Journal of Engineering and Applied Sciences 4 (3): 164-169, 2009
ISSN: 1816-949X

Design, Fabrication and Performance Evaluation of a Powered Soy-Gari Mixer

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Abstract: A prototype mixer consisting of a trough, rotating shaft and blade driven by a 2 horse power electric motor was designed, fabricated and its performance evaluated at 50% of its capacity by volume for mixing of different particle sizes of gari namely small (1.18 mm), medium (1.70 mm) large (2.30 mm) and locally sieved with soybean flour and paste, respectively. Results show that power requirement for mixing of soy-gari increased with the particle size and were higher in the mixture of Gari and Soy-Paste (SGP) than Gari and Soy-Flour (SGF). Small particle sizes were found to mix faster than the larger ones for both SGF and SGP. It was observed that low speeds of rotation and low power requirement of the machine increased the mixing efficiency and throughput capacity. Water absorption capacity and least gelation concentration of all the samples decreased slightly with increasing particle sizes. On the other hand, bulk density and swelling index of all the samples consistently increased as the particle sizes become smaller. The results of sensory analysis indicated that mixture of medium particle size of gari (1.70 mm) with soy flour was rated as having the best quality and was therefore, recommended.

Key words: Design, fabrication, performance, soy-gari, mixing, evaluation

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is the forth most important staple food in the world after rice, wheat and maize (IFAD/FAO, 2000). Cassava can be processed into several local products such as cassava flour, gari, lafun, fufu, pupuru, abacha, dried cassava chips/pellets and other industrial products like starch and alcohol (RAIDS/IFAD, 1991).

Gari is a free flowing particulate product consisting of cassava particles, which have been gelatinized and dried (IITA, 1990). It offers little or no nutrition apart from carbohydrate. Therefore, in a bid to enhance protein content in gari, Ilo (2002) incorporated 20% soy beans paste into gari without adverse effect on the quality to produce a composite product called soy-gari.

Soy-gari is processed differently in different parts of Nigeria. It is processed for the preparation of 'EBA' a popular food in Nigeria and West Africa. Even though, Soy-gari product is gaining wide acceptance leading to increase in commercial production, the production process, particularly the mixing unit operation is largely manual and presents a major challenge. Manual mixing of soy gari is very slow and laborious, with little or no guarantee of homogeneity of the end product.

This research is therefore, devoted to the local fabrication of a low cost electric-powered soy-gari mixer to handle the challenge of manual mixing and improve the yield and the overall quality of the product.

MATERIALS AND METHODS

Materials and sample preparation: Good quality cassava roots and soy beans seeds were purchased in North-bank market, Makurdi Benue State Nigeria and prepared as described by Asiedu (1989). About 20% soy-flour and 20% soy paste were mixed with 80% of the small (1.18 mm), medium (1.70 mm), large (2.30 mm) and locally sieved gari samples, respectively using a locally fabricated mixer. The particle sizes of cassava mesh were obtained as outlined in ASAE 319, using three British standard sieves. During the mixing, samples were withdrawn at every 2 min and gari-fried, cooled and packed in high density polyethylene bags. The bags containing the soy-gari samples were placed in empty powdered milk cans and stored at room temperature (30±2°C) for physical and sensory analysis.

Design considerations: The following equations were used to design the components of the soy-gari mixing machine.

Volume and weight capacity: Using the density mass and volume relationship, an estimate was made of the capacity by volume of the machine as follows:

Total volume of the trough was calculated using

$$V = \pi D^3 L \tag{1}$$

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Based on $D = 0.262$ m, $L = 0.217$ m,
$V = 1.17\times10^{-2}\ m^3$

Considering 25% headspace, the maximum allowable fill volume was taken as 0.75 V.

Density of samples was estimated based on the relationship given as: Density = Mass/Volume and Weight capacity of the machine was determined from the mass of the fill volume.

