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Sustainable technology empowerment in functional beverage production

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ABSTRACT

This community service program was aimed at improving the local functional beverage businesses and was focused on the application of a vacuum evaporator as a relevant technology to improve the sustainability and competitiveness of local functional beverage industries. This was a continuation of the program where a sugarcane juice extractor was developed to produce syrup as the base material. Specifically, the goals of the current initiative were 1) improvement of the efficiency of production and quality of the end products, 2) the development of syrup based functional beverages that could be enriched with local nutritious materials, and 3) the empowerment of local entrepreneurs, farmer groups, and women's groups on value-added processing. The project was implemented through participatory training, demonstration of the technology, and hands-on workshops to 40 community members which included, lecturers, students, community leaders and MSME actors. After the vacuum evaporator was installed, there was a 60% reduction in the heating time, a 75% increase in production capacity and syrup viscosity and stability were improved without loss of flavor. As part of preparing tangible outputs, training materials, SOPs, and documentation of prototypes were also prepared. The program achieved enhanced product marketplace and raised MSME income and awareness on sustainable processing. In community-based entrepreneurship, the application of vacuum evaporation community technology demonstrated positive outcomes and innovation of functional beverages.

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INTRODUCTION

Pagelaran Village is located in Malang Regency, East Java. The community is a developing agricultural area, primarily focused on sugarcane cultivation covering approximately 144 hectares. Despite producing around 3,000 tons of sugarcane annually, the community gains little economic benefit due to heavy structural dependence on sugar mills and the absence of local, value-added sugar processing. Farmers earn minimal income because they must sell raw sugarcane at low prices to mills in Krebet Baru and often face losses from rejected harvests that fail to meet rigid processing standards. These

conditions highlight the need to recalibrate the region's agro-industrial focus and better utilize local resources.

According to local stakeholders, farmers and micro, small, and medium enterprises (MSMEs) lack the necessary technical expertise required to maximize the value of sugarcane sap. They also pointed out the absence of processing facilities and the underdeveloped entrepreneurial capabilities of local stakeholders (Ikhram & Chotimah, 2022; Simarmata et al., 2019). Profit distribution inequities arise from the sugarcane sector's dependency on traditional production coupled with an absence of direct market access. These problems illustrate an even greater challenge in Indonesian rural communities where, for example, the lack of technological investment and business acumen results in agricultural products being sold at low value (Nofianti et al., 2024). Building economic resilience and fostering a culture of innovation requires integrated, multi-faceted and developmental interventions that include a balanced technological approach, entrepreneurship, and sustainable business frameworks (Gunawan et al., 2024).

To close these gaps, Universitas Negeri Malang designed the 2024 PkM program by combining technology and building community capacity. In this case, a vacuum evaporator machine was introduced as a new technology to improve the efficiency, hygiene, and quality of the syrup produced from sugarcane sap. This was a continuation of the 2023 program, which, as its primary goal, successfully introduced a sugarcane extractor (sugar mill) to produce raw sugarcane sap. However, the next processing stages were still inefficient due to the time and energy-consuming traditional boiling methods. With the vacuum evaporator, it was expected that production time would be reduced, and the quality of the syrup would be improved to support local entrepreneurs in refining the products of competitive functional beverages.

Aside from the technological improvements (Khan et al., 2023), the program added on participatory training, entrepreneurial mentoring, and training on the health benefits of sugarcane sap syrup as a low glycemic and high antioxidant functional beverage (Anasrulloh & Basiron, 2017; Nofianti et al., 2024), to empower farmers, MSMEs, and women's groups as producers and innovators in rural agro-industry. The program emphasized product diversification in functional beverages and the creation of digital marketing tools and strategies for promotion. The goal here is to establish a sustainable community-based business ecosystem anchored on local assets.

To conclude, the PkM undertaking is indicative of purposive action to reshape the conventional sugarcane industry to a sustainable local industry, anchored on technological innovation, skill development, and the empowerment of the community, as the sugarcane industry is a core rural agro-industry. The integration of appropriate low-glycemic health product innovation into local entrepreneurship is novel and is likely to enhance the resilience of the local economy. Pagelaran is being steered toward becoming an "Agro-Sugarcane Tourism Village" as envisaged, a testament to the alignment of agricultural productivity, technological empowerment, and community empowerment. The development is indicative of Pagelaran's potential for rural development.

METHOD

The community service activity (Abdimas) utilized a Participatory Action Research (PAR) and Technology Transfer approach, focusing on collaboration between the academic team and community partners for problem identification, solution design, and the implementation of innovations aimed at sustainable empowerment. The process was structured into three phases: planning and needs assessment, implementation and technology transfer, and mentoring and evaluation. This approach integrated the scientific method with participatory learning to achieve tangible and measurable impacts, ultimately enhancing the capacity of partners.

