

Automated *Kalamay Hati* Mixer

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ABSTRACT

This study designed, constructed, tested, and evaluated an Automated Kalamay Hati Mixer intended to reduce the physical demands and process variability associated with continuous manual stirring. A project-development design was combined with a descriptive quantitative evaluation. The machine used a 1.5-horsepower motor, gear-and-pulley transmission, Magkono wooden paddle, 24-inch aluminum wok, digital timer, and kill switch, with a 10-kilogram batch capacity. Ten recorded production trials assessed time and rotational speed across the slurry, caramelization, and setting phases. Fifty Kalamay Hati makers and vendors in Kidapawan City were purposively selected to evaluate durability, materials, and workability through a validated five-point checklist questionnaire. Frequency, percentage, and mode were

used for the acceptability data, while phase durations and speeds were summarized from the trial records. Each trial completed the three-phase process in 3 hours and 30 minutes. The slurry phase averaged 42 minutes and 42 seconds at 30 rpm, the caramelization phase averaged 1 hour, 12 minutes, and 39 seconds at 18 rpm, and the setting phase averaged 1 hour, 34 minutes, and 39 seconds at 11 rpm. Nine of ten durability indicators and eight of ten material indicators had a modal rating of Highly Acceptable. Six workability indicators were Highly Acceptable, while the paddle-lifting mechanism and speed shifting received comparatively lower ratings. The completed mixer demonstrated stable phase-specific operation, consistent batch timing, and strong user acceptance. The machine offers a practical food-processing technology for small-scale producers, although improvements in portability, lifting controls, mechanical guarding, wok capacity, and economic feasibility remain necessary before wider deployment.

Keywords: *automated mixer, Kalamay Hati, food processing technology, mechanical design, workability, product development*

INTRODUCTION

Mixing is a critical food-processing operation because it distributes ingredients, supports heat and mass transfer, and influences the texture and stability of the finished product. The performance of a mixing system depends on the material properties of the food, the geometry of the vessel and agitator, the applied torque, and the control of time and rotational speed (Fellows, 2023; McCabe et al., 2023; Singh & Heldman, 2022). These requirements become more demanding in starch-based and high-viscosity foods because the resistance to flow increases as heating and gelatinization progress (Ahmed & Ramaswamy, 2023; Rao, 2022).

Kalamay Hati is a traditional Filipino delicacy prepared from glutinous rice flour, coconut milk, and sugar. Its desired dense, elastic, and cohesive texture is achieved through prolonged heating and continuous stirring. The manual process can require several hours and exposes producers to repetitive force, heat, fatigue, and batch-to-batch differences. Such concerns are particularly important for household and small-scale enterprises that depend

on physical labor while seeking to preserve traditional product characteristics (Limbaga, 2020; Santos & Magtoto, 2020).

Automated mixing offers a means of standardizing process parameters and reducing operator dependence. Mechanized systems can maintain a controlled motion as viscosity changes, improve reproducibility, and reduce the variation caused by fatigue or inconsistent manual technique (Nakka et al., 2020; Ramaswamy & Marcotte, 2023). However, general-purpose commercial mixers are not always suited to Kalamay Hati because the product becomes highly sticky and requires low-speed, high-torque mixing over a heat source. Locally appropriate equipment must therefore balance mechanical strength, food-contact safety, affordability, ease of operation, and respect for the traditional production process.

The project addressed this need through the development of an Automated Kalamay Hati Mixer with a motor-driven paddle, gear-and-pulley transmission, timer, control switches, and a bolted wok support. The design was intended for a 10-kilogram batch and used decreasing rotational speeds across the slurry, caramelization, and setting phases. In addition to technical performance, the equipment was evaluated by experienced makers and vendors because user judgments of durability, material suitability, and workability are essential to the adoption of locally fabricated food-processing technology (Clark & Paz, 2020; Fernandez & Ocampo, 2020).

This study aimed to design and construct the Automated Kalamay Hati Mixer, test its technical performance in terms of time and speed, and determine its acceptability in terms of durability, materials, and workability. The findings were intended to provide a basis for improving the machine and assessing its potential to support efficient, consistent, and less physically demanding Kalamay Hati production among small-scale producers in Kidapawan City.

