, the harvested vegetables were stored in a cold storage unit at approximately 12°C to enhance the effectiveness of the ozone treatment. The results demonstrated that the combination of ozone and cold storage yielded the best results. Observations showed that vegetables treated with ozone before storage at low temperatures maintained good condition for 3-4 weeks. As a result, the product remained fresh, sustained minimal physical damage, and retained organoleptic qualities such as colour, texture, and aroma.



Figure 6. Comparison of Vegetable Conditions without and with Ozone Treatment after 2 Days

These results demonstrate that the combination and synergy between ozone technology and cold storage can be an innovative solution to post-harvest problems. Ozone acts as a sterilising agent by reducing microorganisms that cause spoilage, while cold storage maintains optimal temperature and humidity levels to slow down plant physiological processes. Through this combination, the shelf life of harvested produce can be significantly extended, giving farmers

greater flexibility in determining the appropriate distribution timing. At the same time, it creates opportunities to achieve more favourable market prices.

Table 1. A Comparative Analysis of Fresh Vegetable Durability under Varying Postharvest Treatments

Treatments	Storage Condition	Durability Average	Product Condition
Without treatment	Room Temp.(28-30°C)	2-3 days	Leaves exhibited rapid wilting, yellowing, and loss of freshness in aroma
Ozone treatment only	Room Temp. (28-30°C)	5-7 days	The leaves retained their green Colour for a longer duration, maintained a fresher texture, with minor deterioration observed on day six
Cold storage treatment only	Temp. 12-15°C	2-3 weeks	The product retained its freshness, exhibited minimal wilting, and maintained acceptable organoleptic quality
Ozone + Cold storage treatment	Temp. 12-15°C	3-4 weeks	The product was in excellent condition, retaining its green Colour, crisp texture, and natural fresh aroma

Table 1 above clearly shows that the combination of ozone treatment and cold storage produced the most optimal results. Fresh vegetables remained in good condition for 3–4 weeks, significantly longer than the control samples, which lasted only 2–3 days. This improvement indicates a synergistic effect: ozone reduces spoilage-causing microorganisms, while cold storage slows the produce's respiration rate. Further observation revealed that vegetables treated with ozone and subsequently stored in cold storage maintained their quality for a significantly longer period than the untreated control, with well-maintained physical and organoleptic properties. These findings reinforce the conclusion that simple technological interventions can be an effective solution for reducing post-harvest losses at the farmer group level while simultaneously increasing the market value of agricultural products.

Mentoring and Training Process

The mentoring process was carried out in several stages: socialisation, technical training, demonstration, and field mentoring. Each stage was designed to progressively strengthen farmers' understanding and skills. During the socialisation phase, the objectives, benefits, and operational concepts of ozone and cold storage technology were introduced to all members of the farmer group. In the technical training stage, participants learned the working principles of ozone generation and cold storage operation through structured instruction and visual demonstrations. Demonstration sessions allowed participants to directly observe ozone sterilisation and cold storage performance on harvested products, fostering practical understanding.



Figure 7. Training and Mentoring on Ozone Machine Operation

Field mentoring was the most intensive stage, conducted through direct supervision and collaborative practice in the farmers' production environment. Participants were divided into small groups to operate the equipment under the guidance of the community service team. Farmers were encouraged to troubleshoot problems, adjust ozone exposure duration, and maintain equipment performance. This participatory mentoring approach promoted active engagement, peer learning, and knowledge sharing among members. Figure 7 illustrates the training and mentoring activities conducted to equip farmers with the skills needed to operate the technology effectively.

Program Outcomes and Farmer Engagement

The mentoring-based implementation produced significant technical and behavioural outcomes. Farmers demonstrated increased competence in operating and maintaining both the ozone generator and cold storage system. They also gained awareness of hygienic post-harvest handling practices and adopted more strategic distribution planning, storing produce until market prices became favourable. Field observations confirmed that ozone treatment combined with cold storage extended the shelf life of vegetables by 3 to 4 weeks, compared to 2 to 3 days without treatment.

