Mindanao Journal of Science and Technology Vol. 24 (2) (2026) 258-275

Development and Performance Evaluation of a Screw-Type Juice Extractor with a Perforator Assembly for Philippine Lime (*Citrofortunella microcarpa*)

Monalyn L. Oloroso*, Arlyn C. Olmo, Efren L. Linan, Darwin Quirao, and Lorelen V. Rano
Department of Agricultural and Biosystems Engineering
Capiz State University, Burias Campus
Mambusao, Capiz, 5807, Philippines
**mloloroso@capsu.edu.ph*

Date received: July 12, 2022
Revision accepted: August 30, 2026

Abstract

In this study, a screw-type juice extractor with a perforator assembly for Philippine Lime (Citrofortunella microcarpa) or calamansi was fabricated and evaluated, and its capacity, extraction rate, extraction efficiency, and percentage of broken seeds were assessed. The essential components of the machine include a perforator assembly, screw-type extraction chamber, feeding hopper, residual outlet, juice outlet, power transmission assembly, and support frame. In operation, the perforator assembly punctures the fruits prior to extraction in the screw-type extraction chamber. The juice extracted is collected from the juice outlet while the peel, pulp, and seeds are discharged through the residual outlet. Performance evaluation showed that the machine has an input capacity of 124.80 kg h^{-1} and an extraction efficiency of 89.7% which is higher than the minimum standard based on Philippine Agricultural Engineering Standards for Multi-Crop Juice Extractors of 75%. This study provides a new reference for the improvement of a calamansi juice extractor with improved extraction performance and operational efficiency.

Keywords: calamansi, juice, juice extractor, perforator, extraction efficiency

1. Introduction

Calamansi or Philippine lime (*Citrofortunella microcarpa*) is an important citrus fruit in the Philippines and is widely utilized in the food and beverage industry for juice, concentrates, and other value-added products. This fruit, however, is highly perishable after harvest and is susceptible to spoilage caused by mechanical, chemical, and environmental factors, thus necessitating processing into juice (Bayogan, 2025; Ladaniya, 2010). Efficient juice extraction is therefore essential to reduce postharvest losses and maintain product quality.

Juice extraction may be performed using traditional or mechanical methods. Traditional extraction practices such as manual squeezing and pressing are labor-intensive, time-consuming, and generally yield low juice recovery. Consequently, mechanical extraction systems have been developed to improve processing efficiency and capacity.

Several studies have reported the development of mechanical juice extractors using different extraction mechanisms. Olaniyan (2010) developed a small-scale motorized orange juice extractor utilizing a worm-shaft mechanism for conveying and pressing fruits. Boih (2015) designed a motorized extractor incorporating a chopping compartment prior to extraction. Peter *et al.* (2017) introduced a horizontal juice extractor employing a rotating spindle for fruit compression, while Qian and Ling (2018) developed a roller-type juicer using concave and convex rollers. For calamansi processing, Madamba and Rafosala (2021) developed a juice extractor equipped with a slicer section to facilitate juice extraction.

From the reviewed literature, juice extraction systems utilize cutting or compression mechanisms that may result in seed and peel damage, particularly in small citrus fruits such as calamansi. Based on the literature reviewed, no study was identified that reported the use of a perforator assembly as a pre-conditioning mechanism in calamansi juice extraction. Hence, this study aimed to develop and evaluate a screw-type calamansi juice extractor integrated with a perforator assembly designed to puncture fruits prior to compression. The performance of the developed machine was evaluated in terms of input capacity, juice recovery, extraction rate, extraction efficiency, and broken-seed recovery. The developed machine is intended to improve extraction efficiency, preserve juice quality, and enhance overall operational performance.