Power requirement: The force required for mixing was calculated using Eq. 1 by Brennan *et al.* (1981).

$$F = mr\omega^2$$

Where,
m = The mass of the mix (g)
r = The radius of the circular path of rotation (m)
ω = The angular velocity ($m\ sec^{-1}$), given in Eq. 2

$$\omega = \frac{N\pi}{30} \quad (2)$$

Where,
N = The rotational speed in revs/sec

The power required for mixing was determined using Eq. 3 by Brennan *et al.* (1981).

Output power:

$$P = F\times R\times\omega \quad (3)$$

Where:
P = Power (W)
F = Force (N)
R = Radius (radius of driven pulley)

Transmitted power: The torque acting on the driving sheave is:

$$T_0 = (T_1 - T_2)\ D_0/2 \quad (4)$$

and on the driven sheave

$$T_D = (T_1 - T_2)\ D_0 \quad (5)$$

T_1 = Tight side tension (N)
T_2 = Slack side tension (N)
$(T_1 - T_2)$ = Effective pull (N)
T_0 = Driving sheave torque (Nm)
T_D = Driven sheave torque (Nm)
D_0 = Driving sheave diameter (m)
D_D = Driven sheave diameter (m)

The effective pull is be related to the power by:

$$P = \frac{(T_1 - T_2)\ V}{1000} \quad (6)$$

Where:
V = Belt velocity ($m\ sec^{-1}$)

Allowable tension ratio (R_A) for V-belts on flat pulley is:

$$R_A = \exp\left[(0.2917)\frac{\theta\lambda}{180}\right] \quad (7)$$

Where:
θ = Arc of contact
λ = 3.14159 rad

$$\theta = \sin^{-1}\left[\frac{D_D - D_0}{2C}\right] \quad (8)$$

C = Center-to-center distance of pulleys

Equation of arc of contacts for open belt drive

$$\theta = \lambda + 20 \quad (9)$$

$$R_A = \frac{T_1}{T_2} \quad (10)$$

$$T_1 = R_A T_2$$

Substituting T_1 into Eq. 4:

$$T_0 = T_2(R_A - 1)\frac{D_0}{2} \quad (11)$$

Since, torque supplied by electric motor = torque on driving pulley, then:

$$T_{motor} = T_2(R_A - 1)\frac{D_0}{2} \quad (12)$$

Belt speed:

$$v = rpmD/19100$$

Where,
D = Diameter of driven pulley
rpm = Average speed of rotation of driven pulley

Effective pull, which can be related to power from Eq. 6:

$$P = \frac{(T_1 - T_2)v}{1000} \quad (13)$$

Calculation of electric motor torque: Power = Torque × angular velocity

$$\text{Torque} = \frac{\text{Power}}{\text{Angular velocity}} \qquad (14)$$

Calculation of the length of v-belt (open belt):

$$l = 2C + \pi\left[\frac{D+d}{2}\right] + \frac{(D-d)^2}{4C} \qquad (15)$$

Where,

C = Center distance (between the two pulleys) = 220 mm = 0.22 m
D = Diameter of driving pulley = 0.058 m
d = Diameter of driven pulley = 0.27 m

Shaft design: The design of shaft is based on strength.

Shaft diameter is calculated as follows (Hall *et al*., 1983):

$$d^3 = 16/\lambda S_S \sqrt{(K_t M_{t1})^2 + (K_b M_b)^2} \qquad (16)$$

Where,

K_b = Combined shock and endurance (fatigue) factor applied to B.M. 1.5 for rotating steel shafts
K_t = Combined shock and endurance (fatigue) factor applied to Tensional Moments (TM) 1.0 for rotating steel shafts
S_S = Allowable shear stress for steel shafts
M_t = Torsion or twisting moment
M_b = Bending moment

Mixing index and mixing time: The mixing index (M) was determined as described by Kramlich (1984) using the equation given by Smith (2003):

$$M = \frac{S - S\infty}{S_0 - S\infty} \qquad (17)$$

Where,

M = Mixing index
S = Standard deviation at a given time
S_0 = Proportion of the component
S_∞ = Random value of S
S_∞ = o (the number of particles in the sample are large)

If M approaches the value of zero the sample is well mixed. However, if M approaches unity, the sample is unmixed.