Literature Review

Automated Mixing of High-Viscosity Food Products

High-viscosity foods behave differently from low-viscosity liquids because their flow resistance changes with composition, temperature, shear, and processing time. Starch-based pastes and confectionery mixtures may exhibit non-Newtonian behavior and require sufficient yield stress before flow occurs. During heating, gelatinization and moisture loss progressively increase resistance, making stable low-speed torque essential during later processing stages (Padmanabhan & Bhattacharya, 1990; Steffe, 2020; Veluri, 2022).

Automated mixers permit the regulation of time, speed, and mechanical input, thereby supporting repeatable processing. In thick food matrices, constant and appropriate shear can reduce localized scorching, incomplete blending, and inconsistent gel formation. Automated systems are particularly useful when the required stirring period exceeds the practical endurance of an operator (Heldman & Hartel, 2020; Nakka et al., 2020; Ramaswamy & Marcotte, 2023).

Kalamay Hati presents a staged mixing requirement. The early slurry remains relatively fluid and benefits from faster dispersion, the caramelization phase requires moderated rotation as the mixture thickens, and the final setting phase requires high torque at a slower speed. A single-speed general-purpose appliance may therefore be less appropriate than a system designed around the rheological transition of the product (Ahmed & Ramaswamy, 2023; Limbaga, 2020; Rao, 2022).

Mechanical Design and Process Control

Food-processing equipment must be designed according to the expected static and dynamic loads. For a viscous product, the frame, motor, shaft, transmission, bearings, and paddle must withstand increasing torque without excessive vibration, slipping, or misalignment. Gear- and pulley-driven systems are suitable where rotational speed must be reduced while the transmitted force is maintained (McCabe et al., 2023; Singh & Heldman, 2022).

Process control improves consistency by reducing reliance on judgment based only on operator fatigue or experience. A timer provides a repeatable processing interval, while speed adjustment allows the system to respond

to changes in the product. Emergency stopping, stable supports, accessible controls, and adequate separation of the motor from heat are likewise important to safe and dependable operation (Noda & Hirose, 2020; Toledo, 2023).

The proposed mixer used a 1.5-horsepower motor, a mechanical transmission, a 24-inch wok, and a wooden paddle designed to scrape and fold the mixture. This configuration reflects the requirement to match equipment geometry with the food matrix. The use of a timer and phase-specific speed settings also supports the broader principle that process standardization improves reproducibility in batch food production (Fellows, 2023; Ramaswamy & Marcotte, 2023).

Materials, Sanitation, and Equipment Durability

Material selection affects structural reliability, sanitation, maintenance, and product safety. Food-contact and adjacent components should resist corrosion, wear, heat, and cleaning agents. Smooth surfaces and secure joints reduce food retention and support effective cleaning, while structural components must withstand repeated mechanical loading (Brennan & Grandison, 2023; Deak & Johnson, 2020; Gonzales & Cruz, 2020).

The source design combined metal angle bars, stainless components, an aluminum wok, and a Magkono wooden paddle. The metal frame provided load-bearing support, while the wooden paddle was selected to mix the sticky product without damaging the wok. The suitability of this mixed-material construction depends on secure fastening, appropriate cleaning, drying, inspection, and scheduled maintenance (Fellows, 2023; Toledo, 2023).

Durability is not limited to the strength of individual materials. It includes the stability of the assembled structure, resistance to vibration and heat, reliability of the control system, and the ability to maintain performance across repeated batches. User assessment is valuable because locally fabricated equipment may perform adequately during a short test but still present concerns related to storage, handling, maintenance, or long-term use (Clark & Paz, 2020; Gonzales & Cruz, 2020).

Ergonomics, Workability, and User Acceptability

Workability refers to the ease, stability, and functional reliability with which a machine performs its intended task in an actual operating environment. For a food mixer, workability involves continuous motion, sufficient torque, manageable controls, safe loading and unloading, minimal spillage, and the ability to complete a batch without overheating or mechanical interruption (Fellows, 2023; Steffe, 2020).

Automation can also serve an ergonomic function by transferring repetitive force from the operator to the machine. Manual stirring of a thick product requires sustained shoulder, arm, wrist, and grip effort in a hot environment. A mechanized system can lessen these demands, but it must not introduce new risks through exposed transmissions, awkward lifting controls, unstable supports, or difficult cleaning procedures (Santos & Magtoto, 2020; Noda & Hirose, 2020).

