DEVELOPMENT AND EVALUATION OF A PNEUMATIC EXTRUDER FOR PRODUCTION OF FORTIFIED RICE NOODLES *(IDIYAPPAM)*

By

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DEPARTMENT OF PROCESSING AND FOOD ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR, MALAPPURAM - 679 573
KERALA, INDIA

2021

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR, MALAPPURAM - 679 573
KERALA, INDIA
2021

DECLARATION

I hereby declare that this thesis report entitled **"DEVELOPMENT AND EVALUATION OF A PNEUMATIC EXTRUDER FOR PRODUCTION OF FORTIFIED RICE NOODLES *(IDIYAPPAM)*"** is a bonafide record of research work done by me during the course of research and that the report has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Place: Tavanur

Date: 10-09-2021

CERTIFICATE

Certified that this thesis, entitled, **"DEVELOPMENT AND EVALUATION OF A PNEUMATIC EXTRUDER FOR PRODUCTION OF FORTIFIED RICE NOODLES *(IDIYAPPAM)*"** is a record of research work done by Ms. Dilsha Suresh under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, associateship to her.

Place: Tavanur

Date: 10. 09. 2021

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We, the undersigned members of the advisory Committee of **Ms. Dilsha Suresh.,** a candidate for the degree of **Master of Technology in Agricultural Engineering** with major in Agricultural Processing and Food Engineering, agree that the thesis entitled **"DEVELOPMENT AND EVALUATION OF A PNEUMATIC EXTRUDER FOR PRODUCTION OF FORTIFIED RICE NOODLES *(IDIYAPPAM)*"** may be submitted by **Ms. Dilsha Suresh.,** in partial fulfilment of the requirement for the degree.

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LIST OF SYMBOLS AND ABBREVIATIONS

^{o}C	:	Degree Celsius
^{o}	:	Degree
%	:	Per cent
&	:	And
/	:	Per
$<$	:	Less than
$>$	:	Greater than
$\leq$	:	Less than or equal to
$\geq$	:	Greater than or equal to
$\pm$	:	Plus or minus sign
cm	:	Centimetre
cm^3/g	:	Cubic centimeter per gram
d.b	:	Dry basis
et al.	:	and others
etc.	:	Etcetera
e.g	:	Example
g	:	Gram

g/cm^3	:	Gram per centimeter cube
g/g	:	Gram per gram
g/kg	:	Gram per kilogram
h	:	Hour
kCal	:	Kilo Calories
kg	:	Kilogram
kg/cm^3	:	Kilogram per cubic centimetre
kg/h	:	Kilogram per hour
Kg/m^3		Kilogram per cubic meter
i.e.	:	that is
I.U	:	International Unit
J	:	Joules
Kcal	:	kilo calorie
Kg	:	Kilogram
kPa	:	Kilopascal
L*		Lightness or Darkness
mg	:	milligram
mg/g	:	Milligram per gram
m/s	:	Meter per second
min	:	Minute (s)
ml	:	Milli Litre
mm	:	Milli Meter

pH	:	Percentage of H+ ions
r	:	Correlation coefficient
R^2	:	Regression coefficient
rpm	:	Revolution per minute
s	:	Second
Sl.	:	Serial
T	:	Temperature
V	:	Volt
viz	:	Namely
W	:	Watt
w.b	:	Wet basis
AACC	:	American association of cereal chemists
ANOVA	:	Analysis of variance
AOAC	:	Association of official analytical chemists
df	:	Degree of freedom
F	:	F value
HCL	:	Hydro chloric acid
H_2SO_4	:	Sulphuric acid
K C A E T	:	Kelappaji College of Agricultural Engineering and Technology
RSM	:	Response surface methodology

CHAPTER 1
INTRODUCTION

The traditional food products of various regions are now developed by food processing organizations. Apart from conserving our culinary habits for coming generations, it also helps in marketing such typically tasty, natural and nutritious foods to other parts of the world which in turn generate more income, jobs as well as minimizes post-harvest losses. Most of the traditional/ethnic foods are made in the kitchen with majority of the unit operations being carried out manually. The process is time consuming, laborious, energy intensive, involves drudgery and has food safety concerns. If food has to be marketed on a commercial scale, the production process has to be shifted to processing units, at least on a small scale level with improved capacity. Also, the safety and hygienic standards stipulated in the food manufacturing process need to be adhered to. All this points towards the need for mechanization of unit operations of the traditional processes.

*Idiyappam*is a popular traditional food preparation in Kerala, Tamil Nadu and Karnataka. It had its origin in Srilanka and spread to South East Asia like Malaysia and Indonesia. Basically, it is rice flour mixed with hot water and salt, pressed into noodles form and then steamed. Traditionally, it is prepared by pressing the rice flour water mix through the die with holes of required diameter manually. Mechanized extruders for the production of *Idiyappam* are not reported in literature. However, some motorized extruders could be used or modified for this purpose. Such motorized extruders are complicated in design, energy intensive and lacking in precision with more moving parts and associated gear mechanisms.

Pneumatics is a branch of engineering that makes use of gas or pressurized air. Pneumatics system used in industry are commonly powered by compressed air or compressed inert gases. A centrally located electrically powered compressor powers cylinders, air motors and other pneumatic devices. Pneumatic control systems are used in industry for various applications because of their inherent advantages over other mechanical systems. The use of compressed air is not restricted by distance, easily transported through pipes and after use it can be released to atmosphere. The pneumatic components are extremely durable and the design of components are simple. Compressed air is less affected by high temperature, dust and corrosion. They can work in inflammable environment without causing fire or explosion. Unlike electromotive components, pneumatic system do not burn or get overheated when overloaded. Pneumatics offers high precision and easy to control. Besides, they are not expensive and can easily be repaired.

The usage of pneumatic technology in food processing is fairly stable, but now a days, it is slightly increased due to the increased demand for more flexible machinery and higher production rates, electric drives are replaced by pneumatic systems.Compressed air is very important in the food industry, both for food processing and in the packaging operations. For example, in many fruit and vegetable processing plants, pneumatic system is used for air cleaning of containers prior to product filling, automated product sorting and product packaging systems. In bakeries, the technology is used for blow off applications. Compressed air is also used to sort, cut, and shape food products. Pneumatics is particularly prominent during the clean-in-place (CIP) processes within the food and beverage industry.

Pneumatic technology could be very well applied for producing extruded products. Hydraulic and electric machines are developed for the production of rice *idiyapppam*. But comparing with these two, pneumatic is more beneficial in terms of cost, maintenance and production. The pressure, speed of the piston and rate of extrusion is accurately controlled by pneumatic components. The cold extruded products could be easily prepared by using pneumatic force.

Rice is a staple food grain in India. The increasing Indian population is reflected by the growing rice demand across the country, as well as production and consumption volumes. In financial year 2019, the yield of rice across India was estimated to be approximately 2.600 kilograms per hectare. Rice flour is used commonly as substitute to wheat flour, as wheat flour contains gluten. The flour contains choline, which is required to maintain vital components of the membranes. At the same time, rice flour is used for the preparation of bakery products, desserts and rice noodles. Rice *Idiyappam* is rich carbohydrate food in the form of refined starch and therefore a great source of energy, contains no cholesterol and low in sodium. But it is very low in protein and fibre content. Therefore, to make *Idiyappam* nutritionally rich, it needs to be enriched with suitable flour supplementations.

Jackfruit is thenational fruitofBangladeshandSri Lanka, and the State fruit of theIndian statesofKeralaandTamil Nadu(Mondal*et al.*, 2013). According to National Horticulture Board report (2017), India stands first in jackfruit production in the world (1731.63 tonnes). Among the Indian states, Tripura shows highest jackfruit productivity (291.93 tonnes) followed by Kerala (190.91 tonnes). The fruit and seed possess high nutritional quality and health benefits. Different kinds of value added post-harvest technologies are succeeded with its pulp and seed.Jackfruit seed flour is rich in nutrients such as proteins and minerals and low in fat and calorific value. It has vitamins like thiamine and riboflavin, minerals such as iron, zinc, calcium, copper, magnesium and potassium (Swami *et al.*, 2012). It is a rich source of dietary fibre and is gluten and cholesterol free. Flour produced from seed may be used as thickening and binding agent in food systems. Therefore, jackfruit seeds could be used in balanced diets and functional foods which can be consumed safely without any concern of health risk.

A combination of rice flour and appropriate level supplementation of jackfruit seed flour would produce a balanced diet food rich in nutrients since weakness of one is strength of the other. Besides, value addition of jackfruit seed will pave way for utilization of the jackfruit by-product which ultimately reduces the post-harvest losses and improve the utilization potential and economy of small scale jackfruit based industries.

Considering the above facts, this study envisages development of a pneumatic extruder typically for the production of jackfruit seed flour fortified rice noodles, traditionally called *Idiyappam* and evaluation of the performance of the machine leading to the optimization of the process parameters. Such a study would not only make the traditional food making process simple, less laborious with reduced drudgery and energy efficient but also produces product at increased capacity and quality following good manufacturing practices. The study would also lead to a new product development with increased nutritional characteristics utilizing a predominant by-product thus contributing to exploitation of the utilization potential of jackfruit which has been declared as the official fruit of Kerala.

Taking the above facts into consideration, this research entitled "Development and evaluation of a pneumatic extruder for production of fortified rice noodles *(Idiyappam)*" was undertaken with the following objectives.

1. To develop a pneumatic extruder for production of rice noodles *(Idiyappam)*.
2. Evaluation of the performance of the developed system towards extrusion of fortified rice noodles leading to the optimization of the process parameters.

CHAPTER II

REVIEW OF LITERATURE

This chapter comprises of review of various research works related to pneumatic extruder for production of fortified rice noodles *(Idiyappam)*. Reviews on jackfruit seed flour, noodles, nutritional properties of jackfruit seed flour, pneumatic system, pneumatic extrusion has been presented.

Jack tree

Jack tree is a medium-sized evergreen tree, and typically reaches 8-25 m in height (Prakash *etal.,* 2009). The tree grows rapidly in early years, up to 1.5 m/year (5 ft/year) in height, slowing to about 0.5 m/year (20 inch/year) as the tree reaches maturity (Ranasingh*et al.*, 2019). It has a straight rough stem and a green or black bark which has a thickness of around 1.25cm, exuding milky latex. The leaves are broad, elliptic, dark green in colour and alternate. (Prakash *et al.*, 2009).

Jackfruit

Jackfruit is a dicotyledonous compound fruit of the jack tree (*Artocarpusheterophyllus* Lam.) which belongs to the family Moraceae grow in many of the tropical countries of Southeast Asia, but it is particularly abundant in India and Bangladesh (Mondal*et al.,* 2013). Jackfruit is the National fruit of Bangladesh and Sri Lanka, and the State fruit of the Indian states of Kerala and Tamil Nadu. It reaches 5.5 kg in weight, 90 cm in length, and 50 cm in diameter and has oblong cylindrical in shape. Jackfruit has a relatively high productivity, about 25.71 t/ha. A mature jack tree produces 200 fruits per year, with older trees bearing up to 500 fruits in a year.There may be about 100-500 seeds per fruit. The fruit and seed which possess high nutritional quality and health benefits. Nowadays, different kind of value added post-harvest technologies are succeeded with this pulp and seed.

Jackfruit seed

Jackfruit seeds are underutilized and less acknowledged by people, but they have considerable nutritional benefits and constitute about 10% to 15% of the fruit weight.In many parts of South India, the seeds are collected from the ripe fruit, dried in sunlight and stored adequately for use in the rainy season. Due to the difficulties encountered during processing and storage, massive amounts of seeds are annually wasted (Hossain *et al.,* 2014).

Colour of seed is light brown, oval, oblong ellipsoid or round in shapes with length of 2-3 cm and diameter of 1-1.5 cm. Upto 500 to 550 seeds can be found in each jackfruit (Abraham and Jayamuthunagai, 2014)

Hossain *et al.,* (2014) reported that the seeds are usually discarded as waste. But, it will have a one month of shelf life when it is stored in a cool, moist environment.Roasted seeds can be made in to powders for the purpose of extension of shelf life and thus it can be used to add value to different food products. In bakery and confectionary products, jackfruit seed flour is used as an alternative flour. It can be blended with different flours like wheat flour and other low-cost flours.

Chowdury*et al.,* (2012) found that the malnutrition is one of the biggest issue in India and it is due to the inadequate protein intake. To tackle this malnutrition issue jackfruit seed flour is the best economic alternative protein source. Nowadays, consumer awareness about the diet-disease relationship has increased. As a part of that, jackfruit seed demand also has been increased. It will impart the additional physiological benefits in addition to basic nutrition. Hence, jackfruit seed is a highly potent functional food ingredient in the food industry.

Chemical properties of jackfruit seed

The starch and dietary fiber contents of the seeds are 22% and 3.19% respectively. Protein content in the seed is about 13.5% and for carbohydrates it is about 79.34%. The seed also contains lignans, saponins and all phytonutrients. It is a powerful weapon for anticancer and antihypertensive action. It has antioxidant property too. (Oclooet *al.*, 2010).

Some antinutrional factors found in the jackfruit are alkaloids, phenols, tannins, saponins, steroids etc. When these are eaten as raw form it would result digestive ailment. (Swami *et al.,* 2012).

The ash content is 2.70% and fat content is 1.27% respectively with jackfruit seed flour. High amount of calcium present in the seed and it is marked as 3087 mg/kg. The amount of iron is 130.74 mg/kg and potassium contains 14781 mg/ kg. The amount of sodium, copper, manganese are 60.66 mg/kg, 10.45mg/kg, and 1.12 mg/kg respectively. The pH and value is 5.78 and 1.12% equivalent lactic acid respectively (Oclooet *al.,* 2010).

Nutritional properties of jackfruit seed

An ample supply of protein, fiber and starch would be provided by the jackfruit seeds. Jackfruit is highly rich in many minerals such as N, P, K, Ca, Mg, S, Zn, Cu, etc (Maurya and Mogra, 2016). Figure 2.1 shows the FTIR spectrum (Fourier Transform Infra Red) of jackfruit seed flour. Dominant peaks of absorption bands and the wavenumber (cm^{-1}) obtained from the absorption spectrum are for amines, amides, and amino acids, which indicate the presence of protein. Biomolecules such as carbohydrates, polysaccharides, and lipids are also found in other absorption bands. Existence of flavonoids indicates presence of aromatic compounds. Presence of sulphur and its derivatives in the jackfruit seeds are responsible for antimicrobial action. (Gat and Ananthanarayan, 2015a.)

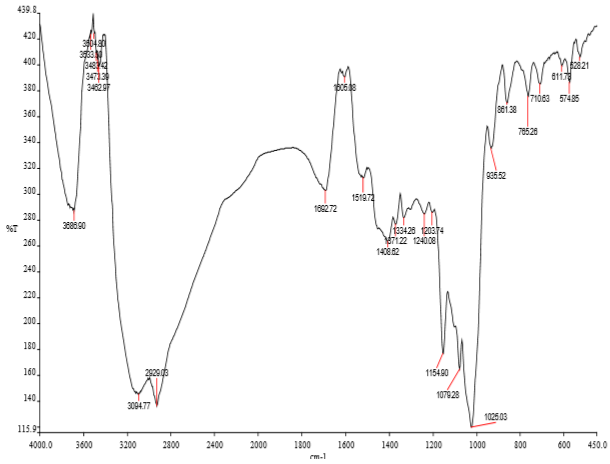


Figure. 2.1 Wave number (cm-1) of dominant peaks obtained from the FT-IR absorption spectrum of jackfruit seed flour.

Abedin*et al.,* (2012) studied on nutritional properties of three varieties of jackfruit seed flour. The result showed that all the seed varieties contained good amount of protein (13%-18%) and amount of crude fiber varies in between 1.56% to 2.60%.

Mukprasirt andSajjaanantakul (2004) reported that higher amylase content would be obtained from starch, which is present in the jackfruit seeds is used as a substitute for modified starch.

Conforti andCachaper, (2009) recognized that due to the high amount of phytonutrients jackfruit seed would be used as a novel functional ingredient with a desirable nutraceutical potential.