2. Methodology

2.1 Materials

The calamansi juice extractor was fabricated using food-grade and corrosion-resistant materials suitable for handling acidic fruit juice. The materials used included AISI 304 stainless steel sheet, stainless steel pipe, stainless steel plate, stainless steel welding rods, stainless steel shafting rod, stainless steel round bars, angle bars, pillow blocks, bolts and nuts, v-belt and pulley, stainless steel drill bit, push-button switch, rubber ball caster wheel, single-phase electric motor, speed reducer, epoxy primer, and consumables. The materials were selected based on availability, strength, toughness, and corrosion resistance against acidic fruit juice. In evaluating the machine, the following materials and devices were used: calamansi fruits having uniform maturity and size, graduated cylinder, digital weighing scale (Lotus DS30X, Lotus Tools Philippines), stopwatch (Casio HS-3V-1R, Casio Computer Co., Japan), stainless steel containers, masking tape, kilowatt-hour meter (Benetech Micro power monitor GM86, Shenzhen Jumaoyuan Science and Technology Co., Ltd., China), rubber gloves, apron, and hair net.

2.2 Description and Operation of the Fabricated Calamansi Juice Extractor

The calamansi juice extractor developed in this study was fabricated to provide continuous juice extraction suitable for medium-scale processing. The design was based on the physical characteristics of calamansi fruits and the need to achieve efficient juice recovery while minimizing excessive mechanical damage during extraction.

The machine consists of seven major components: the main support frame, feeding hopper, perforator assembly, extraction chamber, residual outlet, juice outlet, and power transmission assembly (Figure 1).

The extraction system integrates a perforator assembly and a screw-type conveying mechanism to facilitate controlled fruit compression and continuous juice discharge. The perforator assembly punctures the fruits before compression, thereby reducing resistance during extraction and facilitating juice release. The screw conveyor then conveys and compresses the fruits, allowing juice to pass through the perforated chamber while solid residues are discharged separately. All juice-contact components were fabricated using food-grade AISI 304 stainless steel to ensure corrosion resistance and hygienic operation. The machine was powered by a 1 hp single-phase electric motor, connected via a belt–pulley transmission to achieve the required rotational speed for continuous extraction.

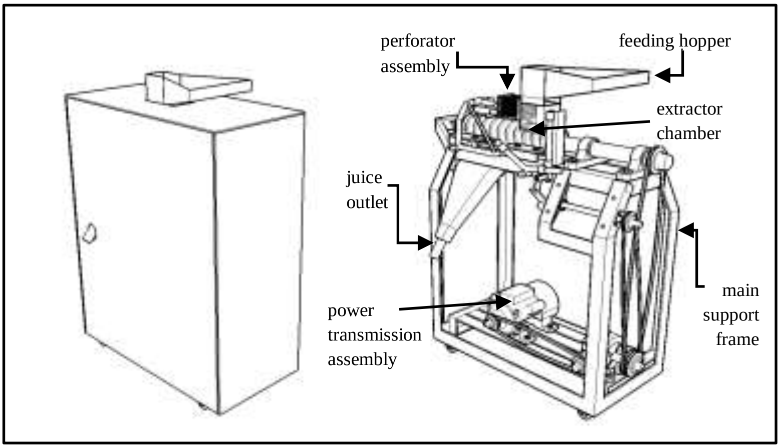

Figure 1. The isometric view of the Calamansi Juice Extractor with housing (a), and isometric assembly drawing of the Calamansi Juice Extractor without the housing, showing the internal components and their relative arrangement, and showing the major components (b)

2.3 Fabricated Components and Design Basis

2.3.1 Screw Conveyor and Extraction Chamber

The screw conveyor and extraction chamber serve as the main extraction unit of the fabricated machine, providing continuous conveying and compression of the fruits during operation. The screw conveyor was fabricated from AISI 304 stainless steel with an outer diameter of 75 mm, a shaft diameter of 38 mm, and a screw pitch of 50 mm. The screw flights were fabricated and welded onto the shaft following standard machining and welding procedures to ensure structural stability and continuous conveying performance.

