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Research Article

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A Cold Millet Extrusion Machine

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Abstract The main objective of this research is to design and construct an extruder for the production of pasta from millet-based dough by using flour from millet to evaluate the effects of mixture levels, die diameter, binder type and water temperature on the rheological properties of millet-based pasta dough. The products obtained compared well in the studied rheological properties with the four commercially available noodles (Indomie, Chikki, Supreme and Golden Penny) acceptable brands already in the Nigerian markets.

Keywords Millet, mixture levels, binder type, extruder, compression tests

Introduction

Over the years, there have been numerous studies on alternate methods for production of pasta from different raw materials, where alternates for raw materials were used for production focusing on reduced cost, matching similar production parameters and improving nutritional value. These methods and processes also have the money spinning potentials in food industries while manufacturers and consumers in Nigeria and other parts of the world using more economical materials to make pasta and leading ultimately to increased demand for millet-based pasta.

Pasta is a popular cereal food that comprises of spaghetti, noodles, vermicelli and many more. It is mostly made from durum wheat, because it maintains a desirable firm texture during cooking and had natural amber colour that is associated with good quality pasta. Various unconventional ingredients such as buckwheat, amaranth and lupin flours [1], finger millet flour [2-3] have been used to increase nutritional and functional quality of pasta and noodles.

Huang *et al.*, [4] also reported that higher levels of gums with modified starch can produce non-gluten pasta similar to wheat based pasta. In general, gums and thickeners such as carboxymethyl cellulose and guar gum aid in gelling, thickening, water retention and texture improvement [5] and can be utilized for the development of non-wheat pasta products.

Wheat, like other grains, is rich in fibre and some other nutrients but wheat contains GLUTEN – a protein brand that can cause inflammation. A systemic process that has harmful effects across all the organs system in the body.

Keeping in view above findings of researchers, it was thought that probably pearl millet flour incorporated with other ingredients and stabilizers may yield acceptable non-wheat pasta. Therefore, the present study was planned with an objective to optimize non-wheat pasta formulation of high nutritive value comprising pearl millet flour, guar gum and Okoho.

The four most important millets cultivated in Africa are: Pearl millet- *Pennisetum glaucum* (L.) (accounting for 76% of total production), finger millet – *Eleusine coracana* L. Gaertn. (19%), Teff – Eragrostis teff (Zucc.) Trotter (1.8%), and Fonio – *Digitaria exilis* Stapf. (acha) and *Digitoriai burua* Stapf. (blackfonio) (0.8%) [6].

Pearl millet (*Pennisetum typhoides*) is an important cereal of tropical and subtropical regions of the world because of its ability to produce good yield under unfavourable conditions. Pearl millet has been used in traditional foods and is the staple crop of many regions of Asia and Africa. In the face of increasing population and stagnant wheat and rice productions, pearl millets can be a promising alternative in solving the problem of food insecurity and malnutrition.

In this study the extrusion process was handled using cold extrusion technology which has been used to shape products [7] by mixing flour and other ingredients with water to obtain uniform dough that is extruded through a die, depending on the desired shape of the product. Application of extrusion technology in Nigeria has been reported for soybean flour and its blends with cereals, roots, tubers and other low protein legumes [8-12]. The ideal temperature for pasta extrusion is between 45°C and 50°C, as anything above 50°C will denature the proteins and impede in gluten matrix formation. It is the objective of this study to develop an extruder with simple technology for small-scale processing and production of pastas.

Materials and Methods

Equipment Design, Construction and Description

One of the objectives of this study was to develop an extruder with simple technology for small-scale processing and production of pastas. This was done and an extruder with a capacity of 3.6 kg/hr and an average efficiency of 68 % was produced and tested (Figure 1). The rated power of the extruder was 227.68 N which is far less than the normal full force a man can exert with his hand (400 N) thus making the extruder energy to use friendly. The summary of the design specifications are as shown in Table 1.