During the phytochemical analysis it is found out that jackfruit seeds had a high amount of saponins, which is about 6.32 g/100 g (Gupta *et al*.,2011)

By the method of free radical scavenging, metal chelating the antioxidant activity can be determined. The conclusion of the study is that jackfruit seed exhibits strong antioxidant properties and a moderate amount of phytochemicals. Studies on four different extracts of jackfruit seed is carried out for getting the information about total phenolic compounds, flavonoids, reducing power and antioxidant activity. The extracts of jackfruit seed showed that plants containing phenols and flavonoids exhibit strong antioxidant potentials. The study recognizes that jackfruit seed extract is a better functional medicine and pharmaceutical plant-based product due to its good flavonoid content (0.86% to 4.05%) and reducing potential (9.56% to 13.12%) (Shanmugapriya*et al.,* 2011)

Health benefits of jackfruit seeds

Noor (2014) stated that phytonutrients such as lignans, saponins, and isoflavones present in the seeds, plays beneficial role in human health.

Butool and Butool (2015) reported that the addition of the jackfruit seed flour to deep-fried products results in a reduction in fat absorption up to a certain limit.

Maurya and Mogra (2016) reported that due to the presence of rich dietary fiber and B-complex vitamins, jackfruit seed will help to lower the risk of heart attack and prevent constipation. To control the blood sugar and to keep the gut healthy, resistant starch is required, which is highly available in seeds. Also jackfruit seeds possess anti-microbial activity, which prevents foodborne diseases.

Jacalin is an important lectin, which is present in the jackfruit seed, is used to evaluate the immune system of an HIV infected person. In China, to overcome the toxicity due to the alcohol, these seeds are used. Also in India, the seeds are a crucial component of an antidote produced for heavy drinkers(Butool and Butool, 2015).

Baliga*et al.*, (2011) stated that for the diseases like diarrhea and dysentery, jackfruit seed is a best medicine. This seeds are very helpful in digestion process taken in the human body.

Bone health is highly associated with absorption of calcium. Jackfruit seeds are highly rich in magnesium which is an essential mineral for the absorption of calcium. Thus seeds are used to strengthen the bone and prevention of diseases like osteoporosis (Maurya and morga, 2016)

Better and faster hair growth can be achieved by the usage of jackfruit seed flour. Seeds would provide healthy blood circulation and healthy digestion (Arpit and John, 2015)

Chowdhury *et al.,* (2012) investigated that jackfruit seeds which shows some antibacterial, antifungal and anticarcinogenic properties due to the presence of a class of glycoprotein called lectin.

Mondal *et al.,* (2013) studied on the dietary fiber present in the jackfruit, which makes it an excellent bulk laxative. Fibre have ability to protect the colon mucous membrane by reducing exposure time and also binding to cancer causing chemicals in the colon.

To reduce the blood pressure and maintain bone health, seeds would contain abundant magnesium since it aids the absorption of calcium (Maurya and Mogra, 2016). Furthermore, the mental stress and anxiety is retarded by action of highly soluble protein present in the seeds. Properties like low water and fat-absorption capacities of seeds would help to prevent obesity.

Value-added products prepared by incorporating jackfruit seed flour

Bakery Products

Hossain *et al.,* (2014) conducted a study to develop nutritionally enriched bread with the jackfruit seed flour supplementation to wheat flour. Different composition of jackfruit seed flour used in the breads were 25%, 35%, 45% and 55%. Comparing with the control, the composite breads with different level of jackfruit seed flour were found nutritionally a better product. But, the increased level of seed flour content in the bread would result a significant decrease in colour, flavour, texture, taste and overall acceptability. Based on these facts, the bread with a supplementation of 25% jackfruit seed flour was most acceptable compared with control and other samples.

Arpit and John (2015) made a study on chocolate cake with the ingredients like wheat flour and jackfruit seed flour. The different mixed ratios are 95:5, 90:10, 85:15 and 100% wheat flour (control). For the formulation of chocolate cake this seed flour is a better option in the food industry. 10% of jackfruit seed flour was found to be successful incorporation in the chocolate cake. Due to the replacement of wheat flour with jackfruit seed flour some of the significant changes has been observed in the product, because there was an increase in the protein content and reduction in the fat content.

David (2016) stated that 5-15% supplementation of jackfruit seed flour for the production of chocolate cake gives a good outcome such as it will improves the dietary fiber content and anti- oxidant activity.

Islam *et al.,*(2015) reported that incorporation of jackfruit seed flour in the preparation of bread shows that good fiber content, whereas baked products are normally insufficient in fiber content.

Incorporation of less than 30% jackfruit seed flour would be a better concentration for the preparation of products like biscuits and bread. Because if further more increase in the jackfruit seed flour supplementation would result the decreased overall acceptability of the bread and biscuits (Butool andButool, 2015).

Khan *et al.,* (2016) attempted to make a cake with supplementation of jackfruit seed flour (10%, 20% and 30%) with wheat flour to increase functionality of the cake. The specific volume of the cake is higher for 20% of seed flour substitution. The addition of seed flour resulted in the changes in crust and crumb characteristics. Carbohydrate, ash, fiber and protein content were increased, but the fat composition is decreased. Significant changes were found in colour, flavour, texture and taste during the sensory test. Also the overall acceptability of cake was observed with different composition. However, the panellists concluded that based on the acceptability, the cake with 10% jackfruit seed flour is the best incorporation.

Traditional products

Santos *et al.*, (2011) reported that 30% and 40% jackfruit seed meal is used for the traditional product called cereal bar. It exhibited high fiber content, better sensory characteristics and nutritive values similar to those bars are available in the market.

The hardness and crispness of cereal bar with 15% jackfruit seed flour is almost same as that of the commercially available cereal bars. In snack bars, protein content increased by the addition of jackfruit seed flour (Meethal*et al.*, 2017).

Sultana *et al.*, (2014) investigated study on chapatis with different combinations of flours. The different flours were jackfruit seed flour, bengal gram flour, and wholemeal wheat flour. In this blend, 10% jackfruit seed flour showed the best overall acceptance.

Chakraborty *et al.* (2013) stated that jackfruit seed flour is a gluten-free component used as a good substitute to wheat flour for the person suffering from some specific allergies. Variety of value added products can be made by adding specific amount of this jackfruit seed flour. In south Indian recipes, this seed flour is incorporated as milled flour with rice flour to prepare dosa, dhokla and idli.

Extruded products

A snack is a portion smaller than a full-fledged meal and is typically consumed between meals. Snacks would provide significantly fewer calories than those provided by a regular meal. For the convenient use and longer shelf life, people will prefer processed snacks. Interest of novel products development is widely increasing in the processed food industry to attract the consumers and to increase the economic ladder in the food sector.

Nandkule*et al.*,(2015) studied on noodles fortification with jackfruit seed flour. The result showed that proximate composition of protein, ash, fat and crude fiber contents were increased but the carbohydrate content is reduced comparing with the control sample.

The effect of supplementation of jackfruit seed flour in the pasta was insignificant moisture content but the increased protein and ash content. Hence, the nutritional profile increased but the cooking and rheological characteristics were similar as control sample. (Abraham and Jayamuthunagai, 2014).

Gat andAnanthanarayan, (2015b.) reported that incorporation of jackfruit seed flour into the rice improved the nutritional and nutraceutical properties of extrudates. The conditions provided such as barrel temperature of 180 °C, screw speed of 300 rpm and ratio of rice and jackfruit seed flour is 70:30, suited for the increment of nutritional composition. When the barrel temperature is decreased, total phenolic and flavonoid contents were found to increase. The highest antioxidant and reducing potential exhibited by the extrudate at temperature of 180 °C and screw speed of 300rpm.

Kumari*et al.* (2015) developed jackfruit seed based noodles. Incorporation of jackfruit seed flour were 10% and 20%. The specified condition were feeder speed of 16 rpm and drying temperature of 60 °C. Lower energy level and carbohydrate content were noticed. But there were higher protein, fiber, and mineral contents and better sensory quality.

Noodles extruded with 20% jackfruit seed flour showed higher yields and lower cooking times, as reported by Kumari and Divakar(2017) and the colour of the pasta changed with the addition of the jackfruit seed flour. The flavor of the jackfruit seed was easily recognizable in pasta with the addition of 15% and 20% seed flour, and it was suggested that the firmness of the pasta also increased with the addition of the seed flour.

Rice

Rice (*Oryza sativa*) is the major food crop in the world.It belongs to the genus *Oryza*, family: *Poaceae (Gramineae)* and tribe: *Oryzeae*. .Cultivated rice is an annual crop but some of its wild relatives are perennial in nature.The rice plant, typically considered as grass. Root, stem (culm), leaves and panicles are the main parts of the rice plant. Based on the varaities and environmental conditions the plant height will change (Dunna and Roy 2013).

Nearly 40% of the world population consumes rice as the major staple food. People who live in less developed countries mostly depend on rice as their primary food. Since the dawn of civilization, rice has served humans as a life-giving cereal in the humid regions of Asia and to a lesser extent, in West Africa. In Europe and America, introduction of rice has led to its increased use in human diets. There are 42 rice producing countries throughout the world. Among them China and India are the major rice production centre (Kenneth and Kriemhild, 2000).

Kaur *et al.,* (2016) stated that rice grain commonly undergo the series of processing steps such as drying, milling, and packaging after harvest to be convenient for consumption. In milling process, husk is removed from the paddy to obtain whole brown rice grain. It contains brown colour outer bran layer. After milling process, second step is to remove the outer bran layer to obtain polished white rice. The bran layer consists of pericarp, aleurone, sub-aleurone layer, and germ, which contains large amounts of nutrients and bioactive compounds.

Nutritional properties of rice

Huang *etal.,* (2016) reported that rice grain is a rich source of carbohydrates and protein as well as other essentials. The main component of rice starch is amylose and amylopectin. Waxy (0-2%), very low (2-10%), low (10-20%), intermediate (20-25%), andhigh (25-33%) are different classification of amylose content.

Starch (80%) and protein (8%) are the major components present in the rice. Albumin, globulin, glutelin, and prolamin are the four different layers of rice protein. High molecular weight containing protein is glutelin. In rice endosperm, 80% of protein is covered by glutelin. Protein content of pre-germinated brown rice is two times more than white rice, i.e. 14.6 g/100 g (brown rice) and 7.3 g/100 g (white rice). Also the fat content is higher in pre-germinated brown rice (24.8 g/100g) but for white rice it is 1.5 g/100g (Tecson*et al.*, 1971).

Amagliani*et al.*, (2017) stated that rice is considered as hypoallergenic food. Rice protein digestibility and biological value is greater than the other major cereals. Rice protein is a functional food ingredient in infant formula and sports nutrition.

Huang *et al.*, (2016) reported that metabolism of human body is carried out by the action of mineral elements. Thus, the vital role of this mineral elements deficiencies may cause malnutrition related diseases. Even though rice is not a good source of minerals, it can provide appreciable amount of minerals. Because rice is considered as the staple food in many regions of the world.

Table 2.1 Nutrients composition of white rice (miiled) (Wu *et al.*, 2013)

Nutrients	White rice (milled)
Protein(g/100g)	6.3–7.1
Crudefat(g/100g)	0.3–0.5
Availablecarbohydrates(g/100g)	77–78
Crudefiber(g/100g)	0.2–0.5
Crudeash(g/100g	0.3–0.8
Energy(kcal)	349–373
Thiamine(mg/100g)	0.02–0.11
Riboflavin(mg/100g)	0.02–0.06
Niacin(mg/100g	1.3–2.4
VitaminE(mg/100g	0.075–0.30
Nicotinicacid(mg/100g	0.8–2.6
Pantothenicacid(mg/100g	0.34–0.77
Ca(mg/100g)	10–30
Na(mg/100g)	2.2–8.5
K(mg/100g)	14–120
Fe(mg/100g)	0.2–2.7
Mn(mg/100g)	1.0–3.3
Zn(mg/100g)	0.3–2.1
P(g/100g)	0.08–0.15

Health benefits of rice

Sodium and fat content in rice is low and it is a cholesterol free cereal crop. It helps to prevent the hypertension. Rice is an allergens free component. Now widely used in the baby food preparation (James and Caskill, 1983).

Juliano (1985) investigated thatrice starch can act as a good substitute for glucose in oral rehydration solution. This solution is used for infants who suffering from diarrhoea.

Gallagher*et al.,* (2004) reported that rice flour is widely used for the production of gluten free bread. Patients who suffering celiac disease would strictly follow the gluten free diet throughout the life time. It results theclinical and mucosal recovery. Due to the presence of low level of prolamin content in rice flour, it is highly acceptable in gluten-free products. Among the different cereal flours, rice flour is the most suitable cereal grain flour for the celiac disease patient's food production.

Rice flour and its products

Kim *et al.,* (2013) stated that both whole kernel and broken kernel are used for the production of rice flour. In flour milling, waxy and non-waxy type are used. Depending upon the specific use, waxy or non-waxy type rice is used for milling purpose. Dry milling is a simple method. Without any pre-processing, rice grains are milled into dry flour with moisture content is about 10%. Due the formation of substantial heat, dry milled rice flour has some starch damage.

Chen *et al.,*(1999) studied about wet milling of rice kernel. Soaking of rice in water for a particular time period is the first step of wet milling. This step will helps to achieve a better conditioned internal structure for subsequent milling. Small scale or household rice milling are mostly based on wet milling. Texture of wet milled rice flour is good. Particle size distribution is very fine and narrow. Thus the damaged starch is less comparing with dry milled flour.

Mari *et al.,* (2018) was observed that the nutritional properties of shua rice flour chapatti (i.e. pH, moisture, ash, fat, protein, crude fiber and carbohydrates) are significantly higher than shadab rice flour chapatti. The presence of vitamins and minerals in the rice flour chapathi. It is a good source of thiamine, riboflavin, vitamin-D, iron and calcium. But the fiber content is very poor. It is a gluten free diet product and has good shelf life. It is softer, much whiter and more delicious than the whole wheat chapathi.

Gallagher *et al.,*(2004) developed a rice bread for celiac disease patients. Specific volume, crumb and crust colour, firmness and moisture of the rice bread is similar with wheat bread reference standards.

In the earlier stages a small amount of rice flour is supplemented to wheat flour to make bread. But nowadays bread made out of 100% rice flour is formulated and it is available in markets (Kim, 2009).

Hur S. (2012) developed a crabstick with rice flour as a functional agent. The desired level is 3-5% rice flour, which is verified by the sensory panel for the acceptance of consumers.

A very good effort is taken to increase the rice consumption by using the rice flour. Many wheat based products like bread, noodle, cake, cookie and muffin are also processed by using rice flour. In the developing stage of food processing sector, rice flour is also used for the production of beverage (alcoholic and non-alcoholic), vinegar, surimi and artificial meat etc.

Rice Noodles

In the beginning stage of rice noodle product development only 10-30% rice flour is used. But recently 100% rice flour products such as dry, wet, and extruded noodle are available in the mark (Yang and Kim, 2010).

Weng*et al.,* (2019) studied on white salted noodles prepared by rice flour, normally it is prepared by wheat flour. The mechanical and sensory qualities of rice flour noodle is compared with the commercial white salted noodles made of wheat flour. The perfect formulation of noodles made up of rice flour would enhance the cooking convenience of rice products and promote the consumption of rice. Wheat flour, vital gluten and transglutaminase is added with rice dough for the formulation of white salted rice noodle instead of white salted noodle made of wheat flour.

Sereewat *.et al.,* (2014) reported that pasta is prepared by incorporating 10% of defatted soy flour into the rice flour. It would increase the protein content from 6.28 to 10.69 g/100 g. The product become more yellowish in colour. The hardness of cooked noodle is higher compared with the product extruded from the rice flour only.

Heo*et al.,* (2013) formulated a gluten-free rice noodles with L. edodes mushrooms, which would have β-Glucan-rich fractions. Quality attributes and β-glucanderived health benefits of the product is increased.

Both dry and wet milled rice flour is utilized for the preparation of gluten free noodles. Based on the rheological and cooking characteristics, the quality is determined. The swelling power of wet milled rice flour causes higher viscosity than the dry milled rice flour. Dry milled rice flour exhibit high degree of starch damage compared with wet milled rice flour. When dry milled rice flour is supplemented into the noodle formation, the extensional resistance of rice noodle is enhanced. But because of its higher water solubility, cooking loss of rice noodle is increased. (Heo*et al.,* 2013).