The fabricated screw conveyor was selected in accordance with PAES 234:2008 (Philippine Agricultural Engineering Standard, 2008b) and at the design input capacity of 100 kg h^{-1}, considering the bulk density of calamansi fruits at 512 kg m^{-3}. It was powered by an electric motor to ensure continuous extraction. The screw operating speed of 60 rpm was estimated using the general screw conveyor capacity equation from ANSI/CEMA Standard No. 350 (CEMA, 2021), as shown in Equation 1:

$$\boldsymbol{N} = \frac{Q_v}{60\left(\frac{\pi}{4}\right)(D^2)(S)(\alpha)} \tag{1}$$

Where,

N = screw speed, rpm
Q_v = the volumetric capacity of the extractor, $m^3\ h^{-1}$
D = screw diameter, m
S = screw pitch, m/rev
α = loading ratio (0.25 for materials with average flowability)

On the other hand, the extraction chamber had a fabricated length of 0.50 m and consisted of a cylindrical housing drum made of AISI 304 stainless steel with strategically placed slits for juice passage. Inside, the screw conveyor, with a central shaft, compresses the fruit to extract juice. A grater plate at the discharge end provides final pressing and directs the expelled peel, pulp, and seeds toward the residual outlet.

2.3.2 Perforator Assembly and Feeding Hopper

The perforator assembly was fabricated as a 5 cm × 5 cm × 5 cm enclosure containing multiple sharpened AISI 304 stainless steel round bars mounted perpendicularly on a plate. Each round bar measures 2 mm in diameter and 5 cm long, arranged at 5 mm spacing, and is sharpened at one end. The perforators were mounted perpendicularly on a supporting block plate and oriented toward the perforated tube enclosure. A slider–crank mechanism converts rotary motion from the drive pulley into reciprocating linear motion, enabling controlled inward–outward perforation of the fruits prior to compression. The perforator assembly was fabricated to puncture the fruit surface without excessive crushing, thereby reducing extraction resistance and facilitating juice release before screw compression.

The fabricated feeding hopper was constructed from AISI 304 stainless steel and mounted by firm welding above the perforator assembly to enable gravity-assisted feeding. The hopper has a total fabricated volume of 0.00557 m^3 (5568.75 cm^3), accommodating approximately 2.85 kg of calamansi fruits per loading cycle. The hopper geometry ensures continuous fruit flow toward the perforator assembly during machine operation.

2.3.3 Power Transmission Assembly

The power transmission assembly consists of a single-phase electric motor, speed reducer, pulleys, V-belts, and a push-button switch, which collectively provide rotational motion to both the screw conveyor and perforator mechanism. A 1 hp single-phase electric motor was selected based on standard efficiency correction relationships for electric motor–transmission systems. The mechanical power requirement of the extractor was determined using the screw conveyor power relationship described by Olaniyan (2010), shown in Equation 2:

$$P = \frac{QL\rho_d gF}{3.6} \tag{2}$$

Where:

P = power required to drive the machine (W)
Q = theoretical machine capacity ($m^3\ h^{-1}$)
L = length of shaft (m)
ρ_d = density of materials ($kg\ m^{-3}$)
g = acceleration due to gravity ($m\ s^{-2}$)
F = material falling factor

Using the information from the design and operating parameters of the calamansi juice extractor: Q = 0.9 m^3/hr, L = 0.5m, ρ_d = 512 kg/ m^3 (calamansi fruit), g = 9.8 m/s^2, F = 1, the computed power required to drive the machine (P) is 627 W.

For the computation of size of electric motor, factors such as efficiency of the electric motor (90%) and transmission system (95%) was considered. The size of the electric motor was determined using Equation 3.

$$P_{motor} = \frac{P}{E_m \times E_t} \tag{3}$$

Where:

P_{motor} = size of electric motor (W)
P = power required to drive the machine (W)
E_m = efficiency of electric motor (%)
Et = efficiency of transmission system (%)

The size of the electric motor is 733.33 W or 0.98 HP. Therefore, a 1 Hp single phase electric motor was used.

2.3.4 Main Support Frame

The main support frame is fabricated from AISI 304 stainless steel, welded into a rectangular structure with multiple legs for stability. It is equipped with rubber caster wheels for mobility and a handle for manual positioning. The upper section supports the perforator, extraction chamber, hopper, juice outlet, and residual outlet, while the lower section houses the motor and speed reducer. All components are securely welded to maintain structural integrity.

