Food Extrusion Technology: Initiatives to Address Food and Nutrition Insecurity in South Africa

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Abstract: The use of extrusion can be regarded as beneficial due to its short production time and wide variety of foods produced by this method. South Africa as a developing country has been involved in food extrusion since the 1980's and this technology is gaining momentum in academic research areas. A number of research efforts related to extrusion in South Africa have shown the consumption of extruded dry beans can reduce plasminogen activator inhibitor levels in hyperlipidaemic men; the production of sorghum-cowpea extruded instant porridge resulted in a nutritional acceptable product and can be used to supplement the diet of young children to assist with protein deficiencies. Furthermore, research has proven extruder parameters play a role in the outcome of the product and can influence product properties. Based on these research initiatives, Vaal University of Technology/Centre of Sustainable Livelihoods (VUT/CSL) has acquired an Extrusion Pilot Plant to implement interdisciplinary research of nutrition and engineering science. The research will look at process optimisation studies to obtain maximum product output and evaluating nutritional compositions of the products under various conditions. It is hoped the future research efforts at VUT/CSL will address food and nutrition insecurity and showcase the pilot plant as a testing facility and potential advancement to commercialisation.

Keywords: Extrusion, Research, South Africa, Production, Nutrition.

1. INTRODUCTION

The global evidence based literature confirmed the link to nutrition, well-being and health is food [1-3]. However, the availability and consumption of this important source of nutrients needed to sustain life is compromised due to political, social, economic and environmental issues leading to food insecurity, inaccessibility and malnutrition. Organisations such as World Bank (WB), World Health Organisation (WHO), United Nations (UN), Food and Agricultural Organisations (FAO), World Food Programme (WFP), and International Fund for Agricultural Development (IFPD) have dedicated their time and expertise in addressing the concerns of food insecurity and malnutrition [4]. Although food and nutrition insecurity are global concerns, the circumstances faced by developed and developing countries do differ from each other. For example, in Sub Saharan Africa, other than political, environmental and socio-economic stresses, food insecurity and malnutrition, can also be attributed to extreme poverty, minimal international trade, weak infrastructure and development, overlooking the usage of resources, supply and demand is difficult due to large population size [5-9]. Hence, for sustainability and efficacy purposes, individual countries and/or regions should look at resources that are available locally to deal with the situation of food insecurity and malnutrition.

In South Africa (SA), the production, acquisition and consumption of food products are similar to those of Western diet system. Food products in SA are processed and packaged by private companies and delivered through a well-established network of whole and retail sale systems and certain companies use specialized processing machinery, such as extruder machines [10-12]. This paper highlights extrusion cooking as a type of food production method to possibly address food shortages and supplying nutritious foods in SA. Therefore, the structure of this mini review paper is as follows: (i) An Overview of Extrusion Technology: the history, advantages, disadvantages, extruder types and (ii) Food Extrusion in South Africa: academic research efforts and the prospects of Vaal University of Technology (VUT) through the Centre of Sustainable Livelihoods (CSL) to address food and nutrition insecurity.

2. AN OVERVIEW OF EXTRUSION TECHNOLOGY

Extrusion is thermo-mechanical, high temperature, short time processing technique. Food extrusion is whereby raw materials of low or high moisture content are chemically modified and transformed into an extrudate [13-18]. The food extrusion process is simply cooking of dry raw materials by steam. The raw materials are added to the feed hopper and via

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ISSN: 2223-3806 / E-ISSN: 1927-5951/17