Acceptability assessment complements technical testing by determining whether prospective users consider the machine durable, appropriate, and convenient. Experienced producers can identify practical issues that are not immediately visible in design drawings, such as storage difficulty, paddle positioning, speed-shifting behavior, cleaning access, and the handling of a thick mixture. Such feedback supports iterative refinement and improves the contextual relevance of technology (Clark & Paz, 2020; Fernandez & Ocampo, 2020).

Prior Art and Design Gap

The source study compared the proposed mixer with three existing stand-mixer technologies. The prior designs provided useful mechanisms for bowl lifting, head adjustment, heavy-duty support, and general mixing. However, none combined all the features identified as necessary for Kalamay Hati, particularly fully automated operation and a configuration optimized for a viscous, sticky product.

The proposed mixer addressed this gap by integrating a bowl-support mechanism, a tilting or lift-access arrangement, multifunctional processing capability, heavy-duty support, and continuous automated mixing. The comparison established the project's practical design rationale without claiming that the prototype had undergone patentability examination or industrial certification.

Table 1. *Comparison of the proposed mixer with prior-art features*

Technology Feature	Prior Art 1	Prior Art 2	Prior Art 3	Proposed Mixer
Bowl lift mechanism	Present	Absent	Absent	Present
Tilting head mechanism	Absent	Present	Present	Present
Multifunctional processing	Absent	Absent	Present	Present
Fully automated operation	Absent	Absent	Absent	Present
Heavy-duty lifting support	Present	Present	Present	Present
Durable for heavy-duty mixing	Present	Present	Present	Present
Optimized for viscous or sticky food	Present	Present	Present	Present

The study was anchored in automation and process-optimization principles. Its source Input-Process-Output model identified ideas, literature, materials, tools, and equipment as inputs; planning, design, construction, fabrication, testing, revision, and evaluation as processes; and the Automated Kalamay Hati Mixer with an operational manual as the principal output. The framework was retained and redrawn below for legibility.

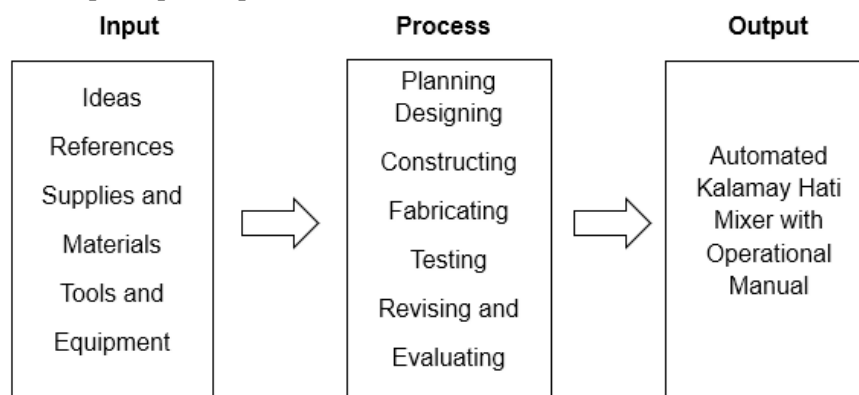


Figure 1. *Conceptual model of the study*

METHODS

Research Design

The study used a project-development design combined with a descriptive quantitative evaluation. The development component covered conceptualization, mechanical design, material selection, construction, assembly, fabrication, prototype testing, revision, and final operation. The descriptive component measured the acceptability of the completed mixer in terms of durability, materials, and workability. No experimental comparison with a manual-control group was conducted.

Research Locale

The machine was developed and evaluated in Kidapawan City, Cotabato, within actual production and kitchen-type settings. The locale was selected because households and local entrepreneurs in the city produce and sell Kalamay Hati and related kakanin products. The setting allowed the prototype to be assessed under conditions resembling small-scale food production.

Participants and Sampling Technique

Fifty respondents composed of Kalamay Hati makers and vendors in Kidapawan City participated in the acceptability evaluation. Purposive sampling was used because the study required individuals with experience in manual Kalamay Hati preparation who could judge the machine's stability, materials, ease of operation, and suitability for the production process.

