DESIGN AND DEVELOPMENT OF A MULTI-TASKS MOTORIZED GINGER RHIZOMES JUICE EXPRESSION MACHINE

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Abstract. Manual ginger juice expression processes are tedious, unhygienic, and inefficient, affecting the quality and quantity of ginger juice extracted. Extraction by chemical means is complex, expensive, and requires high skill to operate. The developed motorized ginger juice expression machine performs two distinct unit operations: size reduction and separation processes. Major components of the machine include the feeding unit, pulverizing unit, juice expression unit, juice drainage point, waste outlet, frame, and power transmission system. The machine is powered by 2 H.P., 1400 rpm and 1 H.P., 1430 rpm prime movers, and the V-belts and pulley assembly speed are 646 rpm and 240 rpm, respectively. The developed expression machine offers an affordable and simple method of processing fresh ginger minimizing loss in ginger rhizome quantity and quality, and ultimately reducing postharvest losses.

Keywords: Ginger, expression, extraction, machine, oleoresin, juice.

INTRODUCTION

Ginger (Zingiber officinale roscoe) is produced from the plant rhizome and belongs to the family of Zingiberaceae. It has essential value for its oil, such as oleoresin and gingerol, used in the beverage industry, bakery, pharmaceutical, culinary and cosmetic preparation [1,2]. [3] published that the percentage composition of volatile oil and non-volatile extract of ginger from Nigeria was given as 2.5% and 6.5%, respectively, which resulted in the high demand for Nigerian ginger in the international market.

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Although, [4] reported that the quality of Nigerian dried ginger has been declining due to poor mechanization in ginger production and processing. Thus, resulting in the attendant mould growth and loss of some important ginger qualities. Nigeria to command the cheapest price in the world market [5,6]. There is a low percentage of oleoresin content per unit volume of ginger due to extended harvest, long storage period, over-drying, and re-drying due to dampness [7,8]. Also, when drying ginger at a high temperature, it denatures the protein content and alters the organoleptic attributes through loss of aroma and colour [9,10]. However, the deterioration of active ingredients in dried ginger reduces its economic value and utilization in the industries. [11] enunciated that pulverization and expression as unit operations can be done using traditional or modern methods, though the former is relatively primitive and favours low capacity output, and is susceptible to increasing the microbial load on the crushed ginger [12,13]. Ginger juice obtained from the mechanical expression of pulverized ginger rhizomes offers a value-added ginger product that will increase farmers' market opportunity [14,15].

Farmers do not generally adopt the chemical extraction method of processing ginger due to the high cost and complexity of the equipment used in the extraction [16]. The ginger extract obtained from this process usually has some elements of impurity resulting from dissolved chemicals used in the extraction [17,15]. Other methods of ginger processing are traditionally done by a manual method such as mortar, pestle, and hand pressing, but this process is described as tedious, unhygienic, and inefficient. Thus, affecting the quality and quantity of ginger juice available in the Nigerian market. The wet extraction process, otherwise known as hot water or steam extraction used traditionally by women in rural communities for processing varieties of oil-bearing biological materials, falls short of the standard, especially in quality [18,15]. The mechanical expression of ginger juice via pulverized ginger rhizomes offers a value-added ginger product that will increase the satisfaction of consumers over convenient food consumption and increase the market opportunity for entrepreneurs and farmers [19,20]. A motorized ginger juice expression machine aimed at processing ginger at the shortest possible time after harvest and increasing the retention level of the active ingredients in ginger was developed to meet up with the high market demand for ginger juice due to its nutritional and medicinal values, reduce the amount of loss of oleoresin and volatile oil in ginger during processing.

MATERIALS AND METHOD

The study was carried out at the general engineering workshop of Agricultural and Bioresources Engineering Department Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria, located at Latitude 5º 28” 3 N and 7º 32” 56 E.

Design Considerations

The following were considered in developing the multi-tasks ginger juice expression machine

1. For durability and prevention of oxidation and corrosion, stainless steel sheet was used for the construction except for the frame (where galvanized steel was used) because it does not react with juice from the ginger rhizomes, which contain oleoresin and volatile oil.
2. The hopper design was based on the recommended average angle of repose (34.60°) and the coefficient of friction on stainless steel of fresh whole ginger rhizome (0.57) to ensure the flow of ginger rhizomes in the hopper.