2.3.5 Juice and Residual Outlets

The juice outlet was fabricated from AISI 304 stainless steel sheet and positioned at the bottom portion of the extraction chamber to allow continuous drainage of extracted juice. During operation, the outlet directs the juice toward a collection channel and into a receiving container. The residual outlet, also fabricated from AISI 304 stainless steel sheet, was installed at the discharge end of the extraction chamber to channel peel, pulp, and seeds away from the extraction unit. The placement of these outlets enables efficient separation of liquid and solid fractions during continuous operation.

2.3.6 Summary of Fabricated Machine Specifications

The fabricated specifications of the developed calamansi juice extractor are summarized in Table 1. These parameters represent the actual dimensions, operating conditions, and material specifications used during fabrication.

Table 1. Fabricated specifications of the calamansi juice extractor

Parameter	Specification
Screw outer diameter	75 mm
Screw shaft diameter	38 mm
Screw pitch	50 mm
Extraction chamber length	0.50 m
Screw operating speed	60 rpm
Perforator enclosure size	5 cm × 5 cm × 5 cm
Perforator rod diameter	2 mm
Perforator rod length	5 cm
Perforator spacing	5 mm
Feeding hopper volume	0.00557 m^3

Hopper loading capacity	2.85 kg
Motor rating	1 hp single-phase
Material (juice-contact parts)	AISI 304 stainless steel

2.4 Performance Evaluation

The Input-Process-Output (IPO) Framework was used to evaluate the performance of the screw-type calamansi juice extractor with a perforator, as shown in Figure 2.

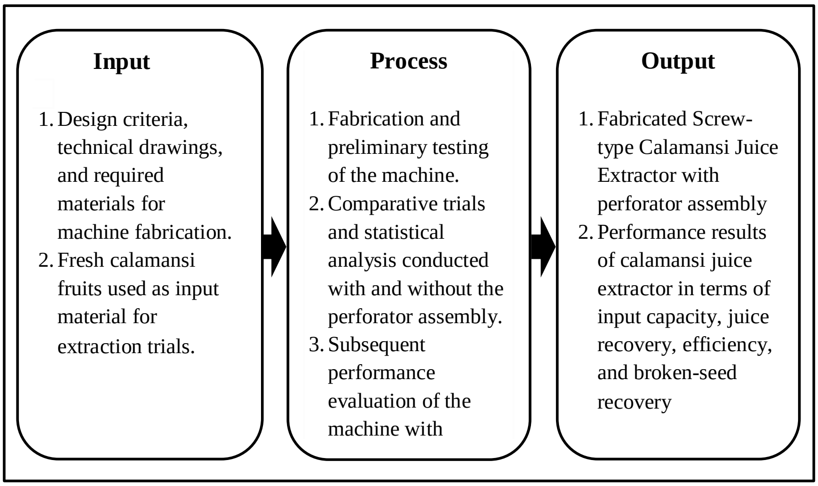

Figure 2. Conceptual Framework of the Screw-type Calamansi Juice Extractor

The extraction performance parameters were based on PAES 235:2008 (Philippine Agricultural Engineering Standard, 2008a). The parameters are as follows:

Input capacity was determined by subtracting the remaining calamansi fruits from the previously prepared test materials (130 kg) divided by 1 hour of operation. It was computed using Equation 4:

$$C_i = \frac{W_i}{T_i} = \frac{130\ kg - weight\ left}{T_i} \quad (4)$$

Where:

C_i = input capacity, kg h^{-1}

W_i = weight of input calamansi fruits, kg

T_i = time required to extract the juice of the input calamansi material, hr

Juice recovery is the ratio of extracted calamansi juice collected from the juice outlet gathered using an electric weighing scale and was divided by the total weight of the input calamansi fruits, expressed in percent. It was computed using Equation 5:

$$R_o = \frac{W_f}{W_i} x\ 100 \tag{5}$$

Where:

R_o = juice recovery, %
W_f = weight of extracted calamansi juice collected from juice outlet, kg
W_i = weight of input calamansi fruits, kg