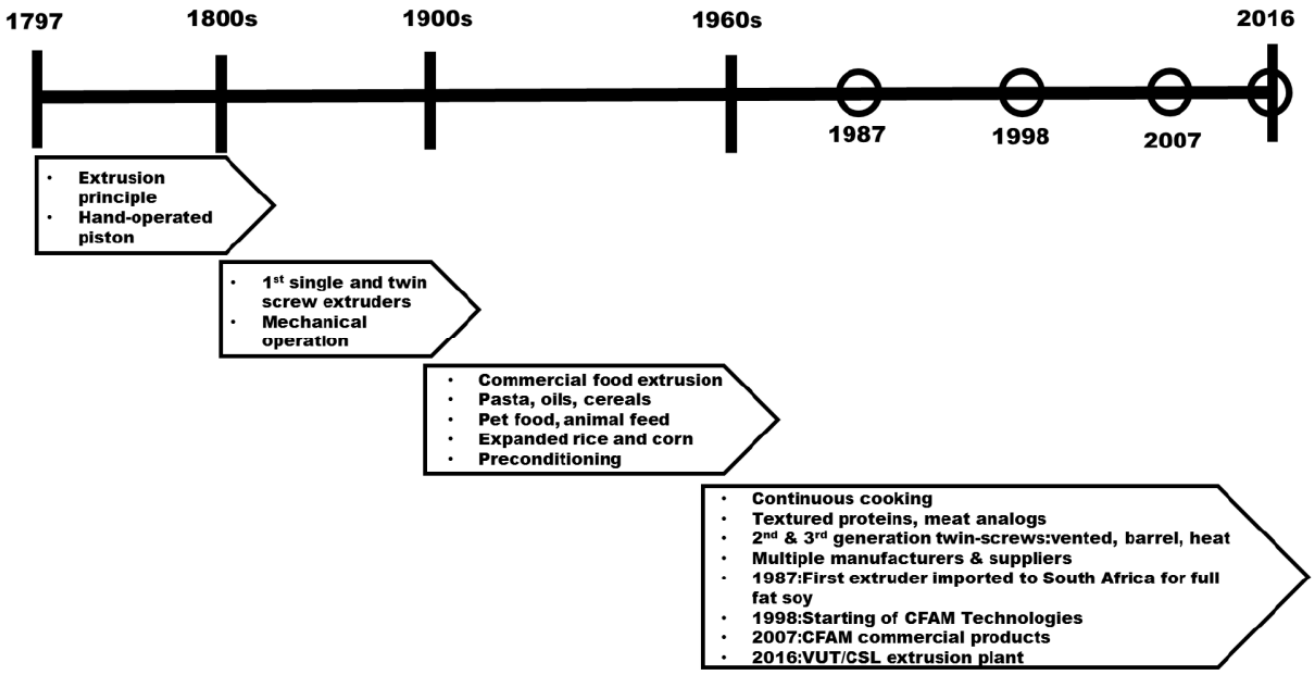


Figure 1: Historical progression of food extrusion technology and milestones related to South Africa [construction of figure based on information from references 13-14, 17, 19-20].

automated pumps fed into the barrel of the extruder. Within this barrel there are rotating screws to convey the materials to the end of the barrel. As the material moves through the screws it is compressed into a dough-like substance by steam. After compression the dough is conveyed towards the die. At the die section (barrel end) the dough expands and is cut by blades into the products or extrudates of varying shapes and sizes [13,18]. Extrusion technology dates back almost 200 years ago (a historic timeline is depicted in Figure **1**).

The advantages of food extrusion cooking are: (i) shorter production or cooking time enabling increased productivity; (ii) a single equipment with multiple operations of kneading, heating, mixing and shaping as well as adapting processing conditions allows for a variety of extrudates; (iii) high temperature processing increases the shelf-life of products by destroying microbial contaminants; (iv) as a continuous production it is economical and requires less energy due to short residence time; (v) high temperatures also improves digestibility of starch and proteins and denatures harmful anti-nutrients such as trypsin inhibitors and fungal allergens [13-14,21-22]. The disadvantages are: (i) selecting process parameters are imperative in preventing molecular changes which can cause the formation of reactive, harmful substances and (ii) initial investment into acquiring the equipment is costly and the maintenance and utilities need to be managed independently to minimize and control additional costs [14-15]. Extruders are classified as single-screw, twin-screw and interrupted flight expanders [13-14]. Single-screw and twin-screw extruders are widely used and the information related to these two types is summarized in Table **1**.