Research Instrument

A researcher-made checklist questionnaire measured acceptability through three domains: durability, materials, and workability. Each domain contained 10 indicators rated on a five-point scale: 5 - Highly Acceptable, 4 - Acceptable, 3 - Moderately Acceptable, 2 - Not Acceptable, and 1 - Highly Not Acceptable. An open-ended portion allowed respondents to give suggestions for improvement. The instrument was reviewed by three experts and obtained a reported validation score of 3.55, interpreted in the source manuscript as valid.

Design and Development Procedure

The development began with the preparation of the conceptual and mechanical design, including isometric, orthographic, exploded, and electrical-control views. Materials and components were then selected and costed. The metal frame and supports were measured, cut, drilled, welded, and aligned. The motor, transmission, shaft, pulley, belt, paddle mechanism, wok holder, timer, control panel, and kill switch were installed. The prototype was checked for alignment, stability, rotation, and safe operation before performance testing.

The project was completed through a five-week sequence covering planning and design, material preparation, construction and fabrication, testing and revision, and final evaluation. Initial dry runs identified movement of the wok and loosening of the Woodruff key. The wok was secured using bolts and lock nuts, and the key was tightened and secured to the shaft before the evaluation phase.

Performance Testing and Data Gathering Procedure

The detailed trial table in the source manuscript contained 10 production trials. Each trial used 10 kilograms of raw materials and followed three operational phases: slurry, caramelization, and setting. Time and rotational speed were recorded for each phase. Medium heat was applied during the first two phases, and low heat was applied in the setting phase. After prototype testing and revision, the machine was demonstrated to the selected makers and vendors, who completed the acceptability questionnaire.

Data Analysis

Phase durations and rotational speeds were summarized using averages and observed ranges calculated from the recorded trial table. Frequency, percentage, and mode were used to describe respondents' ratings of durability, materials, and workability. The article did not reconstruct standard deviations because coefficient-level outputs were not reported in the source results.

Ethical Consideration

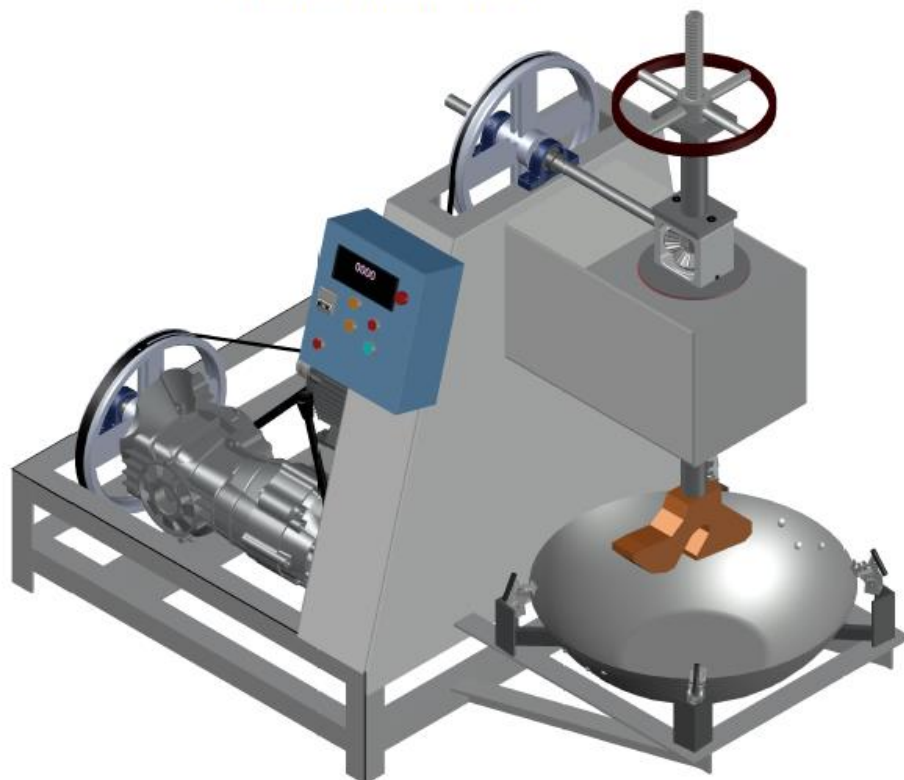
The evaluation involved adult producers and vendors, and findings were reported in aggregate rather than by respondent name. The source manuscript included administrative request and validation documents but did not state a formal institutional ethics-review approval number or a detailed informed-consent protocol. Accordingly, this article does not claim an ethics approval identifier that was not provided in the source.