3. Static and dynamic stresses resulting from direct loading, bending, and torsion was considered in the shaft design.

4. The cost of construction materials was considered by using locally available materials.

5. Variable pitch and tapered screw shaft (auger) were used to ensure maximum conveyance and pressing of the pulverized ginger rhizomes.

Description of the motorized ginger juice expression machine

The developed motorized ginger juice expression machine consists of the following major components: feeding unit, pulverizing unit, juice expression unit, juice outlet, waste outlet, frame, and power transmission system. The developed machine is shown in Figures 1 and 2.

1. Frame

The two design factors considered in determining the material required for the frame are weight and strength. The frame was constructed with 38 mm×38 mm×3 mm mild steel angle iron. The frame provides firm support for the entire assembly. Based on anthropometric considerations, the overall dimensions of the frame were chosen as 610 mm×390 mm×790 mm.
2. Feeding unit
The hopper is a stationary part and, mounted onto the machine, forms the feeding chute through which sliced ginger rhizomes are fed into the grating unit by gravity [21]. The hopper’s passage hole (85 mm×55 mm) was large enough to prevent choking of the product. The hopper was made of stainless steel and a rectangular pyramid shape.

3. Grating unit
The grating unit consisted of a wooden shaft wrapped with a rough stainless plate attached to a pulley through a metal shaft. The grater will rotate and hence shred the ginger rhizomes into smaller sizes in operation. That will be conveyed by gravity to the position where it enters the expression unit through the lower hopper.

![Fig 3: Isometric view of the grater](image1)
![Fig 4: Skeletal view of the grating chamber](image2)

Expression unit
The ginger juice expression unit consisted of a tapered cylindrical barrel covering a perforated tapered cylindrical drum housed a screw shaft [22]. The screw shaft is the main component of the juice expression unit. The screw shaft comprises a stainless shaft with a tapered helical screw of variable pitch. The pitch of the screw flights gradually decreased towards the discharge end to increase the pressure on the pulverized ginger rhizome as it’s been carried through the barrel. The barrel is perforated to allow expressed juice to escape, and the diameter of perforation is 1mm. Thus, the pressed ginger residue (chaff) passes through the waste discharge point in the barrel outlet.

![Fig 5. Expression barrel](image3)
![Fig 6. Expression screw](image4)
Power transmission system
The power transmission system comprises the prime mover (electric motor), shaft, reduction gear, pulleys, and belt. The power was provided by 2 H.P., 1400 rpm, and 1 H.P., 1430 rpm prime movers. The V-belts and pulley assembly were used to transmit the power to the pulverizing and expression units at a speed of 646 rpm and 240 rpm, respectively. The prime movers were mounted on a slotted plate on the frame to facilitate the belt tension adjustment.

Design Calculations for the developed machine components
The component design calculation for the motorized ginger juice expression machine is given below:

(1) Pulverizing shaft speed
Equation (a) was used to determine the pulverizing shaft speed given by [23]

\[ N_1 D_1 = N_2 D_2 \]  

(a)

Where:
- \( N_1 \): speed of driving motor, rev min\(^{-1}\);
- \( N_2 \): speed of the pulverizing shaft, rev min\(^{-1}\);
- \( D_1 \): diameter of the driving pulley, m;
- \( D_2 \): diameter of the driven pulley, m.

(2) Pressure on the barrel
The limiting (maximum) pressure \( P_b \) the barrel can withstand is estimated using the Equations (b) and (c) as given by [24] and [23]:

\[ P_b = \frac{t \delta_a}{D_l} \]  

(b)

\[ \delta_a = 0.27 t \delta_o \]  

(c)

Where:
- \( \delta_a \): allowable stress, MPa;
- \( \delta_o \): yield stress of barrel material, MPa;
- \( t \): barrel thickness, mm;
- \( D_l \): internal diameter of barrel, mm.

\( t = 2 \text{ mm}, \delta_o = 215 \text{ MPa}, \text{ at feed point}, \)
\( D_l = 80 \text{ mm}, \text{ and at the discharge point, } D_l = 65 \text{ mm}. \)

Design of screw shaft for the expression unit
The screw shaft was made using a code equation (d) given by [23] and [24]:

\[ d^3 = \left( \frac{16}{n_s \delta_o} \right) \times \left[ (K_b M_b)^2 + (K_t M_t^2) \right]^{1/2} \]  

(d)
Where:
\[ d \] = diameter of the shaft; mm;
\[ M_t \] = torsional moment; Nm;
\[ M_b \] = maximum bending moment; Nm;
\[ K_b \] = combined shock and fatigue factor applied to bending moment;
\[ K_t \] = combined shock and fatigue factor applied to torsional moment;
\[ S_s \] = Allowable shear Stress, MPa.