3. FOOD EXTRUSION IN SOUTH AFRICA

The use of extrusion technology in the South African food industry began in the1980's (Figure **1**) and has since grown and expanded through various stages and companies, one of which is the Centre for Advanced Manufacturing (CFAM) Technologies (PTY) Ltd. CFAM Technologies is a spin-off company from a research department within North West University (NWU) in Potchefstroom (North West Province, SA) and is one of the leading manufacturers of twin-screw extruders in South Africa. Additionally, CFAM produces a number of commercial products and supplies extruders and related machinery to southern Africa and international markets [20]. From an academic perspective, published data on food extrusion in South Africa dates from 2000 to 2016. Among consulted literature, several authors from NWU and University of Pretoria (Gauteng Province, SA) have reported on the effects of using extruded dry beans on human health; product development of extruded sorghum-cowpea instant porridge; examining physical properties of extruded grains; and investigating nutritional quality of extruded/micronized porridge [34,37,43-46]. These initiatives have encouraged the authors of this paper to

Table 1: Extruded Products from Various Types of Extruder Models

Type	Products[1]	Models and Manufacturers[2]	References
Single-Screw	Corn snacks, Textured vegetable proteins, Cereals, Pet food, Animal feed, Rice bran, DDGS feeds, Barley, Maize-soybean blends, Sweet-potato-soybean blends	PL2000 Brabender, (Plasti-Corder, South Hackensack, NJ,USA) TYE-30 (Tai Yu Co., Ltd, Taiwan) Almex Battenfeld (Almex BV, Zutphen, The Neatherlands) 20DN Brabender (GmbH & Co, Germany)	Riaz [13]; Guy [14]; Moscicki [17] Perez *et al*. [22]; Iwe & Ngoddy [23]; Iwe *et al*. [24-25]; Yang *et al.* [26]; Ayadi *et al.* [27]
Twin-Screw	Pasta, 3D snacks, Meat analogs, Textured vegetable proteins, Beverage powders, Confectionary sweets, Maize grits & snacks, Rice-amaranth blends, Expanded rice & wheat, Modified rice & almond flours, Corn-soybean blends, Sorghum-cowpea blends, Cauliflower & chickpea flour snacks, Corn-common bean snacks	TX32 (CFAM Technologies, Potchefstroom, South Africa) TX-52(Wenger, Sabetha, KS, USA) CM45-F (Cincinnati Milacron, Austria) Continua 37 (Werner & Pfleiderer, Stuttgart, Germany) DS32-II (Jinan Saixin Food Machinery, Shandong, China) ZSK 30/57 (Werner & Pfleiderer, Ramsey, NJ, USA) MPF 50/25 (APV Baker Inc., Grand Rapids, MI,USA) BC-21 (Clextral, FIRMINY, France)	Riaz [13]; Guy [14]; Ding *et al*. [15]; Moscicki [17]; Jin *et al.* [28]; Lasekan *et al.* [29]; Guha *et al.* [30]; Ilo *et al.* [31-32]; Mahungu *et al.* [33]; Pelembe *et al.* [34]; Ding *et al*. [35]; Hagenimana *et al.* [36]; Dlamini *et al.* [37]; De Pilli *et al.* [38]; Stocjceska *et al.* [39]; Anton *et al.* [40]; Meng *et al.* [41]; Fallahi *et al.* [42]; Vilakati *et al.* [43-44]

[1]General extruded products and products related to the models.
[2]Models used for food extrusion research studies.

look at how extruded food products in SA can play an active role in addressing food and nutrition insecurity.

3.1. Research Initiatives

Oosthuizen *et al*. [45] reported on the incorporation of extruded dry beans in the daily diets of hyperlipidaemic men to evaluate the levels of serum lipoprotein (SL), plasma fibrinogen and viscosity (PF/PV) and plasminogen activator inhibitor (PAI-1). The extruded dry beans were supplied by the School of Mechanical and Material Engineering (Potchefstroom then the University for Christian Education now renamed as NWU) and the products used for the experimental analysis were developed by the Dry Bean Producers Organisation South Africa. It was found PAI-1, the elevated of which is a risk factor for thrombosis and atherosclerosis [47] was reduced with no effect on SL, PF and PV, from a daily amount of 91.9g intakes. In a second study, Oosthuizen *et al*. [46] investigated the glycaemic indices (GI) of women and men aged 19-23 after consuming muffins and pasta produced from extruded dry bean flour (supplied by Dry Bean Producers Organisation). The test groups showed low GI and high GI for the muffin and pasta, respectively. Both studies focused on the health aspect of human consumption of an extruded type product which proved to be beneficial [45-46].