RESULTS AND DISCUSSION

Design and Construction of the Automated Kalamay Hati Mixer

The completed design integrated the drive, mixing, support, and control components into a single machine. The motor and transmission generated continuous one-direction rotation, the paddle folded and scraped the mixture, the bolted wok reduced movement, and the timer standardized the operating period. The motor was positioned away from the principal heat source, while the metal frame carried the combined load of the wok, ingredients, mixing mechanism, and transmission.

Front Isometric View

*Figure 2. Front isometric design of the Automated Kalamay Hati Mixer*

The construction process translated the drawings into a functional prototype through frame assembly, motor and transmission installation, connection of the belt-and-pulley system, mounting of the Magkono paddle, installation of the timer and kill switch, alignment, and surface finishing. The completed machine maintained the traditional wok-based heating arrangement while mechanizing the continuous stirring task.



Figure 3. Completed Automated Kalamay Hati Mixer prototype

Table 2. Principal technical specifications and development cost

Specification	Description
Machine type	Automated Kalamay Hati Mixer
Motor	1.5-horsepower electric motor
Transmission	Gear-and-pulley system with phase-specific speed control
Batch capacity	10 kilograms
Mixing container	24-inch aluminum wok
Mixing paddle	Magkono wooden paddle
Control system	Digital timer with kill switch
Mixing motion	Continuous one-direction rotation
Material cost	PHP 20,343.00
Labor cost	PHP 10,000.00
Total project cost	PHP 30,343.00

The total project cost was PHP 30,343.00, consisting of PHP 20,343.00 for materials and PHP 10,000.00 for fabrication and technical labor. The relatively compact cost supports the machine's relevance to small-scale production, although the study did not include return-on-investment, electricity consumption, maintenance cost,

depreciation, or production-volume analysis. These economic variables remain necessary before commercial adoption can be established.

Testing, Revision, and Prototype Stability

Table 3. *Defects identified during testing and revisions made*

Defect Identified	Revision Made
The wok moved during the mixing operation.	The wok was secured using bolts with lock nuts to keep it firmly in place.
The Woodruff key loosened and detached during operation.	The key was tightened and secured to the shaft to prevent loosening or detachment.

The revisions illustrate the value of iterative prototyping. Wok movement and key loosening could have caused vibration, loss of alignment, interrupted rotation, or unsafe operation. Securing these components improved stability before the user evaluation. The source recommendations to enclose the rear mechanical system and improve the lifting control show that the prototype remained a developmental machine rather than a fully certified commercial food-processing unit.

Technical Performance in Time and Speed

Table 4. *Summary of the 10 recorded performance trials*

Mixing Phase	Speed	Average Time	Observed Range	Process Characteristic
Phase 1: Slurry	30 rpm	0:42:42	0:40:45-0:45:15	Initial blending and lump reduction
Phase 2: Caramelization	18 rpm	1:12:39	1:10:30-1:14:30	Increasing viscosity and sugar integration
Phase 3: Setting	11 rpm	1:34:39	1:33:45-1:35:15	Dense, elastic, high-resistance mixing
Total process	-	3:30:00	3:30:00 in every trial	Complete 10-kg batch cycle

All 10 trial records produced a total process time of 3 hours and 30 minutes. Phase 1 had the shortest duration and the highest speed because the mixture remained relatively fluid. Phase 2 required a slower speed as caramelization increased viscosity, while Phase 3 had the longest duration and lowest speed because the dense mixture created greater mechanical resistance. The consistent total time and fixed phase speeds indicate stable and repeatable operation under the recorded 10-kilogram batch conditions.

The progressive reduction from 30 to 18 and then 11 rpm was appropriate to the changing rheological condition of the product. High-viscosity food systems commonly require lower speed and greater torque as resistance increases (Ahmed & Ramaswamy, 2023; Rao, 2022; Steffe, 2020). The results demonstrate technical consistency but do not establish superiority over manual mixing because no controlled manual benchmark, sensory test, energy analysis, or product-quality measurement was included.