Mixing time was determined from extrapolation of the plot of the logarithm of experimental values of mixing index against time: t = ln (M)/-K (min) as reported by Smith (2003).

RESULTS AND DISCUSSION

Assembly drawing of the fabricated mixer is presented in Fig. 1. Results of density of samples are presented in Table 1. The results show that the density of samples increased as the particle size increased and was generally higher in Soy-Gari Paste (SGP) than Soy-Gari Flour (SGF). The relationship between speed of rotation and particle size of 2 samples (SGP and SGF) is shown in Fig. 2. The speed of rotation of the shaft carrying the mixing blade increased with increased particle size. This could be attributed to decrease in weight as the particle

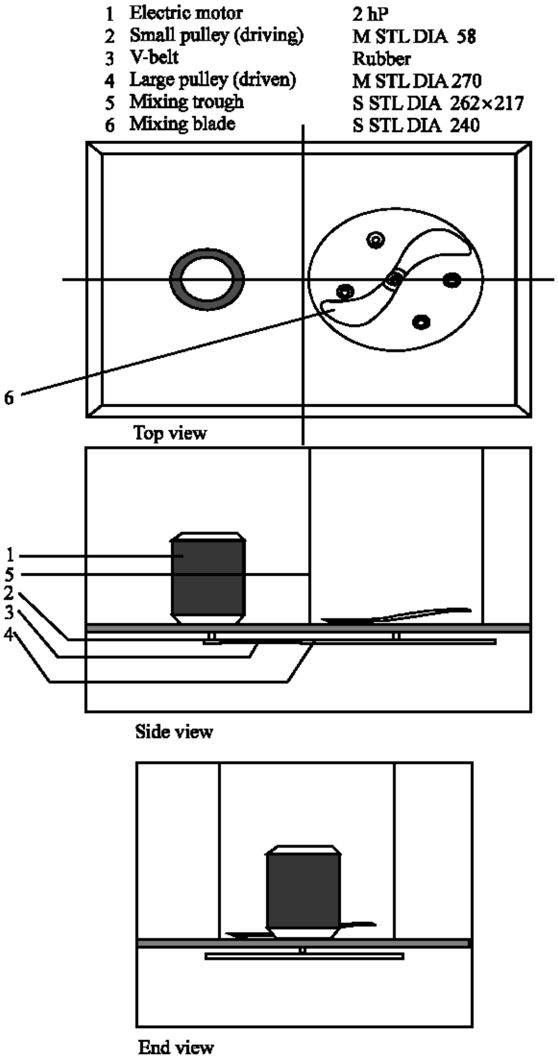

Fig. 1: Assembly drawing of the fabricated mixture

Table 1: Density of the samples

	Density (kg m^{-3})	
Sieve size	SGF	SGP
Small (1.18 mm)	1333.33	1384.62
Medium (1.70 mm)	1341.88	1394.02
Large (2.36 mm)	1344.44	1396.58
Local sieve	1344.44	1397.44

size increased as a result of decrease in bulk with particle size. Consequently, decrease in weight favoured easy movement of the mixing blade resulting to increase in the speed of rotation. Decrease in weight also resulted to decrease in centrifugal force, which is generally mass dependent thus, favouring mixing (Brennan *et al*., 1981). The speed of rotation was higher during mixing of soy-gari flour compared with soy-gari paste. This could be attributed to the weight and more viscous nature of the paste.

The power requirement for mixing increased with particle size and was higher during the mixing of soy-gari paste compared with soy-gari flour (Fig. 3). This is due to higher moisture content and viscosity of the paste. More power was required to cut through and turn the blade when, the weight of the material was more.

From Fig. 4, it is seen that as the particle size increased, the mixing rate increased. This was expected because; small particle sizes have larger surface areas, which can agglomerate easily and mix faster than larger particles sizes. The higher mixing rate generally observed in SGP as compared to SGF could be attributed to the presence of water in soy paste, which may have eased movement of the mixing blade, resulting to faster mixing of the paste than the flour materials. The optimum rate of mixing SGP was generally less, being in the range reported by Chilton and Perry (1973). On the other hand, the mixing rate of SGF was higher than this range, with the smaller particle sizes ranking closer and the larger particle size samples deviating more.

