Journal of Scientific Research & Reports

26(1): 48-55, 2020; Article no.JSRR.54287
ISSN: 2320-0227

Design and Construction of Densification Machine for Vegetables in Rural Settlements

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Authors' contributions

This work was carried out in collaboration among all authors. Authors JKA and IA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SIO and AZ managed the analyses of the study. Author SAO managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2020/v26i130213
Editor(s):
(1) Dr. Levent SON Levent, Professor, Department of Applied Technology and Management, School of Silifke, The University of Mersin, Turkey.
Reviewers:
(1) Sunil Kumar, Banda University of Agriculture and Technology, India.
(2) Pankaj Balasaheb Gavali, Sanjay Ghodawat University, India.
Complete Peer review History: http://www.sdiarticle4.com/review-history/54287

Original Research Article

Received 25 November 2019
Accepted 30 January 2020
Published 11 February 2020

ABSTRACT

This research work was carried out to improve the storage space and effective handling of dried vegetables specifically tomatoes, onion and okra, for consumers and marketers. The machine basically consists of an upper compression plate, machine mould, piston, lower compression plate and a 3-tons hydraulic jack. The machine performance was evaluated based on Output Capacity and Machine Compression Efficiency. The results showed that the machine output capacity and efficiency were 0.291 kg/h and 96.3%, respectively. The machine production cost stood at ₦35,000.00 only. The machine is therefore recommended to farmers.

Keywords: Compression; handling; storage space; dried vegetables.

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1. INTRODUCTION

Fresh vegetables are important food both from economic and nutritional point of view. Vegetable of all types are valuable part of our diet. They play an important role in maintaining general good health owing to the presence of mineral element and vitamin [1].

Nigeria is ranked as the 16th largest tomatoes producing nation in the world and has the comparative advantage and potential to lead the world in Tomato production and exports. The production of Tomatoes in Nigeria in 2010 was about 1.8 million metric tonnes, which accounts for about 68.4% of West Africa, 10.8% of Africa's total output and 1.28% of world output [2]. Tomatoes production in Nigeria is about 4,100,000 tons produced on 589,254 hectares [2]. Table 1 showed the tomatoes production in Nigeria from 2013 to 2017.

Table 1. Tomatoes production in Nigeria from 2013 to 2017

SN	Year	Quantity
1	2017	4,100,000
2	2016	4,128,995
3	2015	4,229,330
4	2014	4,083,500
5	2013	1,925,120

Nigeria is ranked as the 8th largest onions producing nation in the world accounting for 4.8% of production. Presently in Nigeria, onions production for green onions is about 248,072 tons produced on 15,412 hectares and for dry onions is about 996,519 tons produced on 556,466 hectares [2]. Table 2 showed the onion production in Nigeria from 2013 to 2017.

Table 2. Onion production in Nigeria from 2013 to 2017

SN	Year	Quantity
1	2017	248,072
2	2016	248,807
3	2015	235,383
4	2014	235,000
5	2013	35,000

Nigeria is ranked as the 44th largest okra producing nation in the world. Presently in Nigeria, okra production is about 2,060,280 tons produced on 1,480,386 hectares [2]. Fresh okra is among the most important vegetable crops cultivated in Nigeria [3]. Okra is used to thicken soups and stews [4], often sliced and sun-dried [5]. Table 3 showed the okra production in Nigeria from 2013 to 2017.

Table 3. Okra production in Nigeria from 2013 to 2017

SN	Year	Quantity
1	2017	2,060,280
2	2016	2,005,254
3	2015	2,067,900
4	2014	2,039,500
5	2013	1,886,200

In Nigeria, the National Processing and Packaging Utilization Capacity for fruits and vegetables is 450 tonnes per day and 1500 Metric tons per day (mt/day), respectively. The National processing and packaging utilization remain low according to the Ministry's action plan document, this is less than 33% capacity utilization [6]. However, the dried product is not probably packed before storage. The products are thus exposed to the open air thereby predisposing them to further contamination and subsequent deterioration. It is revealed that the shelf life of a packaged food is achieved by controlling the physical characteristic of the product such as water activity, pH value, susceptibility to enzymatic or microbial deterioration, and mechanism of spoilage, requirement for sensitivity to oxygen, light, carbon dioxide and moisture [3]. Moisture loss or uptake is one of the most important factors that control shelf life of food.

Cold storage of large volume of dried products for a long period of time is expensive and energy consuming. This means that it is quite out of reach of local farmers. Meanwhile the storage medium conventionally used by farmers is not fully hygienic, as dry products are left in sacks which can easily be attacked by microorganisms and quite voluminous [7].