Kang *et al.,* (2018) investigated on incorporation of okara into the rice noodles. Okara content is negatively affected the cooking and textural properties. Nevertheless, 10% in rice noodles positively decreases the predicted GlycemicIndex values. To improve the cooking qualities and textural properties, alginate and a calcium chloride coating is added to the rice noodles containing okara. These findings indicated that possibility of applying okara to produce rice noodleswith reduced starch digestion is confirmed.

Other noodles products

Taneya*et al.,* (2014) studied on instant noodles prepared by wheat flour and sweet potato flour. Sweet potato flour is incorporated into wheat flour at different levels such as 0, 10, 20 and 30%. As the increase in sweet potato flour level in the formulations of instant noodle resulted the increased ash, starch, crude fiber and total carbohydrate contents but decreased level of protein content. Based on the composition, sensory attributes and shelf-life, 30% sweet potato flour is best fit for the development of instant noodles.

Noodles prepared from the blends of 20% breadfruit starch and 80% wheat flour showed a better culinary and sensory attributes. The crude fiber content is higher in both breadfruit starch and wheat flour. Hence it helps to reduce symptoms of chronic constipation, heart diseases associated with high cholesterol, diverticular disease and risk of colon cancer. From these inference it is an important functional food, more than normal noodles.

Development of noodle with 75% wheat flour and 25% soybean seems to be better nutritional level. The protein and fat contents increased while carbohydrate decreased with increase in soybean addition to the mix (Omeire*et al.,* 2014).

Extrusion

Extrusion technologies have an important role in the food industry as efficient manufacturing processes. It is a process by which a set of mixed ingredients are forced through an opening in a perforated plate or die with a design specific to the food, and are then cut into a specific size by blades. The machine which forces the mix through the die is an extruder, and the mix is known as the extrudate.

Based on the method of operation, extrusion can be classified into hotandcold extrusion. Also based on the type of construction single or twin screw extruders are available (Mishra and Rao, 2012).

Dalbhagat*et al.,* (2019) made a study on single screw extruder. It contains a single rotating screw in a metal barrel usually having helical or axial grooves on the inner surface which convey the material to the transition section. Extrusion of rice flour through single screw extruder is simple, the control of the finished product characteristics is complicated.

Twin-screw extruders (TSE) are complex and expensive in nature. But it possess many advantages over the single screw extruder. Thorough mixing of ingredients are takes place inside the barrel having two screws before entering into the succeeding zones. It can operate even at low feed moisture. Controlvariables such as time, temperature andscrew speed are operated in a greater flexible manner. Wide variety of food products are manufactured by twin-screw extruder. It includes directly expanded, unexpanded, texturized, modifiedand co-extrudedproducts (Dalbhagat*et al.*, 2019).

The product extruded without cooling or distortion of food is known as cold extrusion process. Extruder consists of a deep flighted screw operates at a low speed in a smooth barrel, to knead and extrude the material with little friction. Typical cold extruded food products are pastry dough, individual pieces of candy or confections, pasta pieces and some types of confectionery. Based on the type of food, the moisture content, processing temperature and the holding time, vitamin losses can occur in the extruded products. But generally, losses due to cold extrusion process is minimum (Fellows, 2000).

Hot extrusion is also called as extrusion cooking. Hot extruded products are ready to eat type food materials. Extruder has a high tolerance screw rotating in a barrel. The food material is fed in to the extruder, note that it should have proper moisture content. Cooking takes place inside the extruder which is due to the generation of viscous shear heat. Then, it is conveyed to the die. This process causes elevation of temperature and pressure.As the dough exits the die, it puffs largely due to flashing of moisture vapour (Smith, 1971).

Dalbhagat*et al.*,(2019) reported that die pressure is the indicator of resistance to the flow of material through die opening which is significantly affected by its geometry.

Die pressure is reduced due to the increase in the feed moisture, temperature and screwspeed. Because the high speed moisture causes the melt plasticity and high temperature decrease the viscosity (Pilli *et al.*, 2012).

Pneumatics

Sorli*et al.*,(1999) reported that most of the earlier pneumatic control systems are used in the process control industries, where the pressure range is 7-bar is easily obtainable and give required fast response. Extensive use of pneumatic systems are present in the field of automatic controls and automation of production machineries etc. Pneumatic circuits can convert the compressed energy of air into the mechanical energy. Performance characteristics such as fuel consumption, dynamic response and output stiffness can be compared for pneumatic actuators such as piston-cylinder and rotary types.

Based on the particular required application, the type and design configuration for pneumatic actuator is chosen. Piston cylinder type pneumatic actuator is most common because of its simplicity and low cost (Tablinand Gregory, 1963).

Pneumatic cylinders and pneumatic motors are used to convert pneumatic power into straight line reciprocating motion and rotary motion. Pneumatic systems are very reliable in nature. The pneumatic position servo systems has the ability to position the loads with high dynamic response and to augment the force required moving the loads. Thus it is extensively used in different kind of applications (Clements and Len, 1985).

Taplin and Gregory (1963) reported that pneumatic servos have more advantage than the hydraulics in high temperature and nuclear environment. Rather than the servo valve, the actuator limits the system response and stiffness. Considering the simplicity and cost, piston cylinder is the best choice. But if minimum fuel consumption is required, rotary type of motor is preferred. Rotary servo has twice the band pass of the piston cylinder servo. This fact is used for numerous applications. The weight of a self-contained solid propellant pneumatic servo may be half that of an equivalent self-contained hydraulic system. Hence, it is used in the short duration missile applications. To replace a heavier hydraulic system, the pneumatic system requires maximum dynamic response and output stiffness. One of the difference between pneumatic and hydraulic system is bulk modulus.

Cho and Hedrick (1985) reported that to improve the vehicle dynamics pneumatic actuators are used actively in parallel with conventional passive suspension.

Bulk materials such as chemicals (soap powders, detergents), food (sugar, flour), cosmetics (talc, face powder) and energy (coal and ash) industries uses pneumatic conveying system for transportation (Williams, 2008).

In the design process, the air brake control valves of heavy and medium duty trucks are centralized modulus. A floor mounted pneumatic application valve is acting on centrally, advanced design is used in air brake control systems of truck. Dash mounted electrical controls and a floor mounted pneumatic application valve acting on a centrally located electro pneumatic controller. Nowadays most of the all modern process plants employ control valves, which is either pneumatic or electric actuators. Factors such as the size of valve, the environment, media and availability of power are desires choice between the two (Singh *et al.*, 1985).

Clements *et al.*, (1985) developed an electro pneumatic positioned process valves. The position uses solid-state electronics to combine the functions of both the electric to pneumatic converter and valve positioner. The use of electronic unit, which is housed in an enclosure to mount an actuator. It achieves savings in size and weight.

Electro pneumatic servo systems are viable alternatives to hydraulic systems for controlling robotic machines. Comparatively small cylinders are used for the most of the research work (Virvalo and Koskinen,1988).

Sano *et al.*, (1988) reported that a pulse width modulation technique is formulated by pneumatic servo mechanism. A pulse motor is developed having electro pneumatic on- off valve with a disk flapper. Experimental result showed that the positioning accuracy and the output power are tolerable in nature, but the speed of the response is less than those of other pneumatic servomechanisms.

An another application of pneumatic actuator is, an electro pneumatic design is developed and tested to meet the engine characteristics such as start ability, load carrying ability, and engine dynamic performance (Ingold and Tice, 1988).

Sebastian *et al.*, (2002) developed a new concept, called micro pneumatically driven actuator. High energy density, large achievable displacement, high generated forces, excellent dynamic behaviour, usage of various fluids as driving medium, usage as final controlling element with continuous action and high design flexibility are the main advantages of this actuation principle.

Faudzi*et al.*, (2014) reported that pneumatic cylinder provides high power to weight ratio, easy use and environmental safety. Pneumatic cylinder uses air as its power source and converts it to a possible movement such as linear and rotary movement. In order to control the pneumatic cylinder, controller algorithm is needed to control the on-off solenoid valve with encoder and pressure sensor as the feedback inputs.

Very high speed and considerable shock forces can be developed at the end of the stroke by the action of pneumatic cylinder. Smaller cylinders have a fixed cushioning, which means to absorb the shock and prevent internal damage to the cylinder a rubber buffer is provided. For large cylinders, this impact effect is absorbed by an air cushion, which decelerates the piston over the last portion of stroke. Through an adjustable needle valve, exhausting air is bleed off slowly but some of the exhausting air is trapped in this cushion near to the end of stroke (Dutt, 2013).

Dutt (2013) stated that the piston force exerted by a working element is dependent on the air pressure, the cylinder diameter and the frictional resistance of the sealing components. To calculate the effective piston force, frictional resistance must be taken into account. Under normal operating conditions (pressure range 4-8bar), the frictional forces may be assumed to be between 3-20% of the calculated force.

For single acting cylinders:

$Fn = A.\ p - (FR+FF)$ .... (2.1)

For double acting cylinders (forward stroke and return stroke)

$Fn = A.\ p- FR$ $Fn = A'.\ p- FR$ .... (2.2)

Where,

F = Effective piston force in Newton (N)

A = useful piston area in cm^2 = D2 xn/4

A' = useful piston ring area in cm² = (D2 - d2) x rc/4

p= operation pressure (kPa, 105 N/m', bar)

FR = frictional force (3-20%) in Newton (N)

FF = force of return spring in Newton (N)

D= cylinder diameter in cm

Normally pneumatic cylinders are manufactured in bore size of 12, 16, 25, 32, 40, 50, 60, 80, 100, 125, 150, 160 and 200 mm with a maximum stroke length of 100–1000 mm depending on the bore of cylinder for standard application.

Electro pneumatics

Integration of pneumatic and electrical technologies has played an important part in the development of a large range of industrial automation solutions. Cost effective and efficient production system, machine cycle times are minimized. An electro pneumatic system offers better advantages to establish a control system. When signals are transmitted over a great distances in a control system, electricity is used as the transmission medium to reduce the time between signal transmission and signal reception. Electrical switch, pressure switch and solenoid valves are important components used in electro pneumatic system. Sensing and processing information are the basic system rules

Dutt (2013) reported that roller actuated limit switches, magnetically actuated switches or electronic sensors sense whether a specified operation has occurred or not. In this way sensing information is carried out. After that, information is passed to the processing device, which may be a relay. Then, processor has the duty of directing and modifying its received signal to drive the output stage of the system. The output stage contains two parts. First one is a final control element which is electrically actuated with a pneumatic output and second one is the pneumatic actuator.

Flexibility, enclosed nature and easy automation are the main advantages of pneumatic conveying over the mechanical conveying system. The major pneumatic conveying systems are dilute phase and dense phase. Dense phase system requires lower conveying velocities, hence lower power consumption compared to dilute phase. More important fact that dense phase system avoids operational problems such as particle attrition and erosive wear of pipeline (Guo*et al.,* 2013).

Pneumatic extrusion

Hagenimana *et al.* (2006) explained the impact of ingredient, moisture content, process variables such as thickness of die and frying oil temperature for the preparation of *poory* using pneumatic extrusion.

Pneumatic extrusion is adopted for the preparation of *poorie* by whole wheat flour dough. It is a challenging task. Pneumatic extrusion process variables such as (pneumatic pressure, rate of extrusion) and quality of deep fried product (oil uptake, frying time, puffed height) were evaluated. All these parameters depends on the moisture content of wheat dough. To optimize the process parameters, response surface methodology was used (Murthy *et al.,* 2014).

Murthy *et al.,* (2014) indicated that uniform rate of extruded sheet is obtained from the conditions such as extrusion pressure ranging from 3-6$\times$ 10^5 Pa and added moisture content of 56-60 %. Also the production capacity of pneumatically extruded whole wheat flour *poory* dough is 500-600 numbers/h.

CHAPTER III

MATERIALS AND METHODS

This chapter describes the details of development of a pneumatic extruder system and methodologies adopted for evaluation of the performance of the developed machine towards extrusion of rice noodles fortified with jackfruit seed flour *(Idiyappam)* leading to the standardization of process parameters. The materials used for fabrication of the pneumatic extruder and the instrumentation employed for measurements of parameters are explained. The details of estimation of physico-chemical and sensory qualities of the extruded product are also explained.

3.1 DEVELOPMENT OF A PNEUMATIC EXTRUDER FOR THE PRODUCTION OF FORTIFIED RICE NOODLES

In this study, a pneumatic system was developed for the production of fortified rice noodles. Functionally the pressurised gas (compressed air) from the compressor is conveyed to the pneumatic cylinder through pneumatic pipes which actuates the piston forward and backward based on the solenoid valve operations. The piston moves in reciprocating motion inside a dough cylinder prefilled with prepared dough in the required proportion and consistency. The movement compresses the dough allowing the same to extrude through the die holes at the other end of the dough cylinder. The developed pneumatic extruder comprised of a frame assembly, pneumatic cylinder, compressor, air filter regulator, double solenoid valve, pneumatic pipes/tubes, pneumatic fittings, timer, flow control valve, extruder die, dough cylinder, noodle collecting plate, plate holding section and DC motor. The schematic of pneumatic extruder is shown in figure 3.1 and the developed system is shown in Figure 3.2.

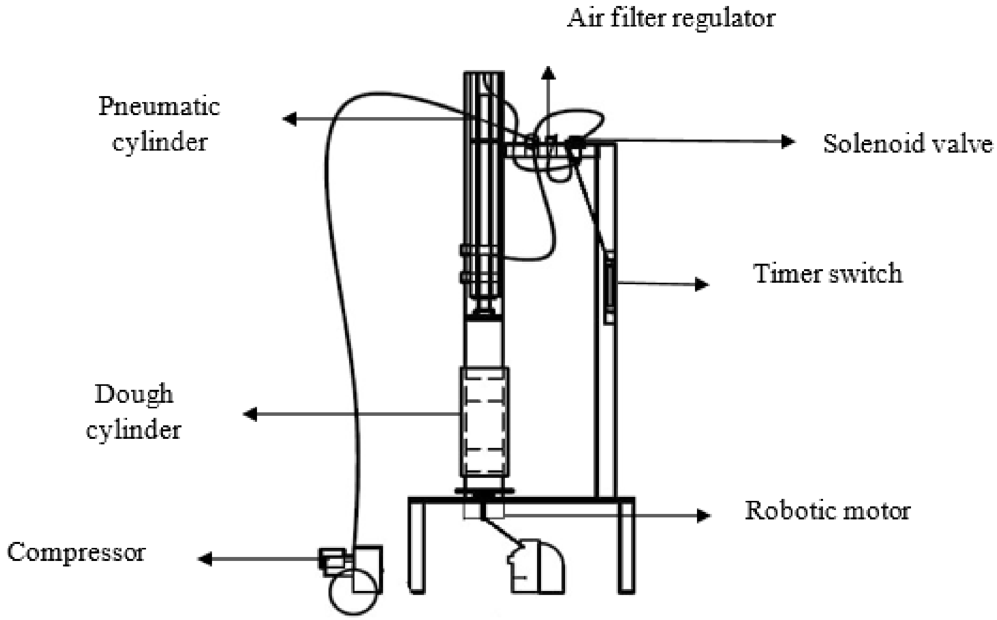


Figure 3.1 Schematic of Pneumatic extruder system

Figure 3.2 Pneumatic extruder

3.1.1 Frame assembly

The mainframe of the system was fabricated out of stainless steel which consists of a vertical section and horizontal plane. The vertical section holds and supports the pneumatic system and dough cylinder. The horizontal section forms a metallic table which supports the rotating noodle collecting plate and the motor assembly. The horizontal frame work is at a height of 810 mm and total height including the vertical section is 2110 mm. The frame assembly is supported by four legs. The horizontal plane that holds the noodle collecting tray has a length and breadth of 605 mm and 410 mm respectively. The diameter of the collecting plate is 160 mm. It is placed on a plate holding section having a diameter of 170 mm. Dough cylinder and pneumatic cylinder are attached to the vertical section of the frame assembly. Height of the vertical section is 1320 mm. The vertical section is fabricated with 60 mm stainless steel square sections. Two numbers of 60 mm square sections of stainless steel having length of 1320 mm were welded together to provide support to bear the load and minimise vibration and ensure stability of the machine. The dough cylinder is fixed vertically on the vertical frame section at a height of 75 mm from noodle collecting plate. Pneumatic cylinder is fixed vertically on to the vertical frame section at a height of 200 mm above the dough cylinder. Stainless steel square sections of 76 mm were welded to the vertical frame for a length of 377.5 mm supported with vertical section on the other side on to which the pneumatic system controls such as filter, solenoid valve and timer switches were attached (Figure 3.2).

3.1.2 Pneumatic cylinder

Pneumatic cylinder or air cylinder (actuator) is a device which converts pneumatic energy into mechanical energy. The work done by a pneumatic actuator can be linear or rotary. Linear motion is obtained by piston cylinder, whereas rotary motion with an angle up to 270^{o} is obtained by vane and pinion type actuators and continuous rotation by air motors. In this study, a linear double acting cylinder was used for the development of the extruder. A double acting cylinder develops a thrust in both extending and retracting directions when air pressure is applied alternatively to opposite sides of the piston. Smaller effective piston area reduces the thrust available on the retracting stroke on the condition that the cylinder pull the same load in both directions. The pneumatic cylinder consists of piston, piston rod, front end cap, rear end cap, piston ring and rod seal etc. Diagrammatic representation of double acting cylinder is shown in Figure 3.3.

Double acting pneumatic cylinder had a bore diameter of 63 mm and stroke length of 400 mm (Figure 3.4). The optimum working pressure was 0.5-10 bar and temperature 5-60 ºC. The pneumatic cylinder gets actuated on the power of compressed gas to produce a force in reciprocating linear motion. Compressed air was used as working fluid which was converted into kinetic energy as the air expands in an attempt to reach atmospheric pressure. Due to the air expansion, the piston was forced to move in the desired direction. A double piston rod was used in the cylinder. The piston rod transfers the developed force to the dough mix which gets compressed and extruded through the die holes.

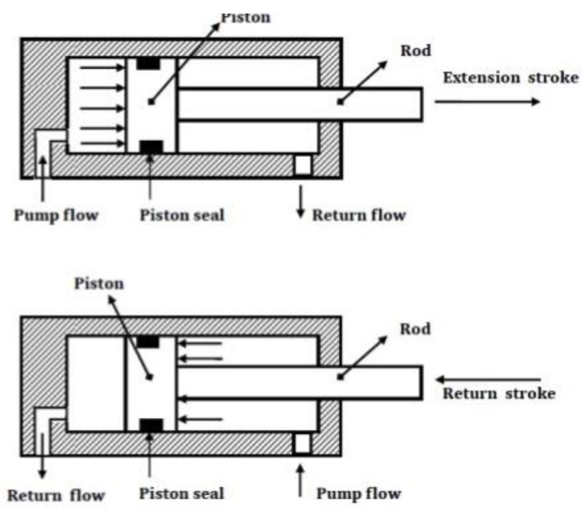


Figure 3.3. Diagrammatic representation of double acting cylinder

Figure 3.4 Pneumatic cylinder

A stainless steel pushing disc with diameter of 920 mm and thickness of 8 mm with a 21.4 mm diameter female threaded adapter rod of 33 mm length was welded on one side of the disc and was threaded to the bottom end of the piston rod. The pushing disc fits in the piston bore with minimum clearance for its movement thus pushing the dough mix through the extruder die to form the noodles. Pushing disc is shown in Plate 3.5.

Figure 3.5 Pushing disc

3.1.3 Compressor

A 1 hp, 220V, 2850 rpm single stage reciprocating air compressor was used for generation and pressurised storage of air. The maximum pressure discharge of the compressor is 14 bar (200 Psi / 14 Kg/cm²). The tank capacity is 150 litre (Figure 3.6). The compressor is fitted with all the associated valves and central instrumentation such as pressure gauges, automatic shutoff switches, safety valves etc. The kinetic energy of the compressed air released during depressurisation was input into pneumatic cylinder for effective movement of the piston.

Figure 3.6 Compressor

3.1.4 Air filter regulator

An FR+L with gauge & metal guard type air filter regulator was used to deliver and control air flow at a fixed pressure rate (Figure 3.7). The filter strain the air, traps the solid particles (dust, dirt and rust) and separates liquids (water and oil) entrained in the compressed air. The automatic pressure regulator reduce and control the pressure in the compressed air systems as is required. The pressure gauge connected to the filter regulator was used to monitor the pressure of the compressed air. It maintains its output at a fixed pressure lower than its input.

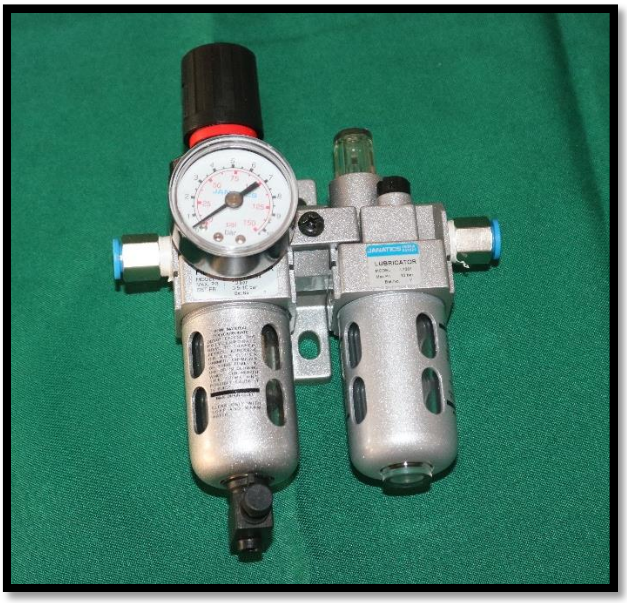


Figure 3.7 Air filter regulator

3.1.5 Double Solenoid valve

A double solenoid valve was used to direct the air flow to and from the cylinders in this pneumatic system (Figure 3.8). A five port two position directional control valve was used. This functions to control both extend and retract actions of pneumatic piston and acts upon the receipt of electric current. Solenoid creates magnetic field from electric current and uses the magnetic field to create linear motion. The pneumatic valves control the pressure, rate and amount of air. To ensure the silencing characteristics, the solenoid valve was fitted with a silencer. It has limit valves that sense the cylinder piston positions. The valve mechanism directs the compressed air supply, through the valve body to the selected output ports or stops the air from passing through the valve. The valve mechanism was moved by electrical solenoid.

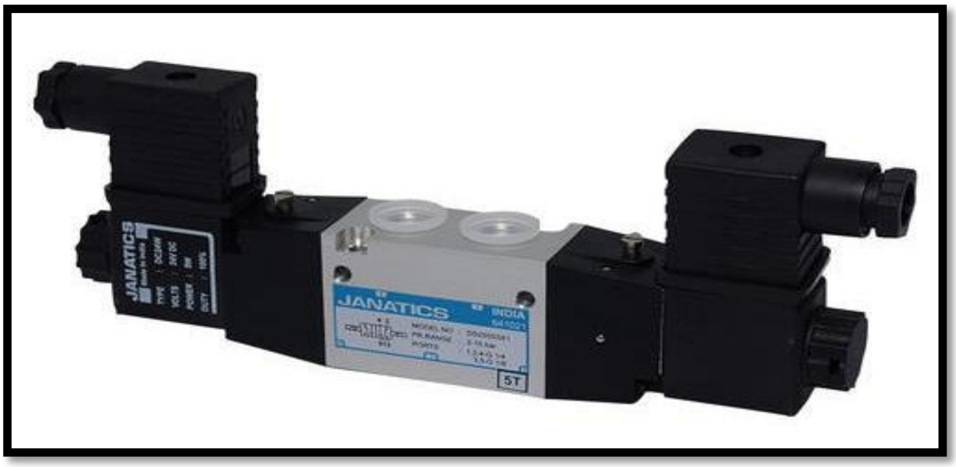


Figure 3.8 Double solenoid valve

3.1.6 Pneumatic pipes/ tubes

Coloured polyurethane tubes of 6 mm outside diameter and thickness of 2 mm (Figure 3.9) was used to transport the compressed air from the compressor to the solenoid valve and to the pneumatic cylinder. Tubes were cut using a tube cutter, the edges were cleaned and were fully inserted in to the adapter (nipples) joints to ensure leak proof joints.

Figure 3.9 Pneumatic pipes/ tubes

3.1.7 Pneumatic fittings

Special pneumatic fittings such as threaded nipples of straight, L and T types were employed to connect the pneumatic tubes to various components of the system. These fittings ensure easy and quick push in connection to the tube and easy removal of tube by pressing the collect cap. Pneumatic fittings are shown in Figure 3.10.

Figure 3.10 Pneumatic fittings

3.1.8 Timer Switch

In this study, a timer switch was used to control the piston movement in the pneumatic cylinder (Figure 3.11). Timer delays the air signal, which ceases the movement of the piston through the dough containing cylinder as per the pre-set time interval. The air timer delay could be varied between 0.5 and 60 seconds as per requirement fixed on the timer required for changing the noodle collecting tray and dough filling time.

Figure 3.11 Timer Switch **Figure 3.12 Flow control valve**

3.1.9 Flow control valve

To control the speed of piston, flow control valve was fitted in the inlet port of the pneumatic cylinder (supply control version). A flow control valve regulates air flow in only one direction, allowing free flow in the opposite direction. In this study, air flow rate was regulated during extension stroke and free flow in retraction stroke. The piston speed was controlled by adjusting the screw cap either in counter clockwise or clockwise direction. Flow control valve is shown in Figure 3.12.

3.1.10 Dough cylinder

Rice flour and jackfruit seed flour mixed in the required proportion and formed into dough which was filled or stuffed in to the dough cylinder. It is placed vertically below the pneumatic cylinder. The dough filling container is made up of stainless steel (SS 304). A slope is provided in one end of the cylinder where the piston begins to move. The slope facilitates the smooth movement of piston through the container. The height of the container is 340 mm, inner radius is 100 mm and outer radius is 106 mm (Figure 3.13).

Figure 3.13 Dough cylinder

3.1.11 Extruder die

The pneumatic piston pushes the dough filled in the dough cylinder. The dough under the required consistency has to come out of the cylinder in the required shape, rate and consistency without much breakage in order to produce the rice based noodles (*idiyappam*). For this, an extruder die was made out of stainless steel plate of 3 mm thickness. The diameter of the die plate (Figure 3.14) is 100 mm and is fitted at the bottom end of the dough cylinder through a threaded coupler. Thirty three circular holes of 1mm diameter were drilled on the plate. The diameter and hole density of the holes were fixed based on the preliminary studies in such a manner that the *idiyappam* noodles come out through the holes smoothly at all required pressure levels, piston speed and dough consistency levels as per the experimental design without much breakage. Also at the pushing end of pneumatic piston, a circular stainless steel plate of 8 mm thick and diameter micromillimeter less than the inside diameter of the pneumatic cylinder was fixed through a threaded joint. This will push the dough filled in the dough cylinder and the minimum clearance permit smooth movement of piston through the cylinder at the same time minimising the back flow of dough.

3.1.12 Noodle collecting plate

The noodles that come out through the extruder die were collected in a stainless steel collecting plate which is having 160 mm of diameter (Figure 3.15). The plate has several holes for the purpose of easy steaming of noodles. It was placed on the plate holding section. Along with the plate holder, the plate will also rotate to collect noodle.

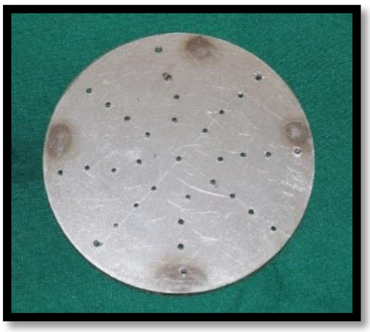


Figure 3.14 Extruder die

Figure 3.15 Noodle collecting plate

3.1.13 Plate holding section

A stainless steel (SS 304) collecting table of 170 mm diameter and 8 mm thickness was fabricated on which the noodle collecting plate would be placed which also rotate at the same rpm of collecting table (Figure 3.16). The table is centrally connected to a DC drive motor

3.1.14 DC motor

A 12 Volt, 36 Watts DC brushless motor was connected centrally to the rotary collecting table that provides rotary motion to it. The motor rotates at 20 rpm so that the extruded noodles forms into the shape of traditional idiyappam. (Figure 3.17)

Figure 3.16 Plate holding section

Figure 3.17 DC motor

3.2 OPERATIONAL PROCEDURE

The machine works on single phase AC supply of 220-230 V. The system uses compressed air to transmit, control and move the pneumatic piston. A pneumatic circuit consists of various pneumatic components such as cylinders, directional control valves, flow control valves etc. as explained in the earlier sections. Pneumatic circuit controls the injection and release of compressed air in the cylinder. When solenoid valve is actuated, the compressed air (dark blue) from inlet 1 is exhausted to outlet 4 where it enters the primary side of the double acting cylinder (Figure 3.18(a)) extending the cylinder piston to right. The exhaust air (light blue) simultaneously escapes via the outlet 2 and 3.

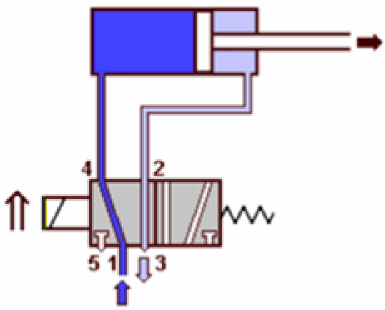


Figure 3.18 (a) extension of pneumatic cylinder

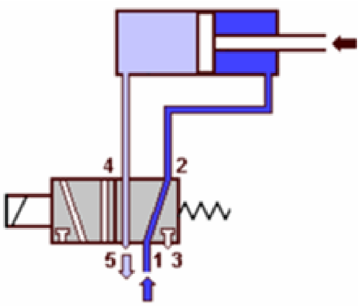


Figure 3.18 (b) Retraction of pneumatic cylinder

When the coil was turned off, the return spring restore the valve to its rest position. The compressed air now passes through the channels 1 and 2 to the secondary side of the cylinder, causing it to retract, i.e., move to the left. Exhaust air now escapes through 4 and 5 (Figure 3.18(b)).

The pressurized gas from the compressor was fed to the solenoid valve through the regulator. The regulator adjusts the incoming pressure to the suitable range required for the operation. From the solenoid valve, a parallel connection was made to the timer where the time interval for extending and retracting piston was adjusted. From the solenoid valve, connections were provided to the pneumatic cylinder. A flow control valve was connected to the inlet port of pneumatic cylinder. This will control the speed of the piston during extending time. In this study, piston extending is more important than piston retraction. The dough movement through the extruder die should be controlled which is effected by the speed of the pneumatic piston. The speed of the piston is controlled by the action of both timer and flow control valve. Piston rod with pushing disc at the farther end pushes the dough against the extruder die in the dough cylinder. The extruded fortified rice noodles would then fall on to the rotary collecting plate placed on the rotary plate holding section. Thus the extruded noodles fall on the rotary collecting plate. So that, it will form to the shape and size of the traditional *Idiyappam.* Once the required shape and size was reached, the collecting plate was removed and next collecting plate was placed to collect *Idiyappam*

The solenoid valve and timer switch were connected to the main supply as shown in Figure 3.19

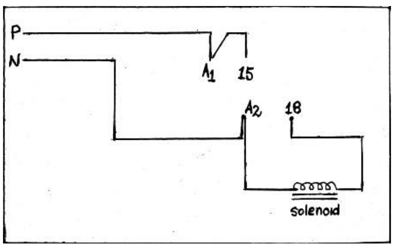


Figure 3.19 Circuit diagram of timer switch

3.3 EXPERIMENTAL DESIGN

The process parameters that influence the noodles extrusion such as pneumatic pressure, speed of the piston and jackfruit seed flour proportion in the blend were taken as independent variables and their ranges for the study were fixed based on thorough of review of literature and preliminary studies conducted. Capacity, Energy required, rate of extrusion and physico-chemical characteristics of extruded noodles were taken as dependent variables.

3.3.1 Independent variables

a) Pneumatic pressure (kPa)

1) P_1 : 600 kPa
2) P_2 : 700 kPa
3) P_3 : 800 kPa

b) Speed of the piston (m/s)

1) V_1 : 0.05
2) V_2 : 0.06
3) V_3 : 0.07

c) Jackfruit seed flour proportion in the blend (%)

1) W_1 : 5
2) W_2 : 8
3) W_3 : 11

3.3.2 Dependent variables

a) Capacity
b) Energy required
c) Rate of extrusion
d) Overall sensory score
e) Nutritional profile of optimized product and control (traditionally prepared rice *idiyappam*)

3.4 STATISTICAL ANALYSIS

Statistical optimization was carried out for effective interpretation of the interaction of process variables. Response surface methodology (RSM) was taken for the design of experimental combinations to optimize the process variables as it emphasizes the modelling and analysis of the problem in which responses is highly influenced (Montgomery, 2001). The method is based on the multivariate non-linear model, which is widely used for optimization process. The main advantage of this methodology is sufficient information for the statistically acceptable results can be given by RSM with reduced number of experimental treatments. The three process variables such as pneumatic pressure (X_1), speed of the piston (X_2), and jackfruit seed flour proportion in the blend (X_3) at three different levels were chosen based on the preliminary trials conducted and through review of literature

After the selection of independent variables and their ranges, the experiments were carried out based on the Box-Behnken design. The experimental designs for three variables of three different levels at three centre point combinations for each were determined. For statistical calculation, the three levels of the process variables were coded as -1, 0 and +1. The values of independent variables at three levels were shown in Table 3.1

Table 3.1 Values of independent variables at three levels of Box–Behnken design

Independent variable	Symbols		Levels	
	Coded	Uncoded	Coded	Uncoded
Pneumatic Pressure (kPa)	X_1	P	-1 0 1	600 700 800
Speed of the Piston (m/s)	X_2	V	-1 0 1	0.05 0.06 0.07
Jackfruit seed flour proportion in the blend (%)	X_3	W	-1 0 1	5 8 11

The experiments were designed using Design Expert Software, Version 7.0 (State-Ease, Minneapolis, USA). According to Box-Behnken design, total experiments to be conducted were seventeen for three independent variables. Seventeen experiments were performed with three variables at three levels as shown in the Table 3.2.

Table 3.2. Experimental design of pneumatic extrusion of rice noodles *(Idiyappam)*

Standard order	Run	Coded variables			Uncoded variables		
		Pneumatic Pressure (kPa)	Speed of the Piston (m/s)	Jackfruit Seed flour proportion in the blend (%)	Pneumatic Pressure (kPa)	Speed of the Piston (m/s)	Jackfruit Seed flour proportion in the blend (%)
1	12	-1	-1	0	700	0.07	11.00
2	1	1	-1	0	600	0.05	8.00
3	14	-1	1	0	700	0.06	8.00
4	13	1	1	0	700	0.06	8.00
5	11	-1	0	-1	700	0.05	11.00
6	17	1	0	-1	700	0.06	8.00
7	9	-1	0	1	700	0.05	5.00
8	5	1	0	1	600	0.06	5.00
9	4	0	-1	-1	800	0.07	8.00
10	15	0	1	-1	700	0.06	8.00
11	6	0	-1	1	800	0.06	5.00
12	3	0	1	1	600	0.07	8.00
13	7	0	0	0	600	0.06	11.00
14	10	0	0	0	700	0.07	5.00
15	16	0	0	0	700	0.06	8.00
16	2	0	0	0	800	0.05	8.00
17	8	0	0	0	800	0.06	11.00

After performing the experiments, prediction of optimal point is based on the second order regression equations, fitted to co-relate the relationship between independent variables and their responses. The equations interpret the variations caused by linear, quadratic and interactive effect of the process variables (Lee *et al.,* 2006).

$$Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_{11} X_1^2 + b_{22} X_2^2 + b_{33} X_3^2 + b_{12} X_1 X_2 + b_{13} X_1 X_3 + b_{23} X_2 X_3 \quad \ldots\ldots(3.1)$$

Where,

Y is the response variable

b_0, b_1, b_2 and b_3 are regression coefficients of linear terms

b_{11}, b_{22}, b_{33} are regression coefficients of quadratic terms

b_{12}, b_{13} and b_{23} are regression coefficients of cross-products terms

X_1, X_2 and X_3 are coded values of the independent variables X i.e. pneumatic pressure (X_1), speed of the piston (X_2) and jackfruit seed flour proportion in the blend (X_3) respectively. Statistical significance was adjudged by F- test. Significance of regression coefficient was determined by P value. Design Expert Version 7.0 (State-Ease, Minneapolis, USA) was used for the determination of coefficients of the equation. Final predictive equation was given by analysis of variance (ANOVA). Response surface equation for response variables were optimized by Design Expert Software. One independent variable was fixed at middle level while other two variables were changed for the purpose of response surface and contour plot analysis.

3.5 EXPERIMENTAL PROCEDURE

The developed pneumatic extruder was evaluated for its performance as per the experimental design explained in the section 3.4. The process parameters for the production of rice *idiyappam* fortified with jackfruit seed flour were optimised based on the machine and product quality characteristics. Good quality raw rice flour was purchased from local market. Jackfruit seed flour was purchased from Murali Jackfruit products, Athirappilli, Thrissur, Kerala. Preliminary studies were conducted based on reviews on earlier studies. To find out the proportion of jackfruit seed flour in the rice flour mix, the pneumatic pressure and pneumatic piston speed, proportion of water in the mix etc. to obtain a reasonably good product. Accordingly, the upper and lower limits of the process variables were fixed as explained in the section 3.4 for carrying out further analysis and statistical optimisation.

3.6 PNEUMATIC EXTRUSION OF IDIYAPPAM

All the cleaning protocols such as caustic rinsing, hot water rinsing and cold water rinsing etc. of the machine handling vessels and premises were carried out before starting the evaluation, so that the food is produced hygienically. The connections to the machine were checked and supply was turned on. Rice flour and jackfruit seed flour were mixed in the proportion required for the experiment and made into dough of appropriate consistency by adding potable water slowly and were mixed and kneaded well by hand. Approximately 1200 ml water was added per kilogram of the flour mix. About 1500 g of prepared dough was filled in the dough cylinder and the machine was turned on. The pneumatic piston with pushing disc pushes the dough through the extruder die holes to produce *idiyappam* noodles which falls on the rotary noodle collecting plate. The speed of the piston was controlled by flow control valve and the pneumatic pressure was varied through pressure regulator.

3.7 PERFORMANCE EVALUATION

3.7.1 Capacity

The capacity of pneumatic extruder is the weight of extruded product produced by the machine in one hour and expressed in kg/h. The weight of the product produced for a batch of dough (1500g) filled in the dough cylinder and time taken were recorded to calculate the capacity of the machine. One minute time interval is taken for loading the dough in the cylinder.

3.7.2 Energy

The energy consumption of the developed machine was determined using an energy meter connected parallel to load and supply time.

3.7.3 Rate of extrusion

Rate of extrusion of noodles is measured in terms of maximum possible length of noodles that can be extruded per second without any break.

3.8 COOKING PROPERTIES OF PNEUMATICALLY EXTRUDED RICE NOODLES

3.8.1 Cooking time

The noodles (5 g) were cooked in 100 ml boiling water (steaming). The cooking time of rice noodles was determined by pressing the product between fingers periodically at every one minute intervals. The time taken for the product become soft were recorded as cooking time (Devi *et al.*, 2014). All experiments were conducted in triplicate and average values were reported.

3.8.2 Cooking Yield

Cooking yield of noodles was determined by method proposed by American Association of Cereal Chemists (AACC, 2000). Ten gram of fortified noodles were cooked in 150 ml of boiling water for 10 minutes. The cooking yield was calculated as:

Cooking yield (g) = Weight of noodles after cooking (g) – Weight before cooking (g) …. (3.2)

3.8.3 Swelling power

Swelling power of noodles was determined as described by Schoch (1964). A known weight of rice noodles (5 g) were cooked in 100 ml of boiling water for 20 minutes. Cooked samples were weighed. From the initial and final weights of rice noodles, swelling power was calculated as:

$$\text{Swelling power} \left(\frac{g}{g}\right) = \frac{W_2 - W_1}{W_1} \qquad \text{…….. (3.3)}$$

Where,

W_1 = Sample weight before cooking, g

W_2 = Sample weight after cooking, g

3.9 PHYSICAL PROPERTIES OF PNEUMATICALLY EXTRUDED RICE NOODLES

3.9.1 Expansion ratio

Expansion ratio was measured as per the standard method described by Fan *et al.*, (1996). Ten extruded noodles samples were selected randomly and their diameter was measured using a digital vernier calliper. The expansion ratio of the extrudates were calculated as:

$$\text{Expansion ratio} = \frac{\text{Diameter of extruded product (mm)}}{\text{Diameter of die hole (mm)}} \qquad \text{...... (3.4)}$$

3.9.2 Moisture content

The moisture content of rice noodles was computed by hot air oven method (AOAC, 2005). Two gram of noodle sample was taken in a pre-weighed petridish and dried at 105 °C for 5-6 hours. Samples were then taken out of the oven and cooled in a desiccator. The final weight was noted using an electronic weighing balance (M/s Contech Instruments Ltd.) with a precision of 0.001 g. The fresh and bone dried weights were used to determine the moisture content on wet basis. Moisture content of the samples and moisture content is calculated by the following equation.

$$\text{Moisture content (M)} = \frac{W_2 - W_3}{W_2 - W_1} \qquad \text{...... (3.5)}$$

Where,

M = Moisture content (%.wb)

W_1= Weight of empty petridish (g)

W2= Initial weight of sample and petridish (g)

W3= Final weight of sample and petridish (g)

3.9.3 Water activity

The water activity of the rice noodles was determined using Aqua lab water activity meter (M/s Aqua lab, Decagon device Inc., USA) (Figure 3.20 (a)). To determine the water activity, the steamed noodles were filled in the disposable cups of the water activity meter and the sample drawer knob is turned to OPEN position. After opening the drawer, the disposable cup with rice noodles was then placed in the drawer and closed. The sample drawer knob was then turned to the READ position and the water activity of the sample was noted from the LCD display of the water activity meter.

3.9.4 Colour

Colour of product is an important parameter that will be valued during product marketing. The colour of the rice noodles was measured using a Hunter lab colour flex meter (Hunter Association Lab, Inc., Reston, Virginia, USA; model: Hunter lab's colour flex Ez) (Figure 3.20 (b). It consists of a sample port, opaque cover and a display unit and works on the principle of focusing the light on the sample and measuring the amount of energy reflected from the sample across the visible spectrum.

The colour of the sample was described by matching a sequence of colour across the visible spectrum in Hunter lab model. The sample was placed on the sample port and it was covered with an opaque cover to prevent interference. The three-dimensional scale L*, a* and b* values were used for colour measurement. The luminance (L*) forms the vertical axis, which indicates light-dark spectrum with a range from 0 (black) to 100 (white). The samples were filled in the sample cup. The deviation of the colour of the sample to standard values was also observed and recorded in the computer interface. The experiment was repeated thrice for each sample and average was reported.

3.9.5 Bulk density

The bulk density of rice noodles was estimated by the method explained by Jhoe *et al*. (2009). A known weight of fortified noodles sample was taken and transferred into a graduated cylinder. The cylinder along with the feed mix was then tapped on a flat surface until a constant volume was achieved. The final volume was noted. The bulk density was calculated using the following equation:

$$\text{Bulk density}\left(\frac{\text{g}}{\text{ml}}\right) = \frac{\text{Weight of sample (g)}}{\text{Volume of sample (ml)}} \qquad \ldots\ldots (3.6)$$

3.9.6 True density

True density of extruded rice noodles was calculated as per the method recommended by Deshpande and Poshadri (2011). One gram of sample was taken and it was poured into a burette containing toluene. The raise in volume in the burette was the true volume of the sample. Then true density was calculated as:

$$\text{True density}\left(\frac{\text{g}}{\text{cm}^3}\right) = \frac{\text{Weight of ground sample (1g)}}{\text{Rise in toluene level (cm}^3\text{)}} \qquad \text{……. (3.7)}$$

3.10 NUTRITIONAL PROFILE

As explained in Chapter I, traditional *Idiyappam* prepared using rice flour contains very less protein and fiber. Fortifying it with jackfruit seed flour could increase its nutritional quality. In order to assess the nutritional quality of the *Idiyappam* prepared from the pneumatically extruded noodles, the important nutritional quality characteristics were found for the optimised samples and compared with the conventionally prepared *Idiyappam.*

3.10.1 Carbohydrate

The carbohydrate content in the samples were determined as per the procedure given by Hedge and Hofreiter (1962). Hundred milligram of sample was taken into a test tube and it was hydrolysed by 5 ml of 2.5 N HCL, keeping it in a boiling water bath for 3 hours. The sample was cooled into room temperature and neutralized with sodium carbonate till the effervescence ends. The sample volume was made upto 100 ml and centrifuged at 6000 rpm for 10 minutes. Supernatant was collected and 0.5 ml, 1 ml aliquots were taken for the experiment. The standards were prepared by taking 0, 0.2, 0.4, 0.6, 0.8 and 1ml of the working standard and zero serves as blank. The volume was made upto 1 ml in the every tubes by the addition of distilled water. About four ml of anthrone reagent was added in each test tube and heated it for 8 minutes in a boiling water bath. The test tubes were cooled rapidly and read the green to dark green colour at 630 nm using a spectrophotometer (make: Systronics; model: PC based double beam spectrophotometer 2202) (Figure 3.20 (c)). The standard graph was drawn between concentration of standard on the X- axis and absorbance on the Y-axis. The carbohydrate present in the sample was calculated from the standard graph.

$$\text{Carbohydrate (\%)} = \frac{\text{mg of glucose}}{\text{Volume of test sample}} \times 100 \qquad \ldots (3.8)$$

3.10.2 Protein

Determination of the nitrogen content is the easiest way to compute the crude proteins using Kjeldahl apparatus (AOAC, 2005, 920.86). A finally ground sample powder of 0.2 g was taken into a digestion tube. Digestion mixture was prepared by mixing potassium sulphate and copper sulphate in the ratio 5:1. Three gram of digestion mixture was added to 10 ml of concentrated sulphuric acid to the sample. The sample was digested in a digestion unit till it become colourless. The tubes were cooled and transferred to the distillation unit. NaOH (40%) solution was allowed into the tube. Liberated ammonium was absorbed in boric acid (4%) solution containing mixed indicator (10 ml bromo cresol green and 7 ml of methyl red). The pink colour of the boric acid solution was turn into green. Later this was titrated against 0.1 N HCl until the pink colour was obtained. The percentage protein was obtained by using the following formula.

$$\text{Protein (\%)} = \frac{(\text{ml of HCL-ml of blank}) \times \text{molarity} \times 14.00 \times 100}{\text{mg test portion}} \times 6.25 \qquad ..(3.9)$$

3.10.3 Fat

The fat content of the samples was determined as per AOAC (2005, 920.85) by Soxhlet extraction method using SOCS - PLUS apparatus (make: Pelican Equipments, SCS-08, Chennai, India) (Figure 3.20 (e)).

Two gram of extrudate was weighed accurately and transferred to a thimble. Weight of the empty beaker was taken and were loaded into the system. The acetone was poured into the beaker from the top and boiled for about 30 minute at 80 °C. Once the process completed the temperature was doubled to 160 °C for 15-20 minute to collect the acetone. All the beakers with residue were dried in hot air oven at 100 °C for 1 hour, cooled in a desiccator and weighed. Final weight of the beaker was taken and fat content was estimated by using following the equation:

$$\text{Fat}\ (\%) = \frac{W_2 - W_1}{W} \times 100 \qquad \text{........}\ (3.10)$$

Where,

W_1 = Initial weight of the sample with beaker, g

W_2 = Final weight of the sample with beaker, g

W = Weight of the sample taken, g

3.10.4 Fiber

The dietary fibre content in the sample was estimated by the method explained by J. Maynard (1970). Two gram of fat removed sample was treated with ether or petroleum ether to remove fat (initial boiling temperature 35-38°C and final temperature 25°C). If fat content was found below 1%, extraction may be omitted. Two gram of sample was boiled with 200 ml of sulphuric acid for 30 minute with bumping chips. Filtered through muslin and washed with boiling water until washings were no longer acidic. Boiled with 200 ml of sodium hydroxide solution for 30 minute. Again it was filtered through muslin cloth. Washed with 25 ml of 1.25% H_2SO_4 and water. Remove the residue and dried it for 2 hour at 130 °C. The dish was cooled in a desiccator and weighed (W2). It was ignited for 30 minute at 600 °C. Again cooled in a desiccator and reweighed (W3). The percentage of crude fibre was calculated by using the following equation:

$$\text{Fiber (\%)} = \frac{\text{Loss in weight on ignition (W2} - \text{W1)} - \text{(W3} - \text{W1)}}{\text{Weight of the sample}} \times 100 \quad \text{.... (3.11)}$$

W1 = weight of sample

W2 = weight of sample after 2 hour drying (130°C)

W3 = weight of sample after 30 minute drying (600°C)

3.10.5 Ash

The ash content in the sample was determined as per AOAC (2000) using muffle furnace (Figure 3.20f). Four gram of sample was taken into a porcelain crucible and ignited at 600 ^{0}C for 2 hour, cooled in a desiccator into room temperature and weighed again. The ash content was determined by using the following equation:

$$\text{Total ash (\%)} = \frac{\text{Ash weight}}{\text{Sample weight}} \times 100 \quad \text{..... (3.12)}$$

Figure 3.20 (a) Water activity

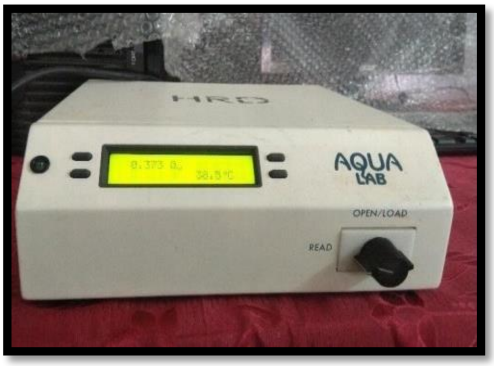


Figure 3.20 (b) Colorimeter

Figure 3.20 (c) Spectrophotometer

Figure 3.20 (d) Kjeldahls apparatus

Figure 3.20 (e) Soxhlet apparatus

Figure 3.20 (f) Muffle furnace

Figure 3. Instrumentation and apparatus for determination of phsico-chemical and nutritional qualities

3.11 SENSORY EVALUATION OF PNEUMATICALLY EXTRUDED FORTIFIED NOODLES

Sensory evaluation of cooked (steamed) jackfruit seed flour fortified rice noodles were carried out by a panel of 12 judges along with control sample. Sensory characteristics such as colour and appearance, texture, flavour, taste and overall acceptability were scored by a semi trained using 9 point Hedonic scale test and average sensory score of the samples were analysed.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter outlines the results on development of a pneumatic extruder system and evaluation of developed system towards the extrusion of jackfruit seed flour fortified rice noodles. The outcome of the experiments laid out for evaluation of the process parameters leading to their standardization are discussed in detail. The effect of jackfruit seed flour addition on the physical, nutritional and sensory characteristics of pneumatically extruded fortified rice noodles were also analysed and discussed.

4.1 DEVELOPMENT OF A PNEUMATIC EXTRUDER FOR THE PRODUCTION OF FORTIFIED RICE NOODLES

A pneumatic extruder system for extrusion of fortified rice noodles was fabricated as shown in Figure 4.1. It consists of frame assembly, pneumatic cylinder, compressor, air filter regulator, double solenoid valve, pneumatic pipes/tubes, pneumatic fittings, timer, flow control valve, extruder die, dough cylinder , noodle collecting plate, plate holding section and DC motor (Figure 3.1). The mainframe of the system was fabricated out of stainless steel which consists of a vertical section and horizontal plane

The compressor is the main source for pressurised gas to perform a pneumatic system. A 1 hp, 220V, 2850 rpm single stage reciprocating air compressor was used for generation and pressurised storage of air. This pressurized gas is fed in to solenoid valve through a regulator.

An FR+L with gauge & metal guard type air filter regulator delivers clean and dust free compressed air from the compressor at a fixed pressure rate to solenoid valve. A pressure gauge connected to the filter regulator was used to monitor the pressure of the compressed air.

A double solenoid valve directs the flow of compressed air to and from the pneumatic cylinder. Extending and retracting action of piston was controlled by the five port two position directional valve. The pneumatic valves control the pressure, rate and amount of air flow into the pneumatic cylinder. From the solenoid valve, a parallel connection was made to the timer where the time interval for extending and retracting piston was adjusted.

From the solenoid valve connections were provided to the pneumatic cylinder. The working pressure of the pneumatic cylinder is in the range of 50 kPa to 1000 kPa. The cylinder has an inlet and outlet port. In the inlet portion a flow control valve was attached through a adapter. The speed of the piston was controlled by this flow control valve during forward movement. Pneumatic cylinder is fixed vertically on to the vertical frame section at a height of 200 mm above a 1.5 Kg capacity dough cylinder. The dough cylinder is made of stainless steel has a height of 340 mm and diameter of 100 mm. Extruder die is inserted into the dough cylinder and then dough is stuffed in or filled in. During the extending time of piston rod, the dough in the cylinder is pushed against the extruder die by a pushing disc connected to the end portion of piston rod.

The extruded fortified rice noodles would then fall on to the rotary collecting plate placed on the rotary plate holding section. The diameter of the collecting plate is 160 mm. A 20 rpm robotic motor was connected to the plate holding section. Along with plate holder, the noodle collecting plate also would rotate to achieve the traditional shape of the rice noodles *(Idiyappam)*. Figure 4.1 shows the developed pneumatic extruder for the production of fortified rice noodles.

Figure 4.1 Pneumatic Extruder

4.2 STANDARDISATION OF THE PROCESS PARAMETERS OF PNEUMATIC EXTRUDER SYSTEM FOR THE PRODUCTION OF FORTIFIED RICE NOODLES

In order to evaluate the fabricated pneumatic extruder system towards the extrusion of fortified rice noodles by the incorporation of jackfruit seed flour into rice flour and for optimization of the process parameters, a series of experiments were conducted. Based on the available literature on pneumatic extrusion and jackfruit seed flour substitution in food products, preliminary studies were carried out to find out a suitable range of pneumatic pressure, speed of the piston and jackfruit seed flour proportion in the blend. Based on the preliminary studies, pneumatic extrusion studies were conducted at a pneumatic pressure of 600 Kpa, 700 kPa and 800 kPa, speed of the piston of 0.05, 0.06 and 0.06 m/sec and jackfruit seed flour proportion in the blend of 5, 8 and 11% as explained in the section 3.4.

For optimizing the parameters, capacity, energy required and rate of extrusion were considered as responses and listed as per the experimental design. To optimize the parameters, seventeen experiments were carried out according to the as Box Behnken design. Second order equation were used to relate the dependent and independent process variables. The coefficient of each term in the second order polynomial were determined using multiple regression analysis through Design Expert software (Version 7.0, State-Ease, Minneapolis, MN).

Multiple regression analysis was used to fit the model, represented by an equation to experimental data. Analysis of variance (ANOVA) was performed to examine each response for statistical significance of the terms in the regression equation. The adequacy and significance of the quadratic model were ascertained. Significance of each term was checked using 'p' values. R^2, Adjusted R^2, Adequate Precision and Fisher's F-test were used to check the adequacy of regression model (Montgomery, 2001).

Amount of variation around the mean, adjusted for the number of terms in the model was measured using Adjusted R^2. As the number of terms in the model increases, the adjusted R^2 decreases if those additional terms do not add value to the model. Adequate precision was used to compare the range of predicted values at design points to the average prediction error.

F-value at probability (p) of 0.1 to 0.01 was computed to judge the significance of all terms in the polynomial statistically. To fit the data, a complete second order quadratic model was employed and values of R^2, Adjusted R^2, predicted R^2 (a measure of how good the model predicts a response value) and Fischer F-test were considered to test the adequacy of the model. During the explanation of variation in behaviour, the smaller the value of R^2 denotes the model have less importance for dependent variables. In order to visualise the relationship between the response and experimental levels of each factors and to deduce the optimum conditions, the fitted equations were expressed as contour plots which were generated using the statistical package, Design Expert software (Version 7.0, State-Ease, Minneapolis, MN).

4.3 PERFORMANCE EVALUATION OF THE PNEUMATIC EXTRUDER

Performance evaluation of pneumatic extruder for the production of jackfruit seed flour fortified rice noodles *(Idiyappam)* under various process parameter treatment combinations are given in table 4.1.

Table 4.1. Performance evaluation of pneumatic extruder towards the production of fortified idiyappam

Sl. No	Sample	Capacity (kg/h)	Energy required (Kwh)	Rate of extrusion (cm/sec)
1	$P_1V_1W_2$	14.850	0.22	6.4
2	$P_1V_2W_1$	15.570	0.19	7.3
3	$P_1V_3W_2$	15.030	0.21	6.6
4	$P_1V_2W_3$	14.490	0.26	5.4
5	$P_2V_3W_3$	14.805	0.24	5.8
6	$P_2V_2W_2$	15.210	0.20	6.9
7	$P_2V_2W_2$	15.210	0.20	6.9
8	$P_2V_1W_3$	14.580	0.25	6.8
9	$P_2V_2W_2$	15.210	0.20	6.9
10	$P_2V_1W_1$	15.750	0.17	7.3
11	$P_2V_2W_2$	15.210	0.20	6.9
12	$P_2V_3W_1$	15.930	0.16	7.5
13	$P_2V_2W_2$	15.210	0.20	6.9
14	$P_3V_3W_1$	16.200	0.14	7.5
15	$P_3V_2W_2$	15.615	0.17	7.1
16	$P_3V_1W_2$	15.390	0.18	7.1
17	$P_3V_2W_3$	14.895	0.23	6.1

P: pneumatic pressure (kPa)

V: speed of the piston (m/s)

W: jackfruit seed flour proportion in the blend (%)

4.3.1 Capacity

The capacity of pneumatic extruder varied between 14.490 to 16.200 kg/h. The maximum capacity was obtained at a pneumatic pressure of 800 kPa pressure, piston speed of 0.07 m/s and jackfruit seed flour proportion in the blend of 5%.

Relationship between independent and dependent variables were examined using response surface methodology. The ANOVA table for the response "capacity" is given in Appendix (Table 1). Based on the experimental results, a second order non-linear regression equation was fitted to the experimental data. Following regression model was obtained to predict the capacity of pneumatic extruder for the production of fortified idiyappam.

$$\text{Capacity} = 15.21 + 0.34\,A - 0.045\,B - 0.51\,C - 0.12\,AB - 0.056\,AC + 0.17\,BC + 0.16A^2 - .017B^2 - 0.084C^2 \qquad \ldots\ldots\ldots\ldots\ldots\ldots(4.1)$$

Where,

A = Pneumatic pessure, kPa

B = Speed of the piston, m/s

C = Jackfruit seed flour proportion in the blend, %

From Table 1 (Appendix), it can be concluded that the values of R^2, R^2-adj and R^2-pred for the capacity of pneumatic extruder were 96.62, 92.28 and 45.97 percent respectively. The coefficient of determination (R^2) of the regression model for capacity was 96.62 percent which implies that the model could account 96.62 percent variability in data. Lack of fit was insignificant and F-value suggested that model was significant at 1 percent and 5 percent level of significance. The adequate precision (17.363) value for capacity indicates that the model can be used to predict the response within the design space. An adequate precision of 4 is a prerequisite for reliable prediction using mathematical models (Montgomery, 2001). Hence the second order model was adequate in describing the capacity of pneumatic extruder.

It is evident from the Equation 4.1 that the capacity was in positive relation with pneumatic pressure, speed of the piston and negative relation with jackfruit seed flour proportion in the blend. Capacity of the machine increased with increase in pressure from 600 kPa to 800 kPa and piston speed from 0.05 to 0.07 m/s. But with increase in the jackfruit seed flour addition to the blend, the capacity was found to decrease. The highest capacity was recorded at a blend proportion of 5%. The decrease in capacity with increase in blend proportion could be attributed to the increase in viscosity of the mix which resist the extrusion of the dough mix through the die openings. The jackfruit seed flour is not as less viscous flour as compared to rice flour in dough form Therefore, feed mix or dough requires more load to extrude fortified rice noodles through the extruder die by movement of piston rod in the container. Table 1 shows that, the linear (A, B, C), interactive (AB, BC, AC) and quadratic (A^2, B^2, C^2) terms had a significant effect on capacity at 1 percent ($p<0.001$) level of significance.

4.3.2 Energy Requirement

The energy required for the pneumatic extrusion of fortified rice noodles using pneumatic extruder varied between 0.14 to 0.26 kwh. The minimum energy (0.14kwh) obtained at a pneumatic pressure of 800 kPa, piston speed of 0.07 m/s and jackfruit seed flour proportion in the blend of 5%.

The ANOVA table for the response "energy required" is given in Appendix (Table 2). Based on the experimental values, a second order non-linear regression equation was fitted in between independent and dependent variables. Following regression model was obtained to predict the power of pneumatic extruder for the production of fortified rice noodles.

$$Energy = 0.20 - 0.20A - 5.000E - 00B + 0.040C - 0.000AB + 5.000E - 003\ AC - 00BC - 003A^2 - 003B^2 - 003C^2 \quad \ldots\ldots\ldots\ldots\ldots(4.2)$$

From Table 2 (Appendix), it could be inferred that the values of R^2, R^2– adj and R^2-pred were 99.99, 99.97 and 99.58 respectively. Adequate precision (2.000) value for energy indicates that the model can be used to predict the response within the design space. The coefficient of determination, R^2 of the regression model for refractive index was 99.99 percent which implies that the model could account for 99.99 percent variability in data. Lack of fit was insignificant and F- value suggested that the model was significant at 1 percent and 5 percent.

It is evident from Equation 4.2 that the variation of energy of pneumatic extruder with variations in input variables are insignificant. Table 2 shows that, the linear (A, B, C), interactive (AB, BC, AC) and quadratic (A^2, B^2, C^2) terms had a significant effect on energy at 1 percent ($p<0.001$) level of significance.

4.3.3 Rate of extrusion

The rate of extrusion of fortified rice noodles using pneumatic extruder varied between 5.4 to 7.5 cm/sec. The maximum length (7.5cm/sec) was obtained at a pneumatic pressure of 800 kPa, piston speed of 0.07 m/s and jackfruit seed flour proportion in the blend of 5%.

The ANOVA table for the response “rate of extrusion” is given in Appendix (Table 3). Based on the experimental values, a second order non-linear regression equation was fitted in between independent and dependent variables. Following regression model was obtained to predict the rate of extrusion of pneumatic extruder for the production of fortified rice noodles.

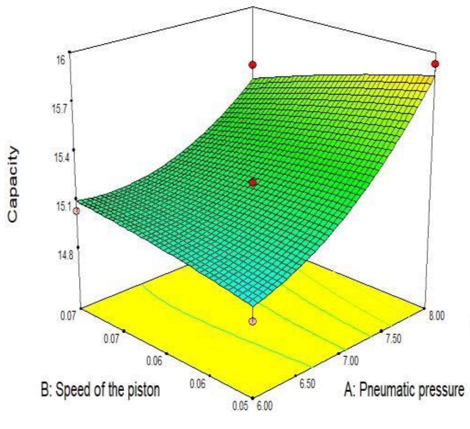
$$\text{Rate of extrusion} = 6.90 + 0.20A - 0.075\,B - 0.63C - 0.050\,AB + 0.12AC - 0.30BC - 0.19A^2 + 0.087B^2 - 0.14C^2 \quad \text{………………(4.3)}$$

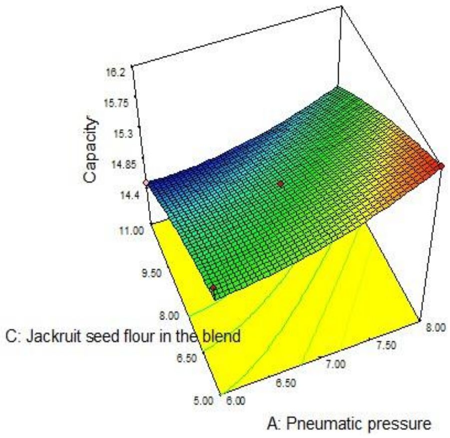
From Table 3 (Appendix), it may be concluded that the values of R^2, R^2-adj and R^2-pred for the rate of extrusion of pneumatically extruded fortified rice noodles were 94.63, 87.73 and 91.58 percent respectively. The coefficient of determination (R^2) of the regression model for rate of extrusion was 94.63 percent which implies that the model could account 94.63 percent variability in data. Lack of fit was insignificant and F-value suggested that model was significant at 1 percent and 5 percent level of significance. The adequate precision (14.556) value for rate of extrusion indicates that the model can be used to predict the response within the design space. An adequate response of 4 is a prerequisite for reliable prediction using mathematical models (Montgomery, 2001). Hence the second order model was adequate in describing the rate of extrusion of pneumatically extruded fortified rice noodles.

It is evident from the Equation 4.3 that the rate of extrusion was in positive correlation with pneumatic pressure, speed of the piston and negative relation with jackfruit seed flour proportion in the blend. Rate of extrusion increased with increase in pressure from 600 to 800 kPa and piston speed from 0.05 to 0.07 m/s. But with increase in the jackfruit seed flour in the blend decreases the rate of extrusion. The maximum rate of extrusion was noted at 5% concentration of seed flour. While increasing the seed flour proportion to 8 and 11 percent, the chance of noodles breakage was higher due to the rough flour nature. The jackfruit seed flour is not a smooth silky flour as compared to rice flour. Therefore, feed mix or dough requires more power to extrude fortified rice noodles through the extruder die by movement of piston rod in the cylinder. Table 1 implied that, the linear (A, B, C), interactive (AB, BC, AC) and quadratic (A^2, B^2, C^2) terms had a significant effect on capacity at 1 percent ($p<0.001$) level of significance.

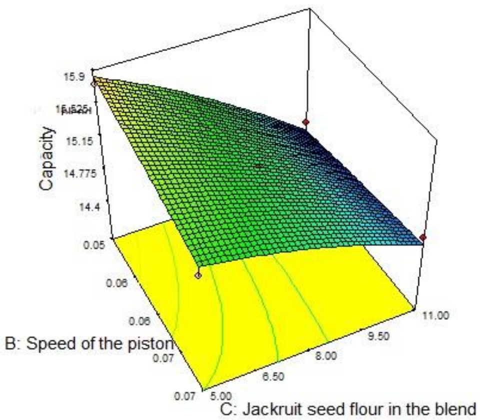
4.4.1 Effect of process parameters on capacity of pneumatic extruder

The 3D response plots of variation of capacity of the extruder at different speed of piston, pneumatic pressure and proportion of jackfruit seed flour in the blend as reported by equation 4.1 are shown in Figure 4.2





a **b**



c

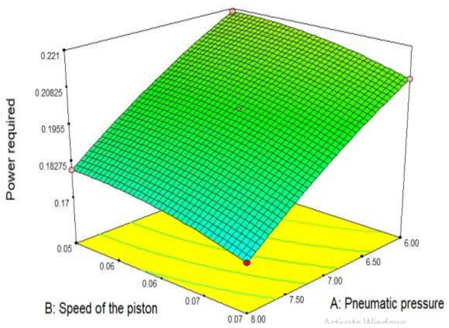
Figure 4.2 Effect of extrusion process parameters on capacity

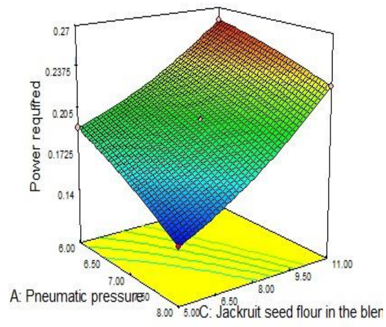
It could be perceived from the Fig 4.2 (a) that capacity increased when pneumatic pressure and speed of the piston increased from 600 kPa to 800 kPa and 0.05 to 0.07 m/s respectively. Also, from Fig. 4.2 (b) and (c) it could be noted that at low jackfruit seed flour proportion in the blend, the capacity was found to be high. Naturally at high piston speeds and pneumatic pressure the throughput would increase due to the increased extrusion of product. Higher proportion of jackfruit seed flour would resist the movement of the noodles through the holes due to the increased viscosity and particles size of the dough blend resulting in decreased capacity.

The maximum capacity (16.200 kg/hr) was obtained at a pressure of 800 kPa, piston speed of 0.07 m/s and seed flour proportion of 5%. The capacity range varied from 14.49 to 16.2 kg/hr. From Figure 4.2 (c) it may be observed that capacity increased with increase in speed of the piston. The maximum capacity was attained at piston speed of 0.07 m/s.

4.4.2 Effect of process parameters on energy required for pneumatic extrusion

The relationship between pneumatic pressure, speed of the piston and jackfruit seed flour proportion in the blend on the energy required for pneumatic extrusion is illustrated by plotting 3D graphs representing the response surface (energy) generated by the model (Equation 4.2). The 3D responses were shown in Figure 4.3.





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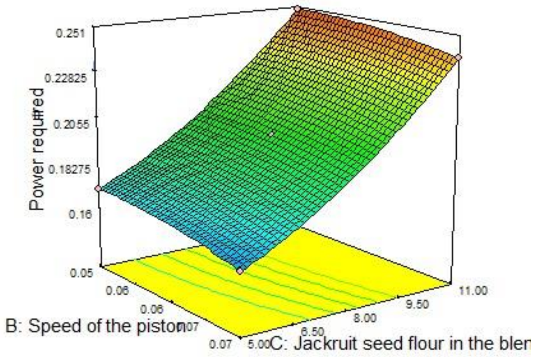


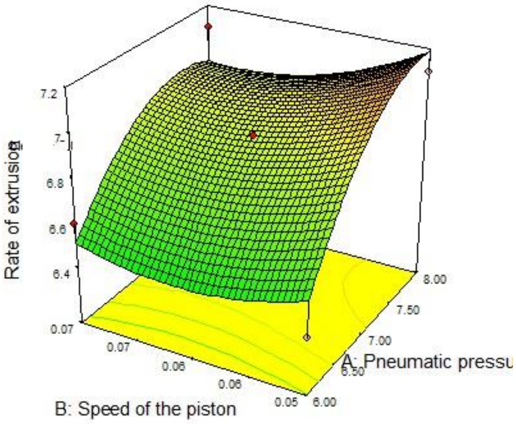
c

Figure 4.3 Effect of process parameters on energy requirement

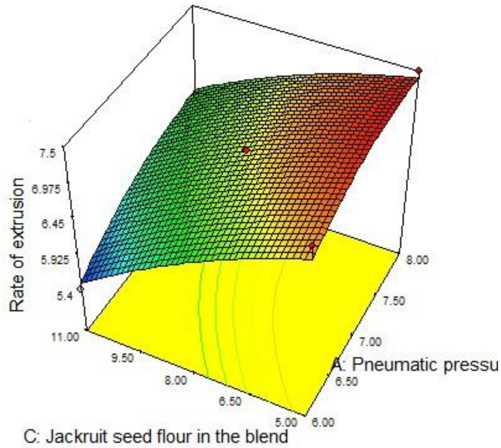
The energy requirement varied between 0.14 to 0.26 kwh. It may be observed from the figure that with increase in pneumatic pressure and speed of the piston within the range of the experimental limits, the energy requirement was found to decrease though the increase was insignificant. Whereas, with increase in jackfruit seed flour proportion in the blend, a significant increase was noted. With increase in jackfruit seed flour, the resistance for the dough to extrude through the die holes would increase due to the increased viscosity and particle size resulting in an increased energy requirement.

4.4.3 Effect of process parameters on rate of extrusion

The relationship between pneumatic pressure, speed of the piston and jackfruit seed flour proportion in the blend on rate of extrusion is represented by 3D graphs dipictig the response surface (Figure 4.4).



a



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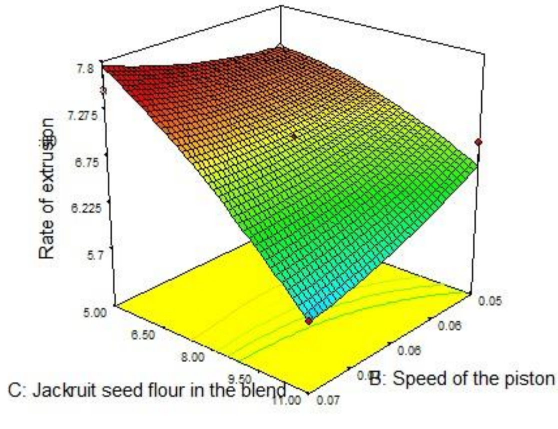

c

Figure 4.4 Effect of process parameters on rate of extrusion

The maximum rate of extrusion was obtained at a pneumatic pressure of 800 kPa, piston speed of 0.07 m/s and jackfruit seed flour proportion in the blend of 5%. From the Figure 4.3 (b) and (c) it may be inferred that jackfruit seed flour proportion in the blend had a significant effect on rate of extrusion. Rate of extrusion decreased with increase in the seed flour addition in the feed mix. It was observed in the study that rice flour extrusion for idiyappam were comparatively faster because of the low viscosity and particle size of the flour mix. Incorporation of jackfruit seed flour to rice flour makes the dough rough and slightly hard to get extruded. This would result in the breakage of noodles during the pneumatic extrusion process. Eventhough jackfruit seed flour addition is for the fortification purpose, increment of seed flour results difficulty in extrusion of noodles and decreased overall acceptability (Butool and Butool, 2015).

Also from the Figure 4.3 (b) it may be concluded that rate of extrusion increases with increase in pressure (from 600 kPa to 800 k Pa). It could be perceived from the Fig. 4.1 (a) that rate of extrusion increased when speed of the piston was increased from 0.05m/sec to 0.07 m/sec for the reasons stated earlier.

4.4.4 Optimisation of process parameters

The jackfruit fortified rice noodles were developed using pneumatic extrusion technology and the various process parameters which will affect the efficiency of machine were studied. Optimization of three independent variables viz., pneumatic pressure (600,700 and 800 kPa), Speed of the piston (0.05, 0.06 and 0.07 m/s) and jackfruit seed flour proportion in the blend (5, 8 and 11%) were performed using Box- Behnken design of response surface methodology in Design Expert Software 7.0. and desirability analysis was carried out. Desirability changes from zero to one for any given response. Individual responses combines into a single number and searches for the greatest overall desirability. The value one represents ideal case and zero indicates that one or more responses fall outside desirable limits (Myers *et al.,* 2009). In this study, the independent variables were kept within the range and the dependent variables were selected as minimum, maximum or range depending upon the requirements to get the desired outcome. From the desirability analysis, the optimal level of various parameters were found and listed in Table 4.2. The optimum conditions for the development of fortified rice noodles were found as pneumatic pressure of 800 kPa, piston speed of 0.07m/s and jackfruit seed flour proportion in the blend of 5%. The capacity, energy and rate of extrusion values at this optimum levels for pneumatic extrusion of fortified rice noodles were found to be 16.2 kg/h, 0.14 kwh and 7.5 cm/s respectively. The desirability of the optimisation of pneumatic extrusion parameters was found to be 0.982. Since the desirability value is closer to one, the optimised values could be considered ideal.

Table 4.2 Optimal level obtained from desirability analysis

Sl.No	Response	Desirability	Optimal level	Low level	High level
1	Pneumatic pressure	Is in range	800	600	800
2	Speed of the piston	Is in range	0.07	0.05	0.07
3	Jackfruit seed flour proportion in the blend	Is in range	5	5	11
4	Capacity	Maximise	16.2	14.49	16.2
5	Energy	Minimise	0.14	0.14	0.26
6	Rate of extrusion	Maximise	7.5	5.4	7.5

4.6 COOKING PROPERTIES OF PNEUMATICALLY EXTRUDED RICE NOODLES

Cooking qualities such as cooking time, cooking yield and swelling power of pneumatically extruded jackfruit seed flour fortified noodles produced at optimised condition were determined as expressed in section 3.8. The results are show in Figure 4.5.

4.6.1 Cooking time

It was found that the cooking time for both optimised sample ($P_3V_3W_1$) and control samples were found to be 10 minutes. Aravind *et al.* (2011) conducted cooking time studies of wheat pasta prepared through mechanical and manual extrusion and the results were shown as same for both methods.

4.6.2 Cooking yield

Cooking yield for optimised sample at pneumatic pressure 800 kPa, piston speed 0.07 m/s and flour blend of 5% was found as 23%. For control sample, it was observed as 23.4%. Higher cooking yield was obtained for control product. Similar trend of cooking yield was reported by Akbani *et al.* (2011) for breadfruit starch-wheat flour noodles. The addition of jackfruit seed flour might be the reason for the decrement in cooking yield of fortified noodles as compared with the control product. When the noodles contain only rice flour, increased starch content resulted in gelatinization absorbing steam causing increased cooking yield. Whereas addition of jackfruit seed flour in rice flour would result in decreased amount of starch in the same volume of mix as jackfruit seed flour has other constitutes other than starch. This would cause reduction of gelatinization and accompanied water absorption resulting in decreased cooking yield compared to control.

4.6.3 Swelling power

Swelling power for optimised sample ($P_3V_3W_1$) was 2.1% and for control it was 2.5%. Swelling power is directly related with the presence of starch which indicates the ability to absorb water and increase in size (Dendy *et al*.(1993). The rice idiyappam (control) contains higher proportion of starch than the optimised noodles which could have contributed for increased swelling power for control sample.

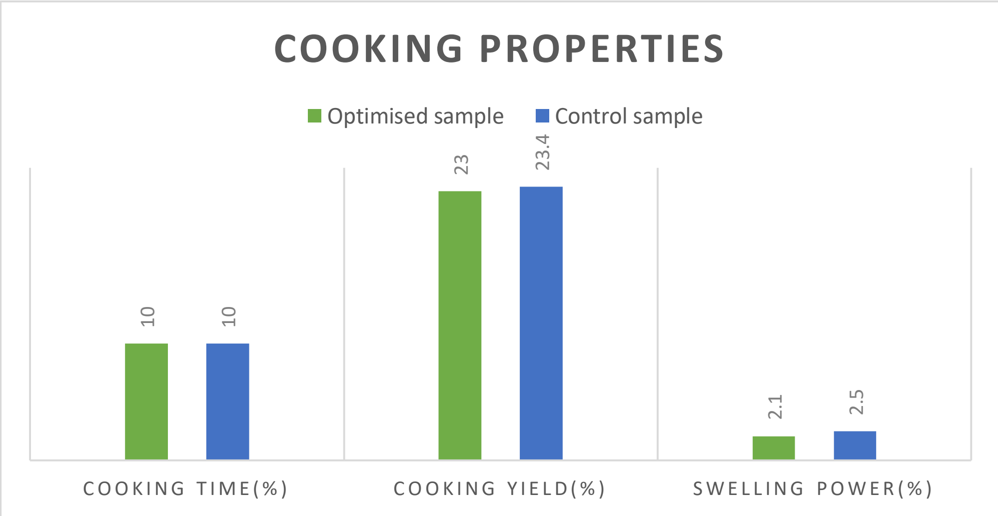

Figure 4.5 cooking properties of optimized and control sample

The resistance offered at the die holes while extruding creates heat generation which would contribute to the increased swelling and expansion of the starch granules.

4.7 PHYSICAL PROPERTIES OF PNEUMATICALLY EXTRUDED RICE NOODLES

The physical properties such as expansion ratio, moisture content, water activity, colour, bulk density and true density of optimised as well as the control samples were determined as detailed in the section 3.9.

4.7.1 Expansion ratio

The expansion ratio of optimised sample ($P_3V_3W_1$) was 2.4. It was observed that the control sample expansion ratio was 3. The jackfruit seed flour contains higher fiber and protein content, which might be the reason for lower expansion ratio of the optimised product. This was in agreement with the study conducted by (Wojtowicz and Moscicki, (2014) for influence of legume content in pasta.

4.7.2 Moisture content

Higher moisture content was found in control sample (5.29% w.b%). Moisture content of optimised sample ($P_3V_3W_1$) was recorded as 4.8% (w.b). The reason for more moisture content in traditionally prepared rice idiyappam is due to higher proportion of starch content. The Starch content retains more moisture through swelling and absorption

4.7.3 Water activity

Water activity of samples were estimated using a water activity meter. Water activity of optimised sample ($P_3V_3W_1$) was 0.987 at 28.5 °C whereas that of control was 0.984. The control sample recorded slightly higher water activity but the increase was insignificant. This was in agreement with the studies of (Hussain *et al.*, 2015) for walnut kernel incorporated rice based snacks.

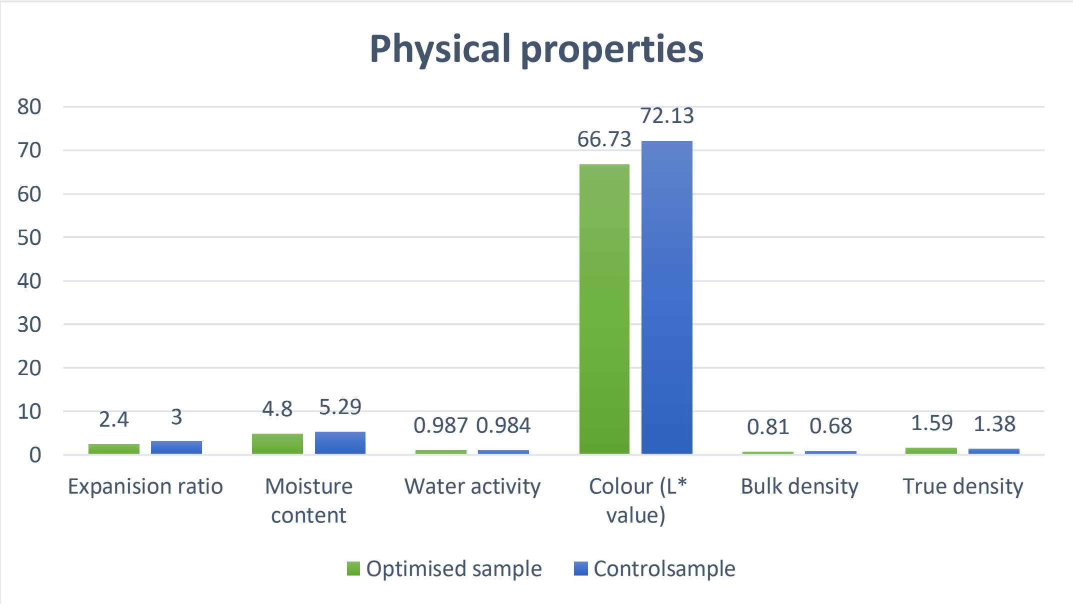

Figure 4.6 Physical properties of optimised and control sample

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4.7.4 Colour characteristics

Tri-stimulus colour characteristics was determined using Hunter lab colour flex meter. The L* value indicates the lightness of the noodles which indicates one of the predominant characteristics with respect to the traditionally prepared rice idiyappam. Therefore, the lightness was taken as parameter for characterisation. The L* (lightness) value observed for optimised sample was 66.73 and that of control sample was 72.13 respectively. At optimised condition, the colour was not much affected by the addition of jackfruit seed flour. According to Hossain *et al.*, (2014) for bread supplemented with jackfruit seed flour, low L values were found with increased substitution of jackfruit seed flour.

7.5 Bulk density

The bulk density of optimised sample was found to be 0.81 g/ml and that of control sample was 0.68 g/ml. The addition of jackfruit seed flour resulted in increased bulk density of the optimised sample. Since flours with high bulk densities are used as thickeners in food products, the jackfruit seed flour could be used as a thickener. This was in agreement to the studies of Ocloo *et al.* (2010) for Physico-chemical, functional and pasting characteristics of flour produced from Jackfruits (*Artocarpus heterophyllus*) seeds.

4.7.6 True density

True density of optimised sample was 1.59 g/cm^3 and for control sample it was 1.38 g/cm^3.

It may be concluded from the analysis of the cooking and physico-chemical characteristics that the properties of the optimally produced pneumatically extruded jackfruit seed flour fortified rice idiyappam were on par with that of traditionally prepared rice idiyappam.

4.8 NUTRITIONAL PROFILE

The important nutritional characteristics of the optimised and control samples, pneumatically extruded jackfruit seed blended rice noodles and traditionally prepared idiyappam were determined as per the procedures explained in the section 3.10. The results are discussed below.

The nutritional profile of optimised and control samples were shown in the Table 4.3.

4.8.1 Carbohydrate

Carbohydrate content of optimised sample was 75% and that of control sample was 78.4%. Similar findings were reported by Nandkule *et al.,* (2015) in the study of noodles incorporated with jackfruit seed flour.

4.8.2 Protein

Protein content of optimised sample was found to be 8.3%. And for control sample it was about 6.4%. Optimised sample shows more protein content. The protein content was increased due to the relative increase in jackfruit seed flour in the feed mix which has higher protein content than rice idiyappam. Similar findings were reported by Abraham and Jayamuthunagai, (2014) for pasta production supplemented with jackfruit seed flour.

4.8.3 Fiber

Fiber content of optimised sample was 2.1%. But for the control sample it was only 0.42%. Hence, there was 1.68%, increase of fiber content in optimised product than that of the control product. Jackfruit seed flour is rich in fiber content. This might be the reason for the increased fiber content presence in fortified optimised rice noodles compared with the control sample. Similar behaviour was observed by Kumar *et al.,* (2015) for jackfruit seed flour based noodles.

4.8.4 Fat

Optimised sample contains 0.82% fat content and for control sample, it was found as 0.36%. Fat content for both optimised and control samples were observed as very low. Both rice flour and jackfruit seed flour contain less fat content. Similar results were obtained by Nandkule *et al.,* (2015) for jackfruit seed flour fortified noodles.

4.8.5 Ash

Optimised sample contains 0.57% ash content and control sample contains 0.42 % ash content. Ash content of optimised sample was much higher than control sample. Relative increase in jackfruit seed flour might be the reason for increased ash content presence in optimised sample, because jackfruit seed flour contains 3.01% ash whereas for rice flour it is only 0.5%. Similar findings have been reported by Abraham and Jayamuthunagai, (2014) for pasta production supplemented with jackfruit seed flour.

Table 4.3 Nutritional profile of Optimised and Control sample

Nutritional content (%)	Optimised sample	Control sample
Carbohydrate	75.0	78.40
Protein	8.30	6.40
Fiber	2.10	0.42
Fat	0.82	0.36
Ash	0.57	0.42

On analysis of the nutritional properties of the optimally produced pneumatically extruded jackfruit seed flour fortified rice idiyappam other than carbohydrate content, all other constituents recorded a significant increase when compared to the traditionally prepared rice idiyappam. A marked increase in protein, fat, fibre and mineral contents were observed which indicate that the pneumatically extruded noodles are nutritionally superior than that of traditionally prepared one.

4.9 SENSORY EVALUATION OF PNEUMATICALLY EXTRUDED RICE NOODLES

Sensory evaluation indicates the acceptability of the product and it was judged on a nine-point hedonic scale. The sensory evaluation was carried out on the basis of colour and appearance, texture. flavor, taste, and overall acceptability of the developed product.

The sensory evaluation of the pneumatically extruded fortified rice noodles showed that there were significant differences among the treatments for the organoleptic qualities. The results of sensory evaluation of selected fortified rice noodles and control sample were given in Table 4.4.

Table 4.4 Mean sensory score card for pneumatically extruded fortified rice noodles

Treatment	Colour & Appearance	Texture	Flavor	Taste	Overall acceptability
$P_3V_3W_1$ (optimised)	8.00	8.50	8.00	8.33	8.75
$P_3V_3W_2$	6.50	6.00	5.00	6.3	6.00
$P_3V_3W_3$	5.00	5.25	6.00	5.4	5.50
Control	8.12	8.00	8.50	8	8.50

The overall acceptability of the optimised sample was higher than that of the control sample. The colour and appearance and flavour score of the control samples were slightly higher than that of the optimised sample. The texture and taste score of the optimally prepared noodles were higher than control. According to David (2016) 5-15% supplementation of jackfruit seed flour gave better colour, taste, flavour and overall acceptability. The jackfruit seed flour fortified rice idiyappam samples prepared through pneumatic extrusion are shown in Figure 4.7 along with the control. The other fortified samples scored significantly lower scores when compared to control sample. The jackfruit seed flour in the blend was found to impart unacceptable changes in colour, taste and flavour of the noodles.

From the above stated studies, it may be derived that the jackfruit seed flour fortified rice idiyappam prepared through the pneumatic extruder developed under this study at optimised operating condition of 800 kPa of pneumatic pressure, speed of the piston 0.07 m/s and 5% fortification of jackfruit seed flour in the rice powder resulted in production of higher capacity of noodles at lower energy level and higher rate of extrusion. The idiyappam so prepared were found to be on par with cooking and physico-chemical qualities, nutritionally rich and organoleptically superior with that of traditionally prepared rice idiyappam.

$P_3V_3W_1$

$P_3V_3W_2$

$P_3V_3W_3$

Control

Figure 4.7 Idiyappam made at different process parameters

CHAPTER V

SUMMARY AND CONCLUSION

The traditional food products of various regions are now developing into food processing business. Marketing of these kind of culinary products will enhance the more income, jobs as well as minimizes post-harvest. Traditional habits always bring typically tasty, natural and nutritious foods. Rice noodles or *Idiyappam* is one of the traditional food preparation popular in Kerala, Tamil Nadu and Karnataka. Traditionally it is prepared by pressing the rice flour water mix through the die with holes of required diameter manually. It is a time consuming and energy intensive laborious process. There are motorized *idiyappam* machines are available. But such motorized extruders are complicated in design, energy intensive and lacking in precision with more moving parts and associated gear mechanisms. Here comes the importance of pneumatic force, because of their inherent advantages over other mechanical systems. Pneumatic engineering is based on compressed air or compressed inert gas. Unlimited supply of air in the atmosphere would produce compressed air and easy storage in large volumes. The use of compressed air is not restricted by distance. The pneumatic system which provides extremely durable components, simple design and economic. It is less effected by temperature, dust and corrosive element. There is less chance of fire or explosion during the working of pneumatic system.

This study envisages development and evaluation of a pneumatic extruder for production of fortified rice noodles *(Idiyappam)*. The developed system consists of frame assembly, pneumatic cylinder, compressor, air filter regulator, double solenoid valve, pneumatic pipes/tubes, pneumatic fittings, timer, flow control valve, extruder die, dough cylinder , noodle collecting plate, plate holding section and robotic motor. The frame part, dough cylinder, noodle collecting plate and Plate holding section were made of stainless steel. The compressor is the main source for pressurised gas to perform a pneumatic system. A 1 hp, 220V, 2850 rpm single stage reciprocating air compressor was used for generation and pressurised storage of air. This pressurized gas is fed in to solenoid valve through a air filter regulator. The air filter regulator delivers always clean and dust free compressed air from the compressor at a fixed pressure rate to solenoid valve. The pressure gauge connected to the filter regulator was used to monitor the pressure of the compressed air. Double solenoid valve directs the flow of compressed air to and from the pneumatic cylinder. Extending and retracting action of piston is controlled by this directional valves. From the solenoid valve, a parallel connection was made to the timer where the time interval for extending and retracting piston was adjusted.

From the solenoid valve, connections are also provided to the pneumatic cylinder which is major part of the machine system. A flow control valve was connected to the inlet port of pneumatic cylinder. It will control the speed of the piston during extending time. Dough cylinder is placed just below the pneumatic cylinder. Capacity of the cylinder is 1.5 Kg of dough. Extruder die is inserted into the cylinder and then dough is stuffed in or filled in. During the extending time of piston rod, the dough in the cylinder is pushed against the extruder die by a pushing disc which is attached at the end portion of piston rod. The pneumatically extruded rice noodles collected in plate, which is placed above a plate holding section. A DC motor is connected to this section to get the rotational motion for achieving traditional shape of rice noodles *(Idiyappam)*. This study was especially for the production of fortified rice noodles. Rice *Idiyappam* is rich carbohydrate in the form of refined starch and therefore a great source of energy, contains no cholesterol and low in sodium. But it is very low in protein and fibre content. Therefor to make rice noodles nutritionally rich, jackfruit seed flour was incorporated with rice flour. The seed flour is rich in nutrients such as proteins, dietary fiber, and minerals and low in fat and calorific value. Also it is a gluten and cholesterol free.

In order to evaluate the developed pneumatic system towards extrusion of fortified rice noodles from rice flour and jackfruit seed flour, the process parameters like pneumatic pressure, speed of the piston and jackfruit seed flour proportion in the blend were chosen as independent variables. Capacity, energy required and rate of extrusion were chosen as dependent variables. Based on the preliminary studies, the three levels of process parameters were selected such as pneumatic pressure of 600 kPa, 700 kPa and 800 kPa, speed of the piston of 0.05, 0.06 and 0.07 m/s and jackfruit seed flour proportion in the blend of 5, 8 and 11 percent.

The experiments were performed by required proportion of dough mix, which was fed into the dough cylinder of the pneumatic extruder. The process parameters such as pneumatic pressure and speed of the piston were controlled by pressure gauge and flow control valve respectively. Extending and retracting function of piston rod is adjusted by specific time interval using a timer mechanism. Fortified rice noodles is collected in a collecting plate which is having a rotational motion by a DC drive motor.

For optimization of the process parameters and to check the efficiency of the experimental design, a second order non-linear regression equation was fitted between dependent and independent variables. Analysis of variance (ANOVA) for the final predictive equation was carried out using Design Expert Software, Version 7.0. Response surface methodology (RSM) was adopted and Box-Behnken design of three variables and three levels, each with three centre point combinations was used. The response surface equation was optimized for the response variables using the above software.

The results showed that with increase in pneumatic pressure from 600 kPa to 800 kPa and speed of the piston from 0.05 m/s to 0.07 m/s, the capacity was found to increase. But, with increase in jackfruit seed flour proportion (from 5 percent to 11 percent) in the blend, the capacity and rate of extrusion were found to decrease. Energy has insignificant effect on the pneumatic pressure and speed of the piston. Pneumatic extrusion of fortified rice idiyappam resulted in capacity of 16.200 kg/hr, energy required of 0.14 Kwh and rate of extrusion of 7.5 cm/sec. The optimised conditions of pneumatic pressure, speed of the piston and jackfruit seed flour proportion in the blend for pneumatic extrusion of fortified rice noodles were found to be 800 kPa, 0.07 m/s and 5 percent respectively.

Optimised sample and control sample were compared on the basis of physical and nutritional and cooking characteristics. Cooking time for both optimised and control samples were found to be same (10 minutes). But cooking yield (23.4%) was found to be higher for control sample. The supplementation of jackfruit seed flour would be the reason for lesser cooking yield (23%) observed in optimised sample ($P_3V_3W_1$). More swelling was observed in control sample due to the presence of starch which indicates the ability to absorb water and increase in size. Physical properties such as moisture content of optimised sample ($P_3V_3W_1$) was 4.8% and control sample was 5.29%. Water activity of optimised sample ($P_3V_3W_1$) and control sample was 0.987, 0.984 respectively. Expansion ratio of optimised sample was 2.4 and control sample was 3.0. The jackfruit seed flour contain more protein and fiber content which reduces the ability of expansion. Engineering properties like bulk density was higher for optimised sample (0.81g/ml) and for control sample ($P_3V_3W_1$) it was 0.68g/ml. True density of optimised sample ($P_3V_3W_1$) was 1.59 g/cm^3 and for control sample it was 1.38 g/cm^3. The colour values were appeared better for control product because it was purely made by rice flour only. Fortified optimised sample possess little brownish colour due to the addition of jackfruit seed flour.

The proximate component such as carbohydrate, protein, fiber, fat and ash content of optimised sample were 75%, 8.3%, 2.1%, 0.82% and 2.23% respectively. Whereas for control sample it was 78.4%, 6.4%, 0.42%, 0.36% and 0.42% respectively. Thus it could be concluded that addition of appropriate level of jackfruit seed flour into the rice flour for the preparation of rice noodles *(Idiyappam)* would enhance the nutritional qualities of the product.

Sensory evaluation was conducted on a nine point hedonic scale by twelve member's consumer test panel for colour, texture, flavor, taste and overall acceptability of the developed fortified rice idiyappam. Overall acceptability of rice noodles varied from 5.50 to 8.75. The mostly accepted rice idiyappam sample was $P_3V_3W_1$ by sensory panel (overall acceptability 8.75) among the fortified products. Overall acceptability of control sample was 8.50. Acceptability decreases with increase in jack seed flour proportion.

The following are suggestions for future research work on the pneumatic extrusion.

1. Installation of more than one plate for easy collection of noodles at a single rotation.
2. Installation of instrumentation of sensor to change each plates after filling the required noodles.
3. Adoption of different shape of extruder dies for the production of more attractive cold extruded products.

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APPENDIX 1

Table 1: ANOVA for Capacity

Source	Sum of squares	df	Mean square	F value	p-