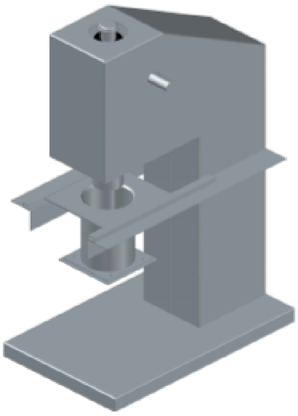

Figure 1: Isometric view of the Extruding Machine

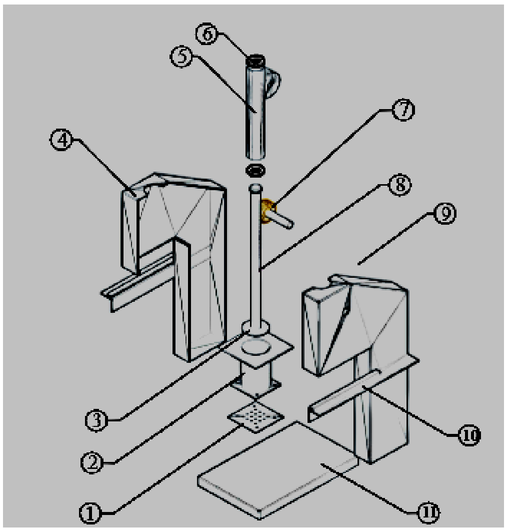

Figure 2: Exploded View of the Extruding Machine

Description of the Extruder

The extruder is made up of eleven distinctive parts (Figure 2) which are:

1. **Die:** This is made of stainless steel to avoid rust since the product which will be extruded through the die is consumable. The dies are in two sizes 2mm and 2.5mm size.
2. **Cylinder/Barrel:** This is where the dough is placed ready for extrusion. It is made of stainless steel and it is detachable for easing of feeding the dough and cleaning.
3. **Piston:** The piston end is also made of stainless steel. It helps to push down the dough in the cylinder as it is extruded through the die.
4. **Casing:** The casing encloses the gear and the shaft housing and also acts as a support for the entire machine.
5. **Shaft Housing:** This is used to enclose the extruding shaft
6. **Seals:** The seals are placed at the ends of the extruding shaft.
7. **Gear:** The gear is made up of mild steel. It helps in the movement of the shaft downwards or upwards whenever the handle is lowered or lifted.
8. **Shaft:** The shaft is attached to the piston. The cuttings on the shaft moves along with the gear when the handle is lowered or vice versa.
9. **Handle:** The handle is attached to the top of the gear at the end in closed in the casing, while the other end is left hanging for clockwise or anticlockwise rotations to bring down or lift the piston.
10. **Cylinder Hanger:** The cylinder hanger is attached to both sides of the housing with slits where the cylinder is placed during extrusion or removed after extrusion for cleaning and re-feeding.
11. **Basement:** This is attached to the housing at the lower part. Pastas extruded are collected with a tray placed on the basement.

Extruder Working Principles

The extruding cylinder (2) is slide out from the cylinder hanger (10). A specific die (1) is then tightened to the base of the extruding cylinder. The dough is filled into the cylinder and the filled cylinder is replaced back into the cylinder hanger. The Piston (3) is pushed down so as to press the dough to enhance extrusion with the aid of the gear – teeth shaft (8) which is driven manually using the handle (9) through a pinion gear. The piston then presses the dough which is then forced through the perforated die as extruded material. The machine is locally fabricated and covered with a casing (4) and well seated on a basement (11).