Dehydration is a highly acceptable process for the preservation and reduction of weight of food. However, there is reduction in volume (or increase) in density from dehydration, for military usage, it has become increasingly important to compact such foods to reduce handling and storage difficulties [8].

Dried tomatoes are convenient alternatives to help meet the recommended daily vegetable servings. Although they may seem like gourmet items, dried tomatoes are readily available and easy to use, straight from the bag. Eating this nutrient-dense food can make overall diet healthier [6].

Studies also showed that glut usually occurs at harvest period few months after harvest. Scarcity sets in which results in price hike of the crops. This shows the need for storage of the surplus product during the season in other to provide sufficient product to meet the needs during off-season. The study aimed at developing a mechanical device for densification of dried vegetables.

2. MATERIALS AND METHODS

In the construction of the densification machine, mild steel sheet of Gauge 16 was used for pipes and plates because of its higher strength to withstanding pressure. Galvanized Steel Pipe was used for cylinder to avoid corrosion and hydraulic Jack.

2.1 Design Considerations

2.1.1 Cost

It is important that the machine cost is low and affordable for dried vegetable processors, since majority of targeted users are local farmers and Marketers.

2.1.2 Portability

The components such as the mould, piston and stands were designed for simplicity and ease of coupling.

2.1.3 Durability

Materials of considerable and provable strength were selected to ascertain durability.

2.1.4 Daily demand of dried tomatoes per household

The daily quantity of dried tomatoes demand per household was assumed to be four cups.

2.2 Design Calculations and Selection of Machine Components

When a cylindrical shell is subjected to an internal pressure, its walls are subjected to tensile stresses. If these stresses exceed the permissible limit, the cylinder is likely to fail by either splitting into two troughs or breaking into two cylinders [9]. Hence, the most important features of the machine design include the determination of the: mould size, allowable tensile stress in the mould, thickness of the machine moulds and capacity of the hydraulic jack. The components of the machine include: piston, cylinder, upper and lower compression Plates, machine frame and Hydraulic Jack.

2.2.1 Determination of mould size

Tomatoes having the highest volume and density was used in the determination of the machine's mould dimensions. For the circular mould, an outer and inner diameter of 88 mm and 80 mm was selected.

A cup of dried tomato occupied approximately 193 cm^3. Likewise, four (4) cups of dried tomato is sufficient for average family of six (6) per meal.

Therefore, total volume requirement for a mould was determined as:

Total volume = 193 × 4 = 772 cm^3

The volume is calculated using Equation (1).

$$v = \frac{\pi d^2 h}{4} \tag{1}$$

Where;

v = Volume of the cylinder, mm^3
π = constant = 3.142
d = mould diameter, 80 mm
h = Height, mm

The height 'h' of the mould is determined as 15.3 cm and therefore, 155 mm height was selected.

2.2.2 Determination of allowable tensile stress

The allowable tensile stress (i.e. circumferential or hoop stress) was calculated using [9] relationship as in Equation (2):

$$\sigma_c = \frac{t_s}{f_s} \tag{2}$$

Where;

σ_c = Allowable tensile stress, MPa
t_s= tensile strength, N
f_s= factor of safety

Using the ultimate tensile strength of mild steel to be 440 Mpa and a factor of safety of 5

$$\sigma_c = \frac{440}{5} = 88\text{MPa}$$

2.2.3 Determination of thickness of cylinder

Failures in cylindrical shell was reported by Khurmi and Gupta [9] to be due to two types of tensile stresses, which are circumferential and longitudinal stresses.

2.2.3.1 Circumferential or hoop stress

As a result of the internal pressure, the mould has the tendency to split into two troughs along its circumferential axis as in Fig. 1.

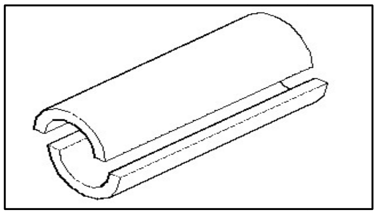

Fig. 1. Schematic diagram of failure due to circumferential stress in cylindrical shell

It is therefore necessary to determine the minimum thickness of the mould shell that will withstand the internal pressure during compaction. The minimum thickness that will prevent the splitting of the cylindrical mould along its circumferential axis is calculated using [9] relationship as in Equation (3):

$$t = \frac{p.d}{2\sigma_c \eta} \quad (3)$$

Where;

t = thickness of shell, mm
P = internal pressure in cylinder, MPa
d = internal diameter of cylinder, mm
σ_c = allowable tensile stress, MPa
η = efficiency of riveted joint. (neglected)
$\therefore t = \frac{5 \, x \, 80}{2 \, x \, 88} = 2.27$ mm$\approx 3 \, mm$

2.2.3.2 Longitudinal stress

Considering the fact that the internal pressure also has the tendency to break the cylindrical mould into two cylindrical pieces along its longitudinal axis as in Fig. 2.