The soy-gari mixing machine's throughput was generally low for SGF compared to SGP (Fig. 5). The higher output in SGP was expected because of its viscous nature, which enabled the mixing blade to sweep the material more easily. The machine's throughput capacity generally decreases as the particle size increased. This may be attributed to the large surface areas of the smaller particles size, which agglomerates easily and mix faster and as such yield higher throughput than the bigger particle sizes.

The results of physical analysis and some functional properties of soy-gari blends presented in Table 2 shows that Water Absorption Capacity (WAC) decreases slightly as particle size increases. This decrease could be attributed to the large surface area of the smaller particle

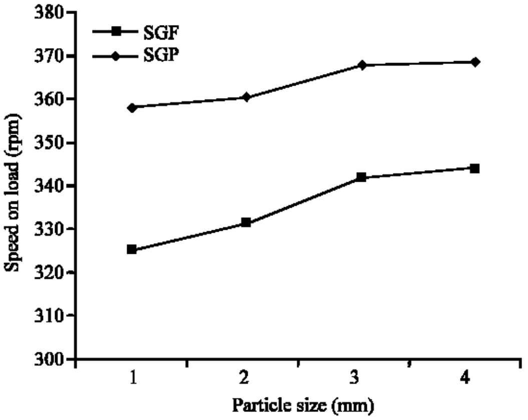

Fig. 2: Effect of speed of rotation on load for different particle sizes

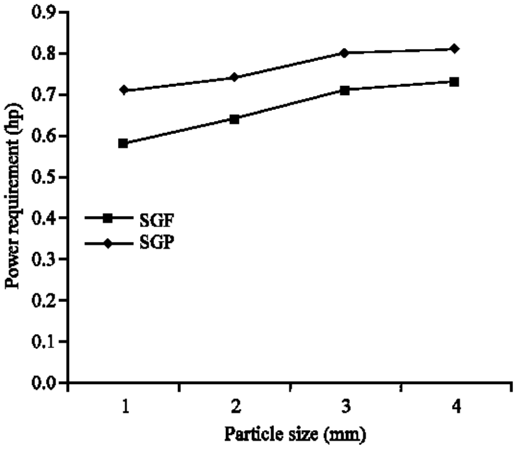

Fig. 3: Effect of power requirement for different particle sizes

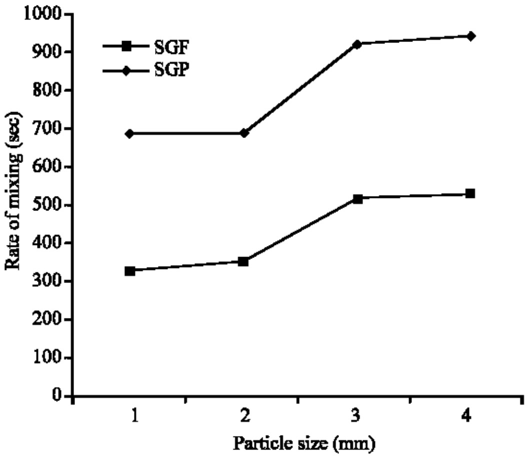

Fig. 4: Effect of time of mixing for different particle sizes

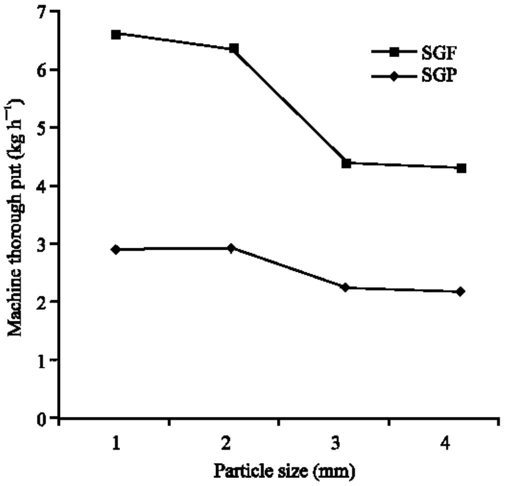

Fig. 5: Effect of throughput capacity for different particle sizes

sizes which favoured moisture absorption more than larger particle sizes. There was no definite trend noticed between WAC of local sieve and hand mixed for both SGF and SGP. This could be attributed to the fact that each particle's water absorption depends on the amount that it is already holding and how much it can take in addition to attain saturation. This may also be due to protein content and its degree of starch damage (Kaze *et al*., 2007).