Calamansi meal recovery is the ratio of the weight of the calamansi meal collected from the meal outlet gathered using an electric weighing scale and was divided by the weight of input calamansi fruits, expressed in percent. It was computed using Equation 6:

$$M_r = \frac{W_m}{W_i}\ x\ 100 \tag{6}$$

Where,

M_r = test calamansi meal recovery, %
W_m = weight of calamansi meal collected from the meal outlet, kg
W_i = weight of input calamansi fruits, kg

The extraction rate is the quantity of calamansi juice extracted per unit of time, expressed in kilograms per hour. It was computed using Equation 7:

$$E_r = \frac{W_f}{T_t} \tag{7}$$

Where,

E_r = extraction rate, kg h^{-1}
W_f = weight of calamansi juice collected from the calamansi juice outlet, kg
T_t = total operating time, hr

Extraction loss refers to the percentage of extracted calamansi juice that was not discharged through the designated juice outlet but was instead collected from other machine components during operation. It was determined by measuring the weight of juice lost relative to the total weight of juice extracted. It was computed using Equation 8:

$$E_L = \frac{W_L}{W_{TJ}} x\ 100 \quad (8)$$

Where,

E_L = extraction losses, %
W_L = Weight of juice collected other than from juice outlet, kg
W_j = total weight of extracted calamansi juice, kg

Extraction recovery refers to the percentage of juice successfully recovered after accounting for extraction losses during the juicing process. It represents the effective performance of the machine in minimizing losses. It was computed using Equation 9:

$$Re = 100 - EL \quad (9)$$

Where,

Re = Extraction recovery, %
EL = Extraction losses, %

Potential Juice Content refers to the theoretical amount of juice that can be obtained per unit time from the input material based on its initial moisture content. In this study, the initial moisture content was used to estimate the potential juice content under ideal conditions. It was computed using Equation 10:

$$P_{JC} = \frac{MC_i}{100} x\ Wi \quad (10)$$

Where,

PJC = Potential juice content, kg
MCi = Initial moisture content of crop, %
Wi = Weight of input material, kg h^{-1}

Extraction efficiency of the Machine is determined using Equation 11, shown below:

$$E_E = \frac{W_f}{cW_i} x\ 100 \quad (11)$$

Where,

E_E = extraction efficiency, %

W_f = Weight of calamansi juice collected from the calamansi juice outlet, kg

W_i = Total weight of the input calamansi fruits, kg

c = initial moisture content used as the theoretical juice fraction, decimal

The extraction efficiency was calculated only from the juice collected at the designated juice outlet, while juice collected from other machine components was accounted for separately as extraction loss.

Moisture Content refers to the amount of water present in the sample expressed as a percentage of its initial weight. It was determined by measuring the weight loss of the sample after drying. It was computed using Equation 12:

$$MC = \frac{W_{is}-W_{fs}}{W_{is}} x\ 100 \quad (12)$$

Where,

MC = moisture content, %

Wis = initial weight of samples, g

Wfs = final weight of samples, g

2.5 Statistical Analysis

The performance data obtained from the comparative trials conducted with and without the perforator assembly were subjected to statistical analysis to determine whether significant differences existed between treatments. An independent-samples t-test was used at a 5% level of significance ($\alpha = 0.05$). Results were considered significantly different when the computed p-value was less than 0.05.

3. Results and Discussion

3.1 Performance of The Juice Extractor with and Without Perforator

This study evaluated the performance of the developed calamansi juice extractor with and without the perforator assembly in terms of input capacity, juice recovery, extraction loss, extraction efficiency, and percentage of broken seeds. The test results were obtained from three replicate trials for each machine configuration, and the resulting data were compared to determine the effect of incorporating the perforator assembly.

A comparison between the machine configurations showed that the perforator assembly significantly increased extraction efficiency and reduced broken-seed recovery. The machine equipped with the perforator achieved a mean extraction efficiency of 89.03%, as presented in Table 2. The statistical analysis showed a significant difference between the machine configurations at the 5% level of significance ($p < 0.05$), as indicated by the different superscript letters in Table 2. This suggests that the observed difference in extraction efficiency was not due solely to variation among the replicate trials.