Table 1: Design Parameters/Specifications of the Extruder

S/No	Design parameter	Specification
1	Design of Extruding Cylinder Volume	$V_D = 0.00055m^3$
2	Extruding Cylinder Dimensions	h = 0.1093m = 0.11m
3	Design of Base Plate	Diameter of holes -2.5mm and 2.0mm Total No. of holes -14
4	Force exerted on the base plate	$F_p = 1049.2N$
5	Internal Pressure of Dough (P_i)	0.2086 N/mm^2
6	Design of Power Screw	Square thread series = Normal Series Screw jack travel distance= 150mm Pitch of square thread (p) = 5mm Height of thread (h) = 0.5p = 2.5mm
7	Diameter of the Extruding Shaft	Screw shaft diameter = 22mm
8	Length of the shaft (column).	L = 150mm
9	The Hand Lever	$T_e = 450450.11Nmm$
10	Force required at the lever to extrude	F = 18.59N
11	Screw shaft Velocity Ratio	V.R = 3

Testing and Evaluation

Samples were prepared and introduced into the extrusion rig of 38mm internal diameter with 2mm, 2.5mm die diameter. The rig is placed on the fixed cross base of the Testometric Universal testing machine. A plunger (piston) is fixed to the moveable cross head having 5kN capacity load cell in between. The tester is set to compress the dough in the rig at 60mm/min thereby extruding through the dies into a receiving tray provision as shown in plate 1. The tester is set to stop automatically at a predetermined position. The plunger is returned to starting position and the test is ended.

The dried samples from the oven after it cools are placed on compression plate mounted to the fixed cross base. Compression probe is selected which is wide enough, such that at no time will some of the sample be out of coverage of the probe throughout the analysis. The probe mounted unto the moveable cross head having 5kN load cell in between. The tester is set to trigger at 5N and compress the sample to 25% strain of its height and end the analysis. It should be noted that preliminary analysis shows that highest rupturing force shall be achieved before 25% compression.

Plate 1: Extruded products ready for drying in the oven

(a) D1T2Q2G1

(b) D1T2Q2G2

(c) D1T2Q2G3

(d) D1T2Q2G4

Plate 2: Samples of extruded dried millet-based pasta of varying Guar gum proportions for Dia. 1

(a) D1T2Q2K1

(b) D1T2Q2K2

(c) D1T2Q2K3

(d) D1T2Q2G4

Plate 3: Samples of extruded dried millet-based pasta of varying Okoho Gum proportions for Dia. 1

(a) D2T2Q2K1

(b) D2T2Q2K2

(c) D2T2Q2K3

(d) D2T2Q2G4

Plate 4: Samples of extruded dried millet-based pasta of varying Okoho proportions for Dia. 2

Table 2: Millet Noodle of Okoho Gum under Compression Load

Test No.	**Height (mm)**	**Force @ Peak (N)**	**Def. @ Peak (mm)**	**Strain @ Peak (%)**	**Energy to Peak (N.m)**	**Force @ Yield (N)**	**Def. @ Yield (mm)**	**Strain @ Yield (%)**	**Energy to Yield (N.m)**
Millet Noodle Under Compression Load @ H_2O/Meal Ratio 7.5ml									
1	20.00	18.520	4.560	2.187	0.022	4.290	1.074	0.515	0.002
2	20.00	23.200	4.990	2.427	0.032	0.840	0.901	0.438	0.002
3	20.00	13.080	2.332	1.093	0.013	4.140	0.656	0.307	0.002
4	20.00	11.000	3.952	1.883	0.021	2.860	0.344	0.164	0.001
Millet Noodle Under Compression Load @ H_2O/Meal Ratio 10ml									
1	20.00	82.750	2.209	1.159	0.046	37.350	1.410	0.740	0.013
2	20.00	41.710	5.049	2.563	0.077	24.640	0.554	0.281	0.006
3	20.00	37.880	4.870	2.520	0.059	13.750	0.314	0.163	0.003
4	20.00	82.850	5.080	2.183	0.142	21.110	1.790	0.769	0.009

Millet Noodle Under Compression Load @ H_2O/Meal Ratio 12.5ml									
1	20.00	67.850	3.959	7.160	0.095	23.390	0.313	0.566	0.004
2	20.00	39.230	4.708	2.194	0.053	8.820	0.629	0.293	0.004
3	20.00	108.400	1.420	2.554	0.041	43.710	0.253	0.455	0.006
4	20.00	99.500	4.985	8.911	0.142	22.860	1.223	2.186	0.013
Millet Noodle Under Compression Load @ H_2O/Meal Ratio 15ml									
1	20.00	45.150	4.865	8.967	0.091	22.290	0.536	0.988	0.009
2	20.00	49.930	5.121	9.161	0.041	23.330	0.455	0.814	0.006
3	20.00	87.160	3.332	6.278	0.081	27.020	1.705	3.213	0.013
4	20.00	66.670	5.022	2.476	0.137	19.590	0.666	0.328	0.008