The least gelation concentration is also presented in Table 2 decreased with particle size and ranged between 8.2-9.5% (w v^{-1}) for SGF and 8.1-9.0% (w v^{-1}) for SGP. Increase in gelation with particle size can be related to higher solute concentration of smaller particles, since gelation is a function of concentration (Kaze *et al*., 2007). The least gelation concentration of the SGF was generally higher than SGP in agreement with the report of Akpapunam *et al.* (1995). The authors reported slight increase in least gelation concentration in SGF due to the nature of the protein in the SGF and the presence of some seed coat fractions in SGF. The nature of protein and seed coat fractions in legumes can interfere with the formation of such a continuous network. There was significant difference ($p<0.05$) in gelation of particle size 2.36 mm and local sieve but the differences are not statistically significant ($p>0.05$) for both 1.18 and 1.70 mm.

The bulk density of both samples of SGF and SGP decreased as the particle sizes increased (Table 2). Decrease in bulk density with particle size was expected since bulk density is a function of particle size. Therefore, more of the finer particles will occupy a unit volume than the larger particles which have larger porosity. The bulk density of SGP was higher than SGF. This could be attributed to the higher moisture content of SGP compared with SGF.

Table 2: Results of physical analysis on soy-gari functional properties

Samples	Water absorption capacity (gwater/gsample)	Least gelation concentration (%w v^{-1})	Bulk density (g cm^{-3})
1.18 (mm)			
SGF	12.9^b	9.5^a	0.62^a
SGP	13.5^a	9.0^a	0.66^a
1.70 (mm)			
SGF	12.7^b	8.7^b	0.61^a
SGP	13.0^a	8.5^b	0.65^a
2.36 (mm)			
SGF	12.3^b	8.2^b	0.59^b
SGP	12.7^b	8.0^c	0.62^a
Local sieve			
SGF	11.8^c	8.3^b	0.56_b
SGP	12.4^b	8.1^c	0.60^b
Hand mixed			
SGF	12.0^c	8.2^b	0.54^b
SGP	12.6^b	8.1^c	0.57^b
$LSD_{0.05}$	0.28	0.59	0.77

Table 3: Mean sensory scores of the soy-gari mixed

Samples code	Colour	Texture	Taste	General acceptability
1.18 (mm)				
SGF	3.3^a	3.1^a	3.5^a	3.4^a
SGP	2.7^b	2.0^c	2.5^c	2.4^b
1.70 (mm)				
SGF	3.3^a	3.2^a	3.6^a	3.5^a
SGP	2.8^b	2.1^c	2.9^c	3.2^a
2.36 (mm)				
SGF	2.6^b	2.9^a	2.8^c	2.2^b
SGP	2.3^c	2.5^b	2.8^c	2.0^c
Local sieve				
SGF	2.3^c	2.1^c	3.0^b	2.7^b
SGP	2.2^c	2.1^c	2.8^c	2.1^c
Hand mixed				
SGF	2.7^b	2.9^a	3.1^b	2.1^c
SGP	2.4^c	2.3^b	2.8^c	2.1^c

Means with the same subscripts on the same column are not significantly ($p>0.05$) different

Figure 6 shows that the swelling index of both SGF and SGP were affected by particle size and temperature of the water used. Swelling capacity is a function of the process conditions, nature of material and the type of treatment (Akpapunam *et al*., 1995). Swelling index decreased with particle size in both SGF and SGP. This could be due to the fact that smaller particles have larger surface areas and absorb more water and hence, swell more than the larger particles (Kaze *et al*., 2007). Increased in swelling index of both SGF and SGP at 30°C was significantly different ($p<0.05$) from 100°C (Fig. 6). This could be due to increase in gelatinization of starch at the higher levels of temperature.