Acceptability in Terms of Durability

Table 5. *Acceptability of the mixer in terms of durability*

Indicator	Rating 5	Rating 4	Rating 3	Mode	Interpretation
Bolted 24-inch wok provides stable cooking and mixing	43 (86%)	7 (14%)	0	5	Highly Acceptable
Suitable for Kalamay Hati production	40 (80%)	10 (20%)	0	5	Highly Acceptable
Motor is positioned away from the heat source	36 (72%)	9 (18%)	5 (10%)	5	Highly Acceptable

Heavy-duty base minimizes vibration	28 (56%)	19 (38%)	3 (6%)	5	Highly Acceptable
Manageable design allows easy storage	3 (6%)	27 (54%)	20 (40%)	4	Acceptable
Stable at different mixing speeds	27 (54%)	23 (46%)	0	5	Highly Acceptable
Magkono paddle is suitable for thick mixtures	31 (62%)	17 (34%)	2 (4%)	5	Highly Acceptable
Stainless coupling tube provides a strong hold	33 (66%)	17 (34%)	0	5	Highly Acceptable
Belt-and-pulley system remains stable	31 (62%)	16 (32%)	3 (6%)	5	Highly Acceptable
Metal frame securely supports all components	33 (66%)	15 (30%)	2 (4%)	5	Highly Acceptable

Nine of the 10 durability indicators had a mode of 5, or Highly Acceptable. Respondents particularly recognized the stable wok support, suitability for Kalamay Hati, position of the motor, stable operation, strong coupling, transmission stability, and metal frame. The only indicator with a mode of 4 concerned storage, reflecting the machine's weight and size. The result indicates structural confidence but also identifies portability as a practical design limitation.

Acceptability in Terms of Materials

Table 6. *Acceptability of the mixer in terms of materials*

Indicator	Rating 5	Rating 4	Rating 3	Mode	Interpretation
Aluminum wok supports continuous mixing	11 (22%)	29 (58%)	10 (20%)	4	Acceptable
Magkono paddle is safe for food contact	21 (42%)	17 (34%)	12 (24%)	5	Highly Acceptable
Belt-and-pulley system operates without slipping	15 (30%)	24 (48%)	11 (22%)	4	Acceptable
Magkono paddle does not damage the wok	32 (64%)	18 (36%)	0	5	Highly Acceptable
Timer supports precise mixing-time settings	26 (52%)	24 (48%)	0	5	Highly Acceptable
Stainless surfaces are easy to clean	31 (62%)	17 (34%)	2 (4%)	5	Highly Acceptable
Stainless coupling tube provides a strong connection	22 (44%)	16 (32%)	12 (24%)	5	Highly Acceptable
Bolts provide secure fastening	34 (68%)	10 (20%)	6 (12%)	5	Highly Acceptable
Angle-bar frame provides structural support	44 (88%)	3 (6%)	3 (6%)	5	Highly Acceptable
Gear transmission supports speed adjustment	29 (58%)	11 (22%)	10 (20%)	5	Highly Acceptable

Eight of the 10 material indicators had a modal rating of Highly Acceptable. The strongest response was for the structural support of the angle-bar frame, followed by secure fastening, cleanable surfaces, and the Magkono paddle's compatibility with the wok. The aluminum wok and belt-and-pulley operation received modes of 4, indicating that respondents considered them acceptable but less strongly than the frame, timer, bolts, and paddle.

The positive material assessment supports the use of durable, cleanable, and structurally adequate components in locally fabricated equipment (Brennan & Grandison, 2023; Deak & Johnson, 2020). Nevertheless, user acceptability does not substitute for formal food-contact certification, corrosion testing, hygienic-design inspection, or long-term fatigue testing. These technical verifications are needed before commercial production or regulatory approval.

Acceptability in Terms of Workability

Table 7. *Acceptability of the mixer in terms of workability*

Indicator	Rating 5	Rating 4	Rating 3	Mode	Interpretation
Handles the mixture without overloading	17 (34%)	23 (46%)	10 (20%)	4	Acceptable
Operates smoothly and continuously	34 (68%)	16 (32%)	0	5	Highly Acceptable
Steering wheel easily lifts and lowers the paddle	2 (4%)	18 (36%)	31 (62%)	3	Moderately Acceptable
Time and speed produce proper consistency	22 (44%)	14 (28%)	14 (28%)	5	Highly Acceptable
Combines ingredients without splashing or spilling	29 (58%)	10 (20%)	11 (22%)	5	Highly Acceptable
Operates continuously without overheating	35 (70%)	11 (22%)	6 (12%)	5	Highly Acceptable
Wok remains stable at varying speeds	23 (46%)	13 (26%)	14 (28%)	5	Highly Acceptable
Paddle mixes ingredients evenly	19 (38%)	20 (40%)	11 (22%)	4	Acceptable
Shifts speeds with controlled interruption	12 (24%)	19 (38%)	19 (38%)	4 and 3	Acceptable/Moderately Acceptable
Frame prevents movement during operation	20 (40%)	12 (24%)	18 (36%)	5	Highly Acceptable