The primary partners in this program were sugarcane farmers and MSME groups from Pagelaran Village, Malang Regency, who were engaged in sugarcane farming but had not yet undertaken postharvest processing. A total of 40 participants, including farmers, MSME owners, women's groups, community leaders, lecturers, and students, were involved in the project. The selection of partners for the assessment phase was based on three criteria: (1) direct involvement in sugarcane farming, (2) adaptability to new technology, and (3) potential for the development of local agro-industrial products. These criteria ensured that the beneficiaries accurately represented the local agricultural and business ecosystem.

The planning and needs assessment phase included field observations, semi-structured interviews, and focus group discussions (FGDs) with village officials and sugarcane farmer representatives. These activities were designed to examine the needs of the partners, identify production constraints, and uncover gaps in existing technology. The assessment revealed the lack of hygienic processing methods and low sap concentration in the production process. In response, the Abdimas team proposed a technology-driven intervention plan centered on using a vacuum evaporator machine to improve processing and syrup quality. Collaboration with Universitas Negeri Malang's Culinary Production Laboratory helped identify optimal processing parameters—such as evaporation temperature, viscosity, and flavor stability—necessary for the formulation and testing of quality products.

In the implementation and technology transfer phase, the focus was on providing practical knowledge and skills through Training of Trainers (ToT) sessions and hands-on demonstrations. The Abdimas team organized and facilitated participatory workshops that encompassed several key areas. One component of the training was technology operation, where participants were introduced to the vacuum evaporator, which was designed to ensure hygienic and energy-efficient processing of sugarcane sap. Another key aspect was product diversification, where the team guided participants in developing four distinct functional beverages using sugarcane syrup along with regional ingredients such as ginger, lime, lemongrass, and turmeric. Additionally, the workshops included entrepreneurial skills enhancement, which involved training on branding, eco-friendly packaging design, and promotional strategies utilizing social media platforms like Instagram, TikTok, and WhatsApp Business.

To support the learning process, participants received a technical handbook and a recipe book that included standard operating procedures (SOPs), quality control guidelines, and nutritional information for the sugarcane syrup. At the end of this phase, the vacuum evaporator unit was transferred to the partner group, ensuring that the technology would be sustainably used and maintained. This transfer was integral to the success of the technology implementation and met the objectives of the phase.

The mentoring and evaluation phase took place over one month and focused on assessing the adoption progress of the implemented technology and addressing any updates or issues that arose post-implementation. On-site evaluations were conducted by the Abdimas team, along with consultative mentoring and feedback sessions. Key indicators for evaluation included reductions in processing time, increases in production volume, improvements in syrup texture and taste, season-appropriate syrup quality, and overall participant satisfaction. The feedback on business readiness was essential for maintaining mentoring relationships, which continued online, providing MSME partners with the independence needed to manage and control product quality after the technology transfer.

The methodology combined elements of Participatory Action Research (PAR), which emphasizes cyclical collaboration between researchers and participants in planning, action, and reflection (Cornish et al., 2023), with a technology transfer model to facilitate the diffusion of innovation in local production systems (Livingston & Perkins, 2018). This approach ensured that the outcomes of the program were both socially transformative, fostering self-reliance and entrepreneurship, and technically measurable in terms of productivity and efficiency.

RESULT AND DISCUSSION

The first stage of this community service activity involved a comprehensive situational analysis to ensure that the program addressed the real needs of the target community. This phase began with a preliminary survey aimed at identifying local resources, challenges, and opportunities that could be leveraged for sustainable development.

The assembling and fabrication of the vacuum evaporator machine is a critical phase towards the achievement of this community service project because it has a direct bearing on the overcoming of the technological limitations of sugarcane farmers and MSMEs in the processing of sugarcane juice into high-value products. This can be seen in Figure 1 below:

Figure 1. Various views of the evaporator machine

For macro-scale production (MSME level), a vacuum evaporator machine is essential to increase productivity. The designed evaporator machine has a capacity of 15 liters per batch and functions to generate steam that increases syrup viscosity and removes water content from sugarcane sap. The vacuum process also lowers the boiling point of the sap, ensuring better syrup quality. In processing sugarcane sap syrup, boiling time and temperature must be consistently controlled.