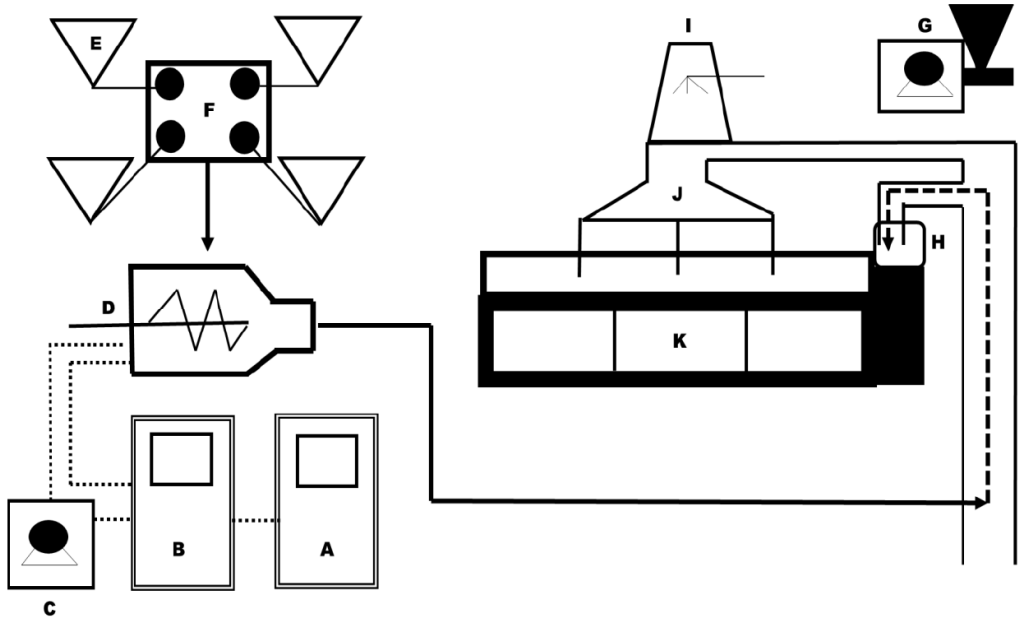
Food extrusion research by Pelembe *et al*. [34], Dlamini *et al*. [37] and Vilakati *et al*. [43-44] focused on the extrusion of sorghum. Pelembe *et al*. [34] studied the development of a sorghum-cowpea instant porridge. The sorghum-cowpea blends were processed using the Continua 37/22D twin-screw extruder (Werner & Pfleiderer) operated at a barrel temperature of 130^{o}C and 165^{o}C in order to determine the effects of temperature and blend ratios on various properties of the final product [34]. With increased cowpea ratio, the protein content, nitrogen solubility index, colour, water absorption and solubility indexes increased. Whereas, when the temperature increased, enzyme-susceptible starch and expansion ratio increased, at lower cowpea ratios [34]. This research is commendable as it showcases raw materials readily available in South Africa and the use of a combined starch-protein composite can be successfully extruded to address the issue of protein deficiencies. Moreover, in comparison to Oosthuizen *et al*. [45,46] the difference to point out is processing conditions can impact the properties of the extrudate.

Dlamini *et al*. [37] investigated extrusion on the antioxidant levels of sorghum (tannin, non-tannin varieties) grains (whole, decorticated). Focusing on the extrusion method, sorghum grains were extruded using the Clextral BC92 twin-screw, co-rotating extruder (Clextral, FIRMINY) at temperatures of 150-160^{o}C. Sorghum extrusion cooking decreased antioxidant levels with the exception of the decorticated NK283 which is a non-tannin variety [37]. From this study, raw material varieties are important when selecting products for extrusion and optimisation of the process parameters is crucial in improving the quality of the extruded grains.