The minimum thickness of the mould that will prevent breaking of the cylindrical mould along its longitudinal axis was determined using [9] relationship as in Equation (4):

$$t = \frac{\mathrm{p.d}}{4\sigma_c \eta} \quad (4)$$

Where;

t = thickness of shell (mm)
P = internal pressure in cylinder (MPa)
d = internal diameter of cylinder (mm)
σ_c = allowable tensile stress (MPa)
η = efficiency of riveted joint. (neglected)
$\therefore$ t = $\frac{5 \, x \, 102}{4 \, x \, 88}$ = 1.449 mm ≈ 1.5 mm

Since the thickness required to prevent failure of the mould along its circumferential axis is greater than that required to prevent failure along its longitudinal axis (i.e. 3 mm > 1.5 mm), the minimum thickness of 3mm (standard size) was considered for the design of the compaction mould.

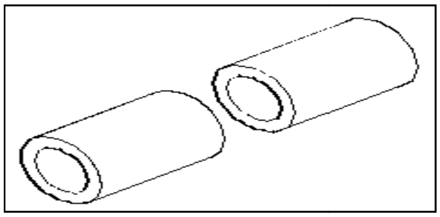

Fig. 2. Schematic diagram of failure due to longitudinal stress in cylindrical shell

2.2.4 Determination of hydraulic jack capacity

The capacity of the hydraulic jack used for the compression machine was determined using [10] procedures which include determination of the following:

i. The weight of the machine components (Wm) lifted by the jack (i.e. lower compression plate and four pistons).
ii. The weight of vegetable produced (Wt) in the mould.
iii. The force required for compacting the dried vegetables (Fc) into mould.

2.2.5 Determination of the weight of lower compression plate

The lower compression plate is made up of mild steel of density 7850 kg/m^3. Considering the size and arrangement of the pipes in the mould, if the compression plate has dimensions of 300 mm x 300 mm x 3 mm corresponding to length, width and thickness respectively, the weight of the lower compression plate was calculated using Equation (5) as used by Nordiana [10]:

$$\mathrm{w_{lcp}} = \mathrm{l} \times \mathrm{w} \times \mathrm{t} \times \mathrm{p} \times \mathrm{g} \quad (5)$$

Where;

W_{lcp} = Weight of lower compression plate, N
l= length of plate = 0.382 m,
w = width of plate = 0.252 m,
t = thickness of plate = 0.005 m,
ρ = density of mild steel = 7850 kg/m^3 and
g = acceleration due to gravity = 9.81 m/s^2.
∴ W_{lcp} = 37.06N

2.2.6 Determination of weight of four pistons

The piston is a cylindrical body with a circular head (top). The piston was made up of a cylinder and a connecting hollow pipe as illustrated in Fig. 3.

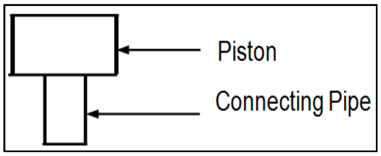

Fig. 3. Schematic view of the piston rams

Considering the size of the mould to be produced and the designed thickness of the machine members, the cylinder has an internal and outer diameter of 80 mm and 88 mm, respectively, the weight of the cylinder was calculated using Equation (6) as used by Nordiana [10]:

$$W_{bc} = \frac{\pi}{4}[(d_o^2 - d_i^2) \times h + d^2 \times t]\rho \times g \qquad (6)$$

Where;

W_{bc}= weight of big cylinder (N)
d_o = outer diameter of big cylinder = 0.088 m,
d_i = inner diameter of big cylinder = 0.082 m
h = height of the cylindrical piston body = 0.13 m,
d = diameter of the circular head = 0.08 m
t = thickness of circular head = 0.003 m,
π = pi = 3.142
ρ = density of mild steel = 7850 kg/m^3 and
g = acceleration due to gravity = 9.81 m/s^2
∴ W_{bc} = 9.282N

The connecting cylinder has an outer and internal diameter of 56 mm and 50 mm, respectively in order to ensure balancing. The weight of the connecting cylinder was calculated using Equation (7):

$$W_{cs} = \frac{\pi}{4}(d_0^2 - d_i^2) \times h \times \rho \times g \qquad (7)$$

Where;