The use of the perforator also significantly reduced broken-seed recovery, with a mean value of 5.20 g kg^{-1} compared with 11.77 g kg^{-1} without the perforator ($p < 0.05$). This indicates that the perforator assembly helped minimize seed breakage during the extraction process. Reducing seed breakage is important in calamansi juice extraction because damaged citrus seeds may release bitter compounds, particularly limonin and nomilin, which can negatively affect juice quality (Jourdan *et al.*, 1985; Emerson, 1948; Kumar *et al.*, 2020). Thus, the lower broken-seed recovery observed with the perforator may be beneficial for maintaining juice quality. However, the present study did not directly measure the concentration of bitter compounds or the sensory properties of the extracted juice; therefore, the effect of reduced seed breakage on juice bitterness cannot be directly confirmed.

Table 2. Performance of calamansi juice extractor with and without the designed perforator

PARAMETERS	MEAN	
	w/ perforator	w/out perforator
Extraction efficiency (%)	89.03^a	86.17^b
Broken seeds recovery (g kg-1)	5.20^a	11.77^b
Extraction loss (%)	1.61^a	1.58^a
Extraction Recovery (%)	98.39^a	98.42^a

Note: Different superscript letters indicate significant differences at 5% level ($p < 0.05$)

The developed machine also demonstrated low extraction losses of 1.61% with perforator and 1.58% without perforator, corresponding to high extraction recoveries of 98.39% and 98.42%, respectively. These values indicate minimal juice loss during the extraction process and confirm the effectiveness of the juice collection and separation mechanisms. The losses measured in this study are lower than those observed in manually operated extractors, such as 4.3% documented by Eyeowa *et al.* (2017) and 1.67% by Odewole *et al.* (2018), and motorized and semi-automated extractors, including 7.05% obtained by Nnamdi *et al.* (2020) and 35% by Ugwu *et al.* (2023). Furthermore, the extraction recovery and loss remained comparable between configurations, indicating that the addition of the perforator improved the containment and discharge efficiency in the developed design.

In addition, a separate performance evaluation with longer duration was subsequently conducted with the perforator assembly; thus, the values presented in Table 3 correspond to a different experimental phase. The developed calamansi juice extractor equipped with the perforator assembly exhibited an input capacity ranging from 123.5 to 125.6 kg h^{-1}, with a mean of 124.8 kg h^{-1}, as shown in Table 3. This capacity exceeds the minimum recommended input capacity of 40 kg h^{-1} for commercial or large juice extractors specified in the PAES 234:2008 (Philippine Agricultural Engineering Standard, 2008b). This indicates that the developed screw-type calamansi juice extractor is suitable for the use of farmer cooperatives and commercial juice processing facilities. For comparison, Eyeowa *et al.* (2017) documented an input capacity of only 15.97 kg h^{-1} for a manually operated orange extractor. Moreover, the developed calamansi juice extractor achieved an extraction rate ranging from 39.99 to 41.79 kg h^{-1}, with a mean of 40.72 kg h^{-1}. This value is higher than the 1.79 kg h^{-1} extraction rate reported for the manually operated extractor developed by Odewole *et al.* (2018). These findings highlight the substantial productivity advantage of mechanized extraction systems over traditional manual methods, which are typically labor-intensive and time-consuming (Mercado *et al.*, 2016).

Table 3. Performance of calamansi juice extractor

PARAMETERS	MEAN
Input capacity (kg hr-1)	124.8
Juice recovery (%)	32.63
Meal Recovery (%)	66.07
Extraction loss (%)	1.30
Extraction Efficiency	89.70
Extraction rate (kg hr-1)	40.72
Potential Juice Content (kg h^{-1})	45.40
Moisture Content (%)	36.38

The bone-dry method was used to determine the initial moisture content of the calamansi fruits and to estimate their potential juice yield. The fruits had an initial moisture content of 36.38%, corresponding to an estimated potential juice output of 45.40 kg h^{-1}. This value served as the theoretical reference for evaluating machine performance. The measured moisture content is consistent with reported characteristics of citrus fruits, where only a portion of the total fruit mass is recoverable as juice. According to Ladaniya (2010), juice content in citrus fruits typically ranges from 30% to 55%, depending on species and cultivar, indicating that a substantial fraction of moisture remains in peel, pulp, and seed tissues rather than in the extractable juice.