For rotating shafts subjected to apply load with minor shocks only, values for suddenly \( K_t \) and \( K_t \) was given as 1.5.

For shafts with allowance for keyways as given by [23].

\[ S_s = 42 \times 10^6 Nm^{-2} \]

A stainless steel rod of diameter 30 mm was selected, considering bearings.

**Screw pitch (\( P_s \))**

Determination of the pitch of the screw shaft in Equation (f) below is given by [25] and [26] as:

\[ P_s = \pi \tan \phi d_{sm} \]  

Where:
\[ \phi \] = lead angle, (°);
\[ d_{sm} \] = mean diameter of the shaft, mm.

The screw has a variable pitch with maximum and minimum lead angles as 26° and 10°, respectively.

**Screw thread design**

The screw shaft is essentially a tapered screw conveyor with the volumetric displacement decreasing from the feed end of the barrel to the discharge end [22]. In this way, the pulverized ginger is subjected to pressure, which expels juice as it is propelled forward during the screwing process. The screw threading system was designed as a step up shaft diameter and decreasing screw depth using the expression in Equation (g) as given by [23]:

\[ U_n = a + (n - 1)d \]  

Where; \( U_n \) = screw depth at the discharge end, mm;
\( a \) = screw depth at the feed end, mm;
\( n \) = no screw turns;
\( d \) = common difference between subsequent successive screw depths.

Given that \( U_n = 16 \) mm, \( a = 24 \) mm, \( n = 8 \); then \( d \approx 2 \) mm.

**Design for capacity of the machine**

The expressing capacity of the fabricated machine was determined using a modified form of the Equation (h) given by [25] as:

\[ Q_P = 60 \times \frac{\pi}{4} (D_{ms}^2 - d_s^2)P_{ms}lNl \Phi \]

Where: \( D_{ms} \) = diameter of the screw; mm;
\( d_s \) = diameter of the shaft; mm;
\( l \) = length of the barrel; mm;
\( P_{ms} \) = expressed force; N;
\( N \) = number of screws;
\( \Phi \) = efficiency factor.
Where:
\[ Q_P = \text{theoretical capacity of the expressing unit, kg s}^{-1}; \]
\[ D_{ms} = \text{mean screw diameter}; \]
\[ d_s = \text{shaft diameter}; \]
\[ \rho = \text{crop density, kg m}^{-3}; \]
\[ P_{ms} = \text{mean screw pitch, mm}; \]
\[ Ns = \text{shaft speed, rev min}^{-1}; \]
\[ \Phi = \text{filling factor}. \]

The pulverizing capacity of the machine was determined using a modified form of Equation (i) given by [23] as:

\[ Q_P = 60 \times \frac{\pi}{4} (D_s^2 - d_P^2) P_s \rho N_P \Phi \]

Where:
\[ Q_P = \text{theoretical capacity of the pulverizer, kg s}^{-1}; \]
\[ D_s = \text{screw diameter, mm}; \]
\[ d_P = \text{pulverizing shaft diameter}; \]
\[ \rho = \text{crop density, kg m}^{-3}; \]
\[ P_s = \text{screw pitch, mm}; \]
\[ N_P = \text{pulverizing shaft speed, rev min}^{-1}; \]
\[ \Phi = \text{filling factor}. \]

**Design for the power requirement of the machine**

The power required by the machine for expressing juice was determined using Equation by [26]:

\[ P_e = Q_{ve} L_s \rho g F \]

Where
\[ P_e = \text{power required for expressing, W}; \]
\[ Q_{ve} = \text{evolumetric capacity, m}^3 \text{s}^{-1}; \]
\[ L_s = \text{length of screw shaft, mm}; \]
\[ g = \text{acceleration due to gravity, m s}^{-2}; \]
\[ F = \text{material factor}. \]

The power required by the machine for pulverizing was determined using Equation (k) by [27] adapted as:

\[ P_p = Q_{ve} L_s \rho g F \]