Table 3: Millet Noodle of Guar gum Under Compression Load

Test No.	**Height (mm)**	**Force @ Peak (N)**	**Def. @ Peak (mm)**	**Strain @ Peak (%)**	**Energy to Peak (N.m)**	**Force @ Yield (N)**	**Def. @ Yield (mm)**	**Strain @ Yield (%)**	**Energy to Yield (N.m)**
Millet Noodle Under Compression Load @ H_2O/Meal Ratio 7.5ml									
1	20.00	23.720	5.098	2.543	0.049	6.790	0.480	0.239	0.003
2	20.00	29.810	4.195	2.116	0.041	6.000	1.087	0.548	0.005
3	20.00	28.910	4.928	2.414	0.067	8.530	0.687	0.337	0.004
4	20.00	15.500	4.394	2.109	0.033	6.060	1.064	0.511	0.005
Millet Noodle Under Compression Load @ H_2O/Meal Ratio 10ml									
1	20.00	7.720	2.190	1.017	0.011	5.890	0.598	0.278	0.003
2	20.00	9.880	2.546	1.197	0.015	7.720	0.180	0.085	0.001
3	20.00	11.610	4.415	2.105	0.036	7.410	0.714	0.340	0.005
4	20.00	11.840	4.380	2.057	0.025	8.090	0.346	0.162	0.002
Millet Noodle Under Compression Load @ H_2O/Meal Ratio 12.5ml									
1	20.00	11.690	4.026	1.861	0.024	11.240	0.306	0.141	0.002
2	20.00	22.490	3.934	1.820	0.030	10.830	0.433	0.200	0.003
3	20.00	12.480	3.327	1.583	0.029	6.800	0.318	0.151	0.002
4	20.00	13.040	2.231	1.019	0.008	5.970	0.214	0.098	0.001
Millet Noodle Under Compression Load @ H_2O/Meal Ratio 15ml									
1	20.00	55.280	4.995	2.445	0.150	12.080	0.630	0.308	0.007
2	20.00	20.200	3.082	1.433	0.027	12.230	0.496	0.231	0.005
3	20.00	63.460	5.022	2.445	0.134	25.870	2.194	1.068	0.024
4	20.00	50.540	4.498	2.156	0.119	15.960	0.811	0.389	0.006

Results

The products of the extrusion process of completely millet-based meals are as shown in Plates 2 (a - d) and 4 (a –d)using the Guar gum binder in two separate die diameters at same temperature and Plates 3(a - d) and 5 (a – d) are that of products using Okoho as binder prior to extrusion, also in two separate diameters.

While Plates 2 (a) indicates H_2O to meal ratio of 10 mls, Plates 2 (b) is for a H_2O to meal ratio of 12 ml then Plates 2 (c) is for a ratio of 12.5 ml and Plates 2 (d) for a ratio of 15 ml. The Plate 3(a - d) follow the same trend but emphasizing Okoho gum binder, with the same H_2O to meal ratios for two die diameters all operating at two temperature ranges.

Tables 2 and 3 are generated data samples from the compression tests of the Millet-basedpastas involving Guar gum and Okoho gum brands of binders.

Conclusion

The device (an extruder) presented in this work developed for household use, will make production and consumption of pasta very easy and convenient since the rated power of the extruder (227.68 N) is far less than the normal force a man can exert with his hand (400 N) thus making the extruder energy to use friendly. The pastas can be produced from various combinations which could help to reduce protein energy malnutrition prevalent in developing countries and add variety to the predominantly carbohydrate-based foods in the market. Jobs can also be created when production plants are structured as an SME.

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