W_{cs} = weight of connecting cylinder (N)
d_o = outer diameter of connecting cylinder = 0.056 m,
d_i = inner diameter of big cylinder = 0.05 m,
h = 0.13 m,
π = pi = 3.142
ρ = density of mild steel = 7850 kg/m^3 and
g = acceleration due to gravity = 9.81 m/s^2
∴ W_{cs} = 5.00 N
The weight of a piston,
$W_p = W_{bc} + W_{cs}$
= 9.28N + 5.00N= 14.28N
The total weight of four (4) piston rams = 14.28N *x* 4 = 57.12N

2.2.7 Theoretical weight of the dried vegetables

The weight of the four moulds will be calculated using Equation (8) as used by Nordiana [10]:

$$W_b = \frac{\pi}{4}[d^2 \times h \times \rho \times g] \qquad (8)$$

Where;

W_b= Weight of mould (N)
d = diameter of the mould 0.08 m
h = height of mould 0.13 m
ρ = density of the dried tomatoes 0.29
g = acceleration due to gravity = 9.81 m/s^2
W_b = 2.36N
The total weight of four mould = 2.36 × 4 = 9.44
Total weight to be lifted by the hydraulic jack was estimated to be:
37.06N + 57.12N + 9.44N = 103.62N

2.2.8 Determination of force for compacting dried vegetables (Fc)

The force required to compress dried tomatoes effectively was determined using Compression Testing Machine. From the experiment the force was determined as 27.0 kN, the minimum capacity required by the hydraulic jack to overcome machine component and mound weight and force of compaction was estimated to be

= 103.62+27.103 kN = 27,206.62 N

Minimum capacity required by the hydraulic jack

$$= \frac{27206}{9.81} = 2{,}773.36 \text{ kg}$$

Therefore, a 3-ton hydraulic jack was selected.

Details or thographic and isometric views of the machine is presented in Fig. 4.

The technical characteristics of the developed machine is presented in Table 4.

2.3 Bills of Engineering Measurements and Evaluations

For the densification machine the following cost were considered i.e. material and labour cost. The material cost for construction as presented in Table 5.

Table 4. Technical characteristics of the machine

Sn	Component	Dimension (mm)	
1	Frame	Length	400
		Width	260
		Height	400
2	Cylinder	Volume	155
3	Hydraulic jerk	Capacity	3 hp

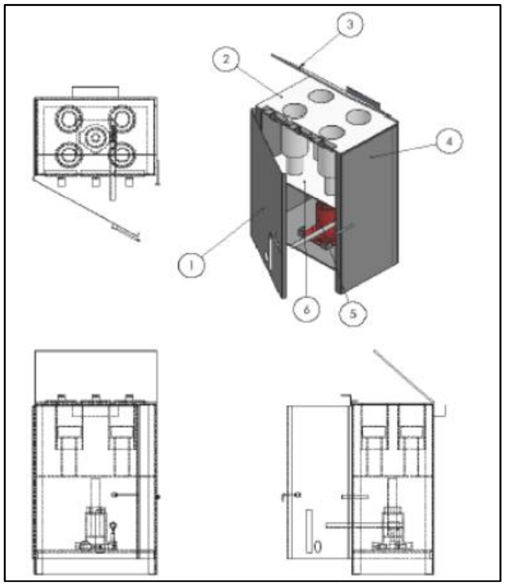

Fig. 4. Orthographic view of the developed densification machine

6	*Lower compression plate with piston heads*	*Galvanized steel*	*1*	*constructed*
5	*Hydraulic jerk*	*---*	*1*	*standard*
4	*Frame/stand*	*Mild steel*	*1*	*constructed*
3	*Upper compression plate*	*Galvanized steel*	*1*	*constructed*
2	*Cylinder head*	*Galvanized steel*	*1*	*constructed*
1	*Door*	*Mild steel*	*1*	*constructed*
SN	*Components*	*Material*	*Quantity*	*Remarks*

Table 5. Cost estimation of the constructed densification machine as February, 2018

S/N	Materials	Quantity	Price(₦)
1	5 mm Mild steel sheet	½	5000
2	2 mm Mild Steel Sheet	½	3000
3	50 mm diameter cylinder pipes for pistons	1 length	5000
4	80 mm diameter cylinder for moulds	1 length	8000
5	Hydralic jack(3 tons)	1	3000
6	Spring	4	800
7	Electrode	1 pack	2700
8	Angle iron	1	5000
9	Grinding Disc	1	1000
10	Cutting Disc	1	1500
	Total		35,000

Labour cost is the cost of workmanship which include cutting, welding and painting; Labour cost = ₦3,500; Total Production Cost = ₦38,500

3. RESULTS AND DISCUSSION

3.1 Principles of Operation of the Developed Densification Machine

Dried vegetables are feed in at the top of the machine. The upper lid is closed and locked. The hydraulic jack is pumped up to compressed the products feed in. After compression, the products are left locked in for some minutes before releasing it. The pictorial view of the developed machine is shown in Fig. 5. The developed machine performance was evaluated based on the machine output capacity and the machine compression efficiency.