In addition to technological improvements, the mentoring process fostered stronger collaboration within the farmer group. Several members emerged as local facilitators who could assist their peers in using the technology, thereby ensuring program sustainability. The integration of training, mentoring, and technology adoption not only enhanced product quality and shelf life but also strengthened farmers' self-reliance, decision-making, and collective capacity in managing post-harvest products effectively.

Social and Institutional Transformation

From a social perspective, changes in farmers' behaviour in handling their harvests are emerging. They have become more aware of the importance of hygienic and sustainable postharvest management. Several farmer group members have even emerged as local champions, serving both as machine operators and mentors for their peers, thereby ensuring the continuity of technology utilisation.

At the institutional level, farmer groups have improved their capacity in manage product distribution strategies. With an extended shelf life, they can now postpone sales until market prices become more favourable. This shift signifies a social transformation in which farmers are no longer bound by traditional practices of quickly selling harvested produce but instead demonstrate a new awareness of managing commodities in a more strategic and competitive manner. Consequently,

institutional strengthening has taken place within farmer groups, empowering them with greater bargaining power to sell higher-quality produce while enjoying greater flexibility in distribution timing.

A summary to comprehend the key findings and impacts of the community service initiative program is provided in Table 2 below.

Table 2. Program Outcomes and Impacts

Aspect	Before Program	After Program	Indicator
Vegetable shelf-life	2-3 days	3-4 weeks (ozone + cold storage)	Field observations
Post-harvest hygiene awareness	Low, no hygiene standard	Improved, applying basic sanitation practices	Observed during sorting and washing
Technical operation skills	Unable to operate equipment	Able to operate and maintain ozone + cold storage units	Demonstrated during mentoring
Distribution strategy	Immediately sell after harvest	Store produce first & sell when the price increases	Shift in sales timing
Social behavior	Conventional, quick sell practices	Increased awareness of efficient and hygienic postharvest management	Farmers can justify storage decisions
Institutional capacity	Low strategic planning at the group level	Strengthened capacity to manage distribution and market timing	Better price outcomes during peak price periods
Bargaining power	Weak position in price negotiation	Higher flexibility and improved selling margin	Better price outcomes during peak price periods

Discussion

Effectiveness of Ozone and Cold Storage Technology

The findings of this program demonstrate that combining ozone treatment with cold storage effectively extends the shelf life and maintains the quality of horticultural products. This result supports previous studies that highlight ozone's potential as a strong oxidising agent capable of inactivating bacteria, fungi, and viruses on fresh produce surfaces (Hidayah et al., 2021; Liu et al., 2021; Sari, Latuserimala, & Ansiska, 2023). The ozone concentration range achieved in this study (15–25 ppm) falls within the optimal range reported in experimental research for post-harvest sterilisation without compromising product quality (de Souza et al., 2018; Papachristodoulou et al., 2018). The system's low energy consumption (± 80 W) and stable performance confirm its suitability for rural farming contexts, where energy efficiency and operational simplicity are critical factors (Hartoyo & Rachma, 2022).

The synergistic effect between ozone treatment and cold storage observed in this study aligns with existing theoretical and empirical frameworks that emphasise the dual benefits of oxidation-based sterilisation and temperature control. Ozone functions as an antimicrobial and antioxidant, suppressing microbial growth, while cold storage slows respiration, enzymatic activity, and moisture loss, thereby maintaining physiological freshness (Sarron et al., 2021). This synergy has been reported to improve the storage quality of perishable products such as spinach, garlic, and carrots (Liu et al., 2021). The extended shelf life of chilli peppers and long beans for up to four weeks achieved in this study corroborates earlier findings that ozone and cold storage together can delay microbial spoilage and preserve organoleptic quality (Tetelepta et al., 2023).

Mentoring Process and Farmer Empowerment

Beyond the technical outcomes, the mentoring process proved crucial in ensuring effective adoption and sustainability of the introduced technology. This multi-stage mentoring model, comprising socialisation, technical training, demonstration, and field practice, follows best practices in community empowerment and participatory technology transfer. Studies on farmer capacity building emphasise that hands-on learning, peer mentoring, and iterative practice foster greater behavioural change and ownership in technology adoption (Davis et al., 2012). The emergence of local facilitators and peer trainers within the farmer group mirrors successful empowerment models in agricultural innovation diffusion, where experiential learning enhances confidence, maintenance skills, and continuity of practice (Bandiera & Rasul, 2006). Consequently, the outcomes observed in this program, including improved farmer competence, reduced post-harvest loss, and enhanced decision-making in market timing, are consistent with established theories of participatory extension and technology adoption in rural communities.