Where:
\[ P_p = \text{power required for pulverizing, W}; \]
\[ Q_{ve} = \text{evolumetric capacity, m}^3 \text{s}^{-1}; \]
\[ L_s = \text{length of pulverizing shaft, mm}; \]
\[ g = \text{acceleration due to gravity, m s}^{-2}. \]
The total power requirement ($P_t$) of the machine was computed using Equation (1) by [27]:

$$P_t = P_e + P_P$$  \hspace{1cm} (1)

The power of the electric motor required to drive the machine was estimated from Equation (m) given by [27] as:

$$P_m = \frac{P_t}{\eta}$$  \hspace{1cm} (m)

Where:
- $P_m =$ power of electric motor;
- $\eta =$ drive efficiency (%)

**Working principle of the developed ginger juice expression machine**

The developed machine performs two distinct unit operations: size reduction and separation processes. The ginger rhizomes are fed into the grater through the hopper. The ginger rhizomes are comminuted by shredding at the grating unit. The screw shaft of the expression unit crushes, presses, and conveys the product that comes from the grating unit in such a way that juice is squeezed out of the grated rhizomes.

The expression is achieved by the action of the screw shaft in squeezing the grated ginger rhizomes against each other and on the surface of the screw. The movement of the materials along the line of travel of the perforated cylindrical barrel also expresses the juice along the line of travel. The fluid expressed is drained through the juice channel into the juice outlet from where it is collected while the residual waste is collected at the waste outlet.

**RESULTS AND DISCUSSION**

**Construction of the juice expression machine**

The motorized juice expression machine was designed for the large-scale production of any ginger juice but can also be used to extract other oil-bearing agricultural products [28,29]. This production involves facing, turning, boring, milling, welding, cutting, tapping, fillings, painting, etc. This can be carried out in any large/medium-sized workshop with average machining and fabrication facilities. Other components such as bearings, electric motors, V-belts, bolts/nuts, etc., were sourced for in the local market. The essential workshop facilities required for the production of the machines are lathe machine, milling machine, welding machine, hand grinding machine, drilling machine, M10 tap, and file.

The quality of construction is an essential factor in the overall performance of any machine [7,30]. This fact was given due consideration in selecting the production processes and sequences of operation in the fabrication of the machine.
CONCLUSION

The motorized ginger juice expression machine has been developed as an easily affordable technology that is very suitable for the environment, energy efficient, and versatile on ginger. It is fully developed to incorporate all stages of ginger rhizome processing; this machine can revolutionize ginger rhizome processing in the country and has the potential for adaptation into a large industrial facility.

Recommendations

The motorized ginger juice expression machine is recommended for large-scale ginger juice expression in rural and urban communities. Further experimental tests such as performance evaluation could be carried out on the ginger juice expression machine.

Conflict of Interest

The Authors have no conflict of interest.

REFERENCES

DIZAJN I RAZVOJ MAŠINE SA MOTOROM SA VIŠE OPERACIJA ZA CEĐENJE SOKOVA OD KORENA DUMBIRA (Zingiber officinale roscoe)

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Abstrakt: Procesi ručnog ceđivanja soka od dumbira su monotoni, nehigijenski i neefikasni, što utiče na kvalitet i količinu ekstrahovanog soka (Zingiber officinale roscoe). Ekstrakcija hemijskim putem je složena, skupa i zahteva veliko iskustvo i visoku veštinu za ovaj process.

Razvijena mašina sa motorom za ceđenje soka od dumbira obavlja dve različite operacije: smanjenje zapremine korena dumbira i proces odvajača. Glavne komponente mašine uključuju jedinicu za punjenje, jedinicu za usitnjavanje, jedinicu za ispuštanje soka, cev za odvod soka, izlaz za otpad, okvir i sistem za prenos energije. Mašinu pokreću motori od 2 KS, 1400 o/min i 1 KS, 1430 o/min, a brzina klinastih kaišnika i remenica je 646 o/min i 240 o/min, respektivno.

Razvijena mašina za ekspresiju nudi pristupačan i jednostavan metod obrade svežeg dumbira koji minimizira gubitak količine i kvaliteta korena dumbira i na kraju smanjuje gubitke nakon ubiranja.

Ključne reči: Dumbir, ekspresija, ekstrakcija, mašina, uljna smola, sok.

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