Table 1. Specifications of the vacuum evaporator machine

Machine Type	:	EV 10
Capacity	:	15 liter/proses
Overall Dimensions	:	120 cm x 60 cm x 122 cm
RPM	:	30 rpm
Electric Power	:	400 watt

The vacuum evaporator machine processing stages begin with the feeding stage where sugarcane sap is supplied to the evaporation tank. This machine doesn't just process sugarcane sap but also other raw materials such as fruit juice to produce syrup and milk products, so it can serve multiple purposes. Once the liquid is pumped into the chamber, the vacuum pump is applied to create a low-pressure environment. Reducing the pressure this much drops the boiling point of water significantly, enabling the process of evaporation to occur at a much lower temperature than it would under usual atmospheric pressures. In the following stage, the heating unit is turned on to warm the liquid. Due to the reduced boiling point, water within the solution evaporates at relatively lower temperatures, maintaining the nutritional and sensory qualities of the product. Solution water is evaporated as the process of evaporation continues, while dissolved solids such as sugars and proteins remain in a concentrated form. The resulting vapor is then channeled to the condenser, where the vapor is condensed and brought back into liquid condensate form, which can be collected in a separate manner. Finally, the concentrated liquid product is discharged from the system for further applications in other industries, either for food products like sugarcane syrup and fruit concentrates, for pharmaceutical use for medical extracts, or for industrial operations requiring concentrated solutions. The systematic and controlled operation ensures

efficiency, sanitation, and consistent quality of the final product, aligning with the program's goal of producing high-value, marketable products from sugarcane sap.

Product trials of sugarcane sap herbal syrup serve as an essential stage in transforming raw agricultural resources into innovative, high-value products that are both functional and marketable. This process is not merely about testing recipes but also about ensuring that sugarcane sap, when combined with selected herbal ingredients, produces a beverage with superior taste, health benefits, and commercial potential. The trials are conducted systematically to evaluate formulation accuracy, processing techniques, and sensory acceptance, while also considering nutritional content and product safety. By integrating sugarcane sap with locally available herbs known for their functional properties, the program aims to create a natural sweetener–based product that can promote health, particularly in relation to blood glucose regulation and disease prevention. Furthermore, these product trials are designed to pave the way for standardized production methods that can be easily adopted by farmers and MSMEs, ultimately strengthening innovation, entrepreneurship, and community-based economic growth.

Figure 2. Recipe herbal

Recipe and preparation method for herbal sugarcane sap syrup, comparing conventional boiling and vacuum evaporator processing.

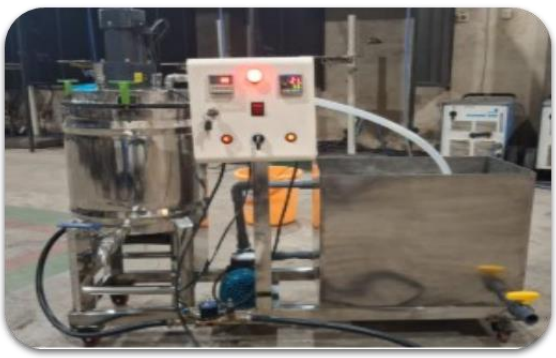

Figure 3. Using an evaporator machine

The second stage of the Abdimas program was the implementation stage, and the activity began with the opening remarks provided by the committee head and the village head, highlighting the importance of collaboration between the academic team and the community. The presentation proceeded with the demonstration of the concentration process in real-time, in which sugarcane sap was being transformed into syrup through the vacuum evaporator machine. The exercise not just proved the viability of the technology but also provided participants with skills to be able to perform it themselves.

Aside from the training of the technical side, the activity also included a presentation of the health advantages of sugarcane sap syrup, the focus of which was its potential as a natural sweetener possessing functional properties that can result in improved health status. To complement the production aspect, stakeholders were also educated on digital marketing as a way to promote sugarcane sap products more effectively. The subject provided exposure to the use of platforms such as Instagram, TikTok, and WhatsApp as part of an attempt to reach wider markets and strengthen product branding.

The activity concluded with the official handover of the vacuum evaporator machine from the team of Abdimas to the Pagelaran Village Head, Malang Regency. The ceremonial act reinforced the purpose of sustainability so that the technology would continue to be utilized by the people for future production and business development.

Figure 4. Documents the abdimas activities conducted in Pagelaran Village, Malang Regency, on 31 July 2025

This Community Service Program has brought tangible impacts that extend far beyond production technology. The program has succeeded in spearheading a broad-based transformation encompassing production activities, product quality improvement, as well as building partners' capacity in marketing and business management. Before innovation adoption, the sugarcane sap syrup manufacture in Pagelaran Village was traditionally conducted using an open evaporation system. The open evaporation system carried several drawbacks, including high risk of contamination, nutrient loss due to excessive heat, and few product shelf lives. These drawbacks resulted

in low market value and narrow marketing coverage—the products were only marketed locally and lacked clear differentiation from other sweet drinks products. The second area of enhancement was production efficiency. In accordance with performance indicators, the conventional equipment required 8.2 hours of boiling at temperatures 70°C and 80°C to evaporate 10 liters of sugarcane sap to yield 1.7 liters of syrup. This was contrasted with requiring 9 hours by means of a vacuum evaporator in order to evaporate 20 liters of sugarcane sap, yielding 2.6 liters of syrup.