However, some studies also caution that excessive ozone exposure may adversely affect certain produce, causing surface bleaching or phytochemical degradation (Zhu, 2018; Liu et al., 2021). Thus, while the applied dosage and exposure time in this program yielded positive results, further research is recommended to determine optimal parameters for various commodity types under different storage conditions. Future studies should integrate quantitative microbial analyses, biochemical quality assessments, and long-term socio-economic evaluations to strengthen the evidence base for scaling up ozone-cold storage technology in smallholder contexts.

Behavioural and Socio-Economic Impact

The mentoring-based implementation of ozone and cold storage technologies led to significant behavioural change among participating farmers. Improved technical competence, gained through intensive training and hands-on practice, translated into better post-harvest management behaviours. Farmers began applying systematic handling procedures, using ozone treatment and cold storage to maintain product hygiene and freshness before distribution. This shift reduced post-harvest losses, improved storage efficiency, and enhanced farmers' capacity to plan harvest and marketing schedules more strategically.

As farmers developed confidence in operating and maintaining the equipment, they became more proactive in decision-making, particularly regarding the timing of sales. The prolonged freshness and hygienic quality of stored products enhanced their market value, particularly in modern markets that demand high-quality standards (Hartoyo & Rachma, 2022). The ability to store produce for extended periods allowed them to avoid selling during low-price periods, thereby improving income stability. This behavioural change reflects the transition from reactive to strategic marketing practices, aligning with empowerment outcomes described in participatory extension frameworks (Davis et al., 2012). Farmers' improved autonomy in managing production and distribution demonstrates that technological competence can catalyse broader socio-economic resilience.

These findings are consistent with the technology adoption model proposed by Bandiera and Rasul (2006), which emphasises the role of social learning and peer influence in facilitating behavioural change (Bandiera & Rasul, 2006). In this program, group-based mentoring fostered an environment where early adopters shared experiences and encouraged peers to adopt the new technology, creating a network-driven diffusion effect. This aligns with evidence that social networks amplify adoption rates when individuals can observe tangible benefits within their community. Consequently, the integration of mentoring, peer learning, and accessible technology in this initiative not only strengthened technical skills but also fostered sustainable behavioural and economic improvements across the farmer group.

Conclusion

The application of ozone technology and cold storage during the community engagement program in Asmorobangun Village has proven effective in extending shelf life while maintaining the quality of agricultural produce. The combination of ozone treatment with cold storage successfully suppresses microbial activity and slows down the physiological processes of horticultural products, thereby preserving freshness, Colour, texture, and natural aroma for a longer period. This achievement provides a practical solution to the long-standing problem of high post-harvest losses, which have traditionally reduced the economic value of agricultural yields.

Beyond its technical benefits, the technology also generates significant social and economic impacts. The equipment employed is relatively simple, user-friendly, energy-efficient, and environmentally sustainable, as it does not leave harmful residues on the products or in the environment. With this technology, farmers gain greater flexibility in determining harvest and distribution timing, enabling them to market their produce when prices are more favourable. This positive impact enhances the competitiveness of local agricultural products while simultaneously increasing farmers' income opportunities.

Furthermore, the program demonstrates a model of community empowerment based on appropriate technology, well aligned with local needs. The successful implementation in Asmorobangun Village indicates that simple yet well-targeted innovations can strengthen farmers' capacity to manage post-harvest produce more efficiently and sustainably. Supported by training, mentoring, and the involvement of university students, this initiative not only delivers direct benefits to partner farmers but also reinforces the university's mission of advancing applied knowledge. Consequently, this initiative has the potential to be replicated and scaled across other farming communities as a strategic approach to strengthening agrobusiness systems through technological innovation.

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