Six workability indicators had a mode of 5. Respondents recognized smooth and continuous operation, coordination of time and speed, control of splashing, resistance to overheating, wok stability, and frame support. Handling the load and uniform mixing received modes of 4. The paddle-lifting steering wheel received a mode of 3, and speed shifting produced a tie between ratings 4 and 3. These findings show that the core mixing function was accepted, while manual adjustment mechanisms remained the principal usability concern.

The source study concluded that the mixer was highly acceptable overall. The pattern of responses supports this conclusion because low ratings of 1 or 2 were absent from all three domain tables. However, the machine's adoption should be based not only on acceptance but also on improvements to lifting ergonomics, portability, guarding, sanitation, and mechanical adjustment. User-centered refinement is especially important for small enterprises in which one operator may be responsible for loading, monitoring, unloading, cleaning, and storage (Clark & Paz, 2020; Fernandez & Ocampo, 2020).

Development Implications

The Automated Kalamay Hati Mixer demonstrated that a traditional, labor-intensive process can be partially mechanized without abandoning the use of a wok and a product-specific paddle. Its stable 3-hour-and-30-minute cycle and phase-specific speeds provide a basis for standardized operation. The machine's strongest contribution is the transfer of continuous stirring from the operator to a controlled mechanical system, which may reduce physical demand and improve repeatability.

The evidence remains developmental. The study did not measure energy use, sensory quality, moisture, texture, color, microbial safety, cleaning time, operator muscle load, productivity relative to manual mixing, or long-term durability. The findings therefore support prototype functionality and user acceptability rather than definitive claims of industrial efficiency, food-safety compliance, profitability, or product-quality superiority.

CONCLUSION

The study successfully designed and constructed an Automated Kalamay Hati Mixer capable of processing a 10-kilogram batch through slurry, caramelization, and setting phases. The integration of a 1.5-horsepower motor, mechanical transmission, Magkono paddle, bolted wok support, timer, and kill switch enabled continuous one-direction mixing. Across the 10 recorded trials, every batch completed the three phases in 3 hours and 30 minutes, with rotational speed decreasing from 30 rpm to 18 rpm and 11 rpm as the mixture became more viscous.

Experienced makers and vendors rated most durability, material, and workability indicators as Highly Acceptable. The results indicate that the prototype was stable, structurally supported, suitable for the intended thick mixture, and generally reliable during operation. The lower assessments for storage, paddle lifting, load handling, and speed shifting identify clear priorities for further development. The project contributes a locally fabricated food-processing solution that can support more consistent production and reduce dependence on prolonged manual stirring, but additional engineering, food-safety, economic, and comparative testing is required before commercialization.

Recommendation

The lifting mechanism should be redesigned to make raising and lowering the paddle easier and safer. The wok may be enlarged or reshaped with a lower slope to increase capacity and reduce spillage, while the frame may be made more portable through wheels, detachable sections, or weight reduction without compromising stability. The exposed rear transmission should be enclosed to reduce contact, contamination, and component damage.

Future versions should examine refined glutinous rice flour, alternative heat sources such as induction, and technically feasible renewable-energy options such as solar-assisted power. A formal return-on-investment and cost-effectiveness study should include electricity, labor savings, maintenance, depreciation, repair, and production capacity. Food-contact materials, sanitation, electrical safety, guarding, and emergency controls should be evaluated against applicable standards.

Future research should compare automated and manual mixing under equivalent batches and measure processing time, energy use, operator workload, texture, moisture, color, sensory acceptability, microbial safety, cleaning time, and long-term component wear. Testing with larger and more diverse groups of producers and repeated commercial-scale operation would provide stronger evidence of reliability, scalability, and market feasibility.

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