Table 3 shows the sensory evaluation results of the soy-gari blends. At 0.05 level of significant. The soy-gari mix (SGF and SGP) of particle size 1.70 mm was the most acceptable. It produced finer and more uniform mix compared to the other particle sizes. Soy-Gari Paste (SGP) mixture of particle size 2.36 mm was rated least acceptable. Based on overall acceptability result, the SGF of particle size 1.70 mm was the most preferred product.

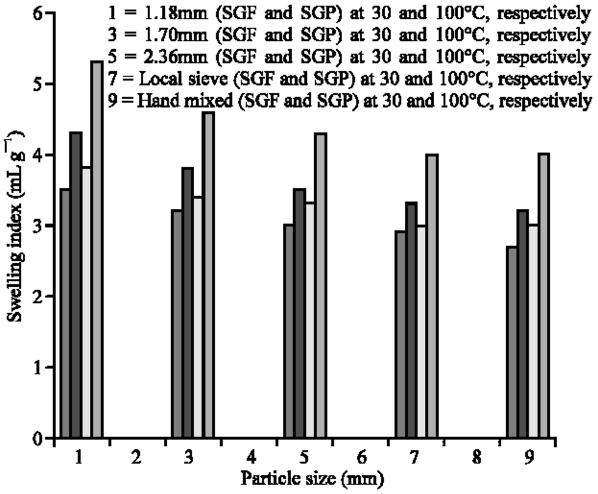

Fig. 6: Trends of swelling index of soy-gari blends

CONCLUSION

The locally fabricated soy-gari mixer offers great improvement over the tedious manual method of soy-gari mixing in terms of higher throughput capacity, homogeneity of end product and higher mixing rate with the larger particle sizes mixing faster. Results of sensory analysis indicated that Soy-Gari Flow (SGF) of medium particle size (1.70 mm) was rated as being the best quality.

REFERENCES

Akpapunam, M.A., S.O. Igbedioh and I. Aremo, 1995. Effect of matting on physico-chemical properties of soybean and Bambara groundnut flours. Int. J. Food Sci. Nutr., 46: 41-42.

Asiedu, J.J., 1989. Processing Tropical Crops: A Technological Approach. 1st Edn. Macmillan Publication London, pp: 3-8.

Brennan, J.G., J.R. Battlee, N.D. Cowell and A.E.V. Liily, 1981. Food Engineering Operations. Applied Science Publisher Ltd. London, pp: 84-129.

Chilton, H.C. and H.R. Perry, 1973. Chemical Engineers's Handbook. 5th Edn. Mc-Graw Hill Int'l Book Company Tokyo, Japan, pp: 386.

Hall, A.S., M.S. Holowenko and H.G. Laughlin, 1983. Theory and Problems of Machine Design. McGraw-Hill Int. Book Comp. Singapore, pp: 113-130, 290-300.

IFAD/FAO, 2000. The world cassava economy. Facts, trends and outlook. IFAD/FAO, Rome, pp: 58.

Ilo, F.O., 2002. Physico-chemical and sensory properties of Soy-enriched gari (B.Sc. project, University of Agriculture, Makurdi), pp: 53.

IITA, 1990. International Institute of Tropical Agriculture, Annual report on Cassava in Tropical Africa, pp: 90.

Kaze, A.S., J.O. Onuh and C. Agude, 2007. Study of Physical Characteristics of Bambara. Proc. 31st Annual. Conferences of Nigeria Institute of Food Sciences Technology, pp: 110-111.

Kramlich, W.E., 1984. Processed Meats. 4th Edn. The Avi Publishing Company, Inc. Westport, Connecticut, USA, pp: 294-296.

RAIDS/IFAD, 1991. A Compendium of household and small scale cassava processing machine. Rural Agro-Industrial Development Scheme and International fund for Agricultural Development Workshop on Cassava processing, Ijebu-Ode.

Smith, P.G., 2003. Introduction to Food Processing Engineering. Kluwer Academic/Plenum Publishers, Moscow, pp: 3-46.