Vilakati *et al*. [43-44] investigated nutritional value of sorghum-cowpea porridge by a combination of extrusion-micronisation cooking. Sorghum grains were extruded using the TX32 twin-screw co-rotating extruder (CFAM, Potchefstroom, South Africa) at a temperature range of 130-159^{o}C and the cowpeas were micronized. Both processes resulted in flour and the sorghum-cowpea flour composite was blended with cowpea leaves to produce a ready-to-eat (RTE) porridge [43-44]. The resultant porridge has increased protein, lysine, zinc, iron and calcium with reduced antinutrients (trypsin inhibitor activity) [43,44]. The purpose of this study was to produce an RTE porridge to supplement the diet of children between the ages of 2-5 years old and the outcome of the study was positive as the product contained nutrients beneficial to the age group under the study. It would be interesting to evaluate the use of extrusion cooking only for the sorghum-cowpea-cowpea leaves, as Pelembe *et al*. [34] in order to detect if a single cooking technique will produce similar results.

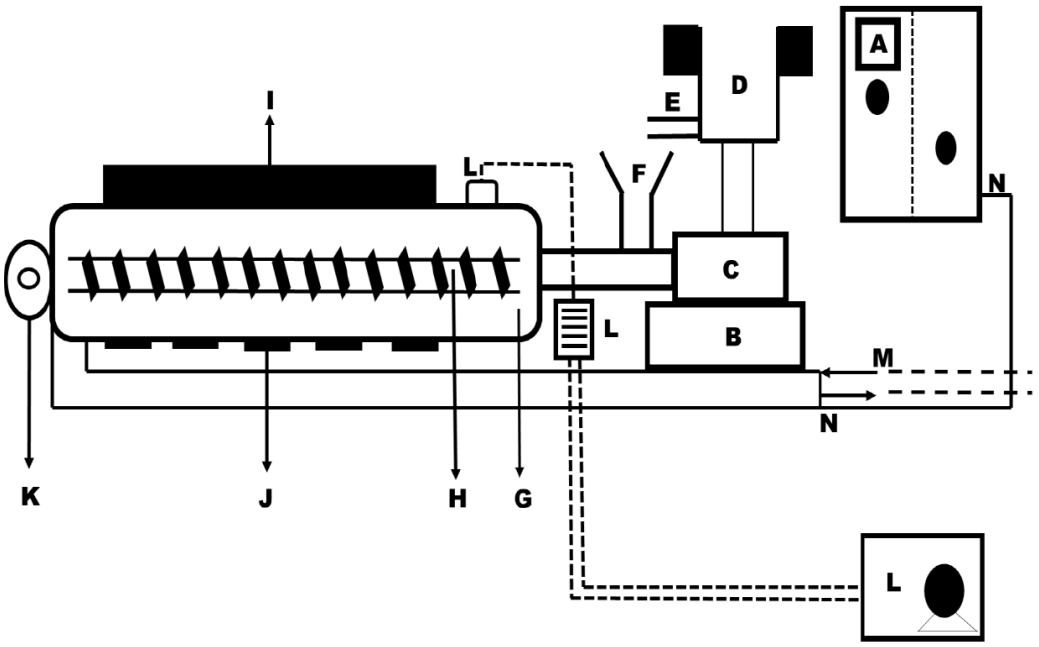
3.2. Prospects of VUT/CSL

The Vaal University of Technology (VUT) was established in 1966 as Vaal Triangle Technikon triggered by the Advanced Technical Education Act to provide industries with technically skilled individuals [48]. Over the past 50 years Vaal Technikon advanced to a University and through a number of Technology Stations or Centres progressed into research and development. One such centre, Centre of Sustainable Livelihoods (CSL) (formerly Institute of Sustainable Livelihoods) was established in 2006 from initial research activities in the Department of Hospitality and Tourism, VUT [49]. CSL has devoted it's time to research in food and nutrition science and has served local communities in the Vaal area by investigating household food insecurity, improving nutritional status of children, addressing hypertension, diabetes and obesity in the elderly and developing nutritional intervention programmes to drive education in nutrition [50-51]. A notable aspect of CSL is the involvement in stimulating Soy research. A series of Soy Seminar/Workshops, the most recent held from 20th-24th June 2016, was initiated to provide a platform for soy grain producers, stakeholders and researchers to discuss heightening soy food production and consumption, addressing general nutrition concerns, and to strengthen the existing knowledge of food product technologies in SA. The seminar presentations by national and international delegates described aspects related to production, applications, metabolics, health, small-holder farmer empowerment, emerging markets, and school feeding schemes from extruded soy products. Theses workshops also included practical demonstrations by community leaders on household soy cooking techniques and product development techniques by privately owned production companies. Over the years, a number of presentations and demonstrations from local companies in the field of extrusion stimulated VUT/CSL in advancing towards food extrusion technology. VUT/CSL sought and gained both internal and external funding support to materialize soy and other grain based extruded food product development research studies. These efforts



a

(Figure 2). Continued.