The developed calamansi juice extractor achieved mean juice and meal recovery values of 32.63% and 66.07%, respectively. These results correspond closely with the known composition of calamansi fruit. Manalo *et al.* (1995) reported that calamansi consists of approximately 31% juice, 20% pulp, 19% seeds, and 30% peel, showing that roughly one-third of the fruit mass is available as juice. This is further supported by citrus processing literature, which explains that significant moisture remains in the solid fractions after extraction (Kimball, 2012; Ladaniya, 2010). The obtained juice recovery of 32.63% aligns with the documented juice proportion of calamansi and falls within the typical range for citrus fruits. Meanwhile, the 66.07% meal recovery reflects effective separation and discharge of peel, pulp, and seeds. The combined recovery of 98.70% indicates minimal material loss during operation and demonstrates that the extraction system efficiently separated the liquid and solid components of the fruit.

The developed calamansi juice extractor attained an extraction efficiency of 89.7%, surpassing the minimum requirement of 75% set by the PAES 234:2008 (Philippine Agricultural Engineering Standard, 2008b). The efficiency evaluation was based on the theoretical juice fraction estimated from the initial moisture content of the calamansi fruits. This performance is comparable to or higher than efficiencies reported in related studies, including 84% by Olabisi *et al.* (2015), 68.2% by Nnamdi *et al.* (2020), and 64% by Ugwu *et al.* (2023), which evaluated other citrus fruits. Mercado *et al.* (2016) likewise reported extraction efficiencies of 88.11% for apple and 76.67% for carrot, demonstrating the influence of commodity structure and moisture distribution on extraction performance. For calamansi, Madamba and Rafosala (2021) reported an efficiency of 83.96% using a slicer-based mechanism. The higher extraction efficiency observed with the perforator indicates that its incorporation improved the extraction performance of the developed machine. These results indicate its potential suitability for medium- to large-scale calamansi processing, subject to compliance with the applicable national standards.

Table 4. Extraction efficiency of the calamansi juice extractor with the designed perforator compared with literature-reported efficiencies

MACHINE	REFERENCE	CROP TESTED	EXTRACTION EFFICIENCY (%)
Calamansi extractor with perforator	Present study	calamansi	89.7
Citrus juice extractor	Olabisi *et al.* (2015)	orange	84.00
Motorized fruit juice extractor	Nnamdi *et al.* (2020)	orange	68.20
Semi-automated citrus juice extractor	Ugwu *et al.* (2023)	orange	64.00
Medium-scale multi-juice extractor	Mercado *et al.* (2016)	apple	88.11
Medium-scale multi-juice extractor	Mercado *et al.* (2016)	carrot	76.67
Calamansi juice extractor with slicer	Madamba & Rafosala (2021)	calamansi	83.96

4. Conclusion and Recommendation

Based on the results of the study, it can be concluded that the designed extractor efficiently processed the calamansi fruits, achieving effective juice recovery. The system demonstrated a consistent extraction rate, indicating smooth operation under the designed capacity. Additionally, the machine achieved high extraction efficiency while reducing seed breakage during the extraction process. These findings suggest that the design is suitable for practical juice extraction applications and can serve as a basis for further optimization or scale-up.

The use of the perforator resulted in reduced seed breakage during the extraction process. The reduced seed breakage may be associated with the perforation of the fruits before the extraction phase, although the reason for this reduction was not directly determined in the present study.

The extractor may be further improved by incorporating a continuous fruit-feeding system and a screw conveyor that can accommodate different sizes of calamansi and other citrus fruits. Future studies may also evaluate juice bitterness and bitter compounds to further determine the effect of reduced seed breakage on juice quality.

5. Acknowledgement

The authors would like to thank Capiz State University for the research funding and academic consulting, as well as for providing the facilities used in this study.

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