The vacuum evaporator technology brought a better quality to the product. With this technology, sugarcane sap evaporation is feasible at low temperatures under vacuum conditions, which preserves the natural nutrients and distinctive flavor of the sugarcane sap. It produces a more hygienic, stable, and nutrient-rich syrup with a longer shelf life. This improved quality is the foundation for rebranding the product as a functional drink, offering not only natural sweetness but also health benefits. The technological revolution has been succeeded by a shift towards broader and sustainable marketing strategies. Several key improvements have been successfully implemented, such as:

Product Branding and Positioning. The syrup of sugarcane sap is now being positioned as a natural local-based functional drink. This position focuses on its health advantage and nutritional value, thus promoting greater consumer appeal to individuals who are increasingly health-oriented and are aware of natural and healthy products.

Market Access Expansion and Brand Visibility. The new strategy allows for easier market access while increasing the product's brand visibility within competitive beverage markets.

Product Certification and Standardization. Enhancing quality allows the product to be potential in compliance with food safety standards, allowing BPOM (National Food and Drug Authority) licensing, Halal certification, and healthy food labeling. Though this stage is not yet instituted due to ongoing preparations in terms of facilities and management systems, it is a clear target for future development.

Digital and Education Promotion. Once approved by BPOM, the product can be promoted through digital and education campaigns, including educative materials on the health benefit of sugarcane sap, reviews from customers, and online promotion activities. This is a crucial function in creating emotional bonds with customers and strengthening the brand image as a local and healthy product.

Use of a vacuum evaporator in the process of concentrating the sugarcane sap in Pagelaran Village is an innovation that closely adheres to food technology literature. Concentration at low temperature allows thermal damage, color alteration, and bioactive compound degradation reduction. For instance, experiments on fruit syrups have shown that low-temperature vacuum evaporation (at around 40°C and vacuum pressure of around 80–100 kPa gauge) provides greater clarity, superior color quality, and lower processing time than open heat processes can achieve (Syakdani et al., 2019). For sugarcane sap products, use of a doubled-effect system adapted to operate under

pressures less than 1 atm enhances energy efficiency in concentration. Experiments in sugarcane sap concentration confirmed that vacuum evaporators effectively increase °Brix levels and thermal efficiency. Similarly, determined that vacuum evaporation in longan syrup concentration could preserve floral notes and reduce caramelization.

With the background of this community service project, the use of vacuum evaporator has been successful in improving the quality of sugarcane sap syrup to a product that is cleaner, rich in nutrients, with longer shelf life, and provides technical grounds for restaging the product as a functional drink. With its improved quality (fewer contaminants, nutrients preserved, longer storage life), the collaborating MSMEs are now in a position to sell sugarcane sap syrup not just as a natural sweetener, but also as a value-added "functional drink." This shift aligns with the literature that illustrates how latest processing technology has the ability to reposition existing products to premium market segments. Technical progress and increased production efficiency are an impetus for marketing transformation, as explicated by Rusdi et al. (2024), who argues that improved product quality forms a new Unique Selling Proposition (USP).

The functional drink made from local ingredients in Pagelaran Village thus captures extra value through technology and branding to enable the product to compete in wider markets than to remain trapped within the very competitive domestic supply chain (Sudirjo, 2023). Furthermore, the product, which is based on local knowledge and health- and sustainability-driven, positions the partners in a strong position in the creative economy and agro-tourism supply chain. This kind of initiative fits with the Asset-Based Community Development (ABCD) approach, which emphasizes that mobilizing local assets and resources can create comparative advantages and strengthen local economic resilience.

CONCLUSION

The program has three implications. One, it demonstrates the technical feasibility of small-scale low-cost vacuum evaporation technology for food processing within the rural areas. Two, it strengthens the local innovation ecosystem by integrating technological development with entrepreneurship. Three, it provides a platform for sustainable functional beverage production, aligned with the principles of SDG 8 (Decent Work and Economic Growth) and SDG 9 (Industry, Innovation, and Infrastructure).

In short, this community service initiative has successfully implemented a contextually appropriate technological innovation that increases production efficiency and product quality and builds local entrepreneurial capacity. Its value added lies not in the promotional success of a single product, but in establishing a replicable model of technology-based empowerment that bridges academic research and community-based innovation. Refinement, scientific validation, and institutional collaboration are needed to ensure the continuity, scalability, and measurable long-term success of the initiative.

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