b

Figure 2: a. Schematic representation of VUT/CSL Extrusion Pilot Plant. **b**. TX32 Twin-screw Extruder, manufactured and supplied by CFAM technologies (PTY) Ltd., South Africa.

are in collaboration with various Universities and research institutions both in SA and abroad. The first step in initiating the extrusion research was acquisition of funding and purchase of an Extrusion Pilot Plant. The plant, purchased from CFAM Technologies (PTY) Ltd., Potchefstroom, South Africa is housed at Science and Technology Park-Sebokeng, South Africa. A schematic representation of the pilot plant and the extruder model are depicted in Figures **2a** and **2b**, followed by a description of the components in Tables **2a** and **2b**.

Table 2a: Description of Plant Components

Labels	Components
A	Plant control panel
B	Extruder control panel
C	Extruder dosing water
D	Extruder
E	Raw material storage
F	Live Feeder
G	Milling station
H	Product collector
I	Cooling tower
J	Cooler/Dryer
K	Product storage

Table 2b: Description of Extruder Components and Functions

Labels	Components	Functions
A	Control panel	Automated control system with user interface and on/off switches for panel and extruder
B	Motor	Drive motor 22kW,AC
C	Gearbox	Oil to prevent thermal shock
D	Hopper with agitators	Raw material addition point
E	Hopper feed throat	Raw material feed into chute
F	Feed chute	Raw material extruder inlet
G	Barrel	33.5mm diameter, houses the screws and heat exchanger
H	Twin screws	32:1 (L/D ratio), product processor
I	Heat exchanger	Heating/cooling through barrel
J	Temperature zones	Five zones of varying temperature profiles
K	Die	Product outlet and shaping
L	Dosing water	Water to lubricate screws via pump tank, dosing syringe and inlet
M	Water inlet/outlet valves	External water supply to heat exchanger
N	Control panel connection	Electrical connection

The pilot plant will be used for dual research purposes of producing nutritional foods to supply local South African markets and testing the plant for commercialization through optimisation studies. The researchers wish to accomplish: a foundation for local, affordable products in SA thus reducing import costs; for CSL to be a testing and production facility which continuously supplies nutritious food to local communities; and to further enhance extrusion cooking to national and possibly international markets.

CONCLUSION

The food extrusion industry and technology relating to academic research sectors was considered in this paper. This paper examined an overview of extrusion technology including its historical development and types of extruders used in the food industry. The historical progression is briefly outlined from 1797 to 2016 and the milestones of the South African extruder industry were shown. Two types of extruders, the single-screw and twin-screw extruders are widely used in the food industry and information related to the products and worldwide extruder manufacturers and models were provided. The main component of the paper was to demonstrate the achievements of food extrusion in South Africa, by reviewing research work undertaken in various provinces. Thus far, published research has involved the consumption of extruded dry beans to detect its human health implications; development of a novel extruded sorghum-cowpea porridge; examining changes in the physical properties of extruded grains; and evaluating nutritional quality of an extruded and micronised porridge. This paper also revealed the extrusion pilot plant housed at VUT/CSL. The VUT/CSL initiative is to contribute knowledge in food extrusion technology by conducting interdisciplinary research applied to the fields of nutrition and engineering sciences by running an extrusion test facility focused on product plant optimization linked to achieving extrudates of high nutritional quality.

ACKNOWLEDGEMENTS

The authors kindly acknowledge: National Research Foundation-South Africa and Vaal University of Technology, for research financial contributions; South African Department of Higher Education and Training (DHET) for financial support to first author; Ms. N. Taseski (NWU/CFAM), for extruder demonstration and training; Mrs LJ. Dube (VUT/CSL), for administrative support.

CONFLICTS OF INTEREST

The authors declare no Conflicts of Interest.

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Received on 24-03-2017 Accepted on 29-05-2017 Published on 14-07-2017

DOI: https://doi.org/10.6000/1927-5951.2017.07.03.7