Fig. 5. Pictorial view of the developed densification machine

3.2 Average Production Time

Table 6 showed the production time. An average time for the densification of dried tomatoes and onions was 10,863 seconds which is equivalent to 181.05 minutes was used per four moulds using the developed densification machine while the average time for the production of okra was 83 seconds. Tomatoes and onions needed to be left in the cylinder under pressure for 3 hours to compact since there was no binder used. For okro, water was used to wet the surface to aide its compaction while for tomatoes and onions nothing was used.

3.3 Average Output Capacity of the Machine

This is the mass of dried densified vegetable produced in kg to the average time used in production; the maximum mass is shown in Table 7.

From Table 7, maximum of 880 is used to calculate the machine capacity as in Equation (9):

$$M = \frac{Q_L}{t} \qquad (9)$$

Where;

M = Machine Output Capacity, kg/h
Q_L= maximum quantity load, kg
T = production time, h
$\therefore = \frac{0.880}{3.0175} = 0.291\ kg/h$

3.4 Average Machine Compression Efficiency

This is the average number of un-shattered compacted dried vegetables to the average number of compacted dried vegetables produced; the result is shown in Table 8.

Table 6. Production time using the developed densification machine

Production time	Mean time (Seconds) for tomatoes	Mean time (Seconds) for onions	Mean time (Seconds) for okro
Loading time	12	12	12
Compactions time	31	31	31
Residence time (180mins)	10,800	10,800	20
Ejection time	20	20	20
Total	10,863	10,863	83

Table 7. Maximum mass loaded in the machine

Vegetables	Maximum quantity loaded (g)
Tomatoes	880
Onions	880
Okra	720

Table 8. Average number or shattered and un-shattered

S/N	Vegetable	Number of un-shattered densified dried vegetable	Number of shattered densified dried vegetable
1	Tomatoes	36	0
2	Onions	36	0
3	Okra	32	4
Average		34.67	

From Table 8, machine efficiency is calculated below using Equation (10):

$$ME = \frac{Nu}{Ns} \qquad (10)$$

Where;

ME = machine efficiency, %
Nu = Number of un-shattered densified vegetable
Ns = Number of shattered densified vegetable
$\therefore = \frac{3\ 467}{3\ 6} \times 100 = 96.3\%$

4. CONCLUSION

The design and construction of the densification machine was successful. The densification machine includes: the upper compression plate, the mould, the pistons lower compression plate and the machine stand. the machine output capacity and efficiency were 0.291 kg/h and 96.3%, respectively.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Adegunwa MO. Proximate and bioactive contents of some selected vegetables in Nigeria. American Journal of Food and Nutrition. 2011;1(4):171-177.
2. FAO; 2005,2009,2010,2014,2017. Available: http://www.fao.org
3. Fennema OR, Tannencbaum SR. Introduction to food chemistry, 2nd edition. Marcel Dekker Inc. New York. 1985;7-12.
4. Ihekoronye AI, Ngoddy PO. Integrated food science and technology for the tropics. London: MavMillan; 1985.
5. Inyang UE, Ike CI. Effect of blanching, dehydration method and temperature on the ascorbic acid, colour, sliminess and other constituents of okra fruit. International Journal of Food Sciences and Nutrition. 1998;49(2):125-130.
6. Kalu S. The great tomatoes waste in Nigeria. A web Blog.
   (Retrived on 20/03/2017)
   Available:http://kalusam.wordpress.com 2013
7. Coles R. Food packaging technology. A textbook published by Blackwell publishers and CRC press; 2003.
8. Abdul RR, Glenn S, George RT, Donald EW. Studies on reversible compression of dehydrated vegetables. Technical Report by United States Army Laboratory Natick Massachusetts; 1969.
9. Khurmi RS, Gupta JK. A textbook of machine design. 14th edition. Eurasia Publishing House (PVT.) Ltd. Ram Nagar, New Delhi - 110 055; 2005.
10. Nordiana JO. Development and performance evaluation of an electrically operated biomass briquetting machine. International Journal of Natural and Applied Sciences. 2009;5(2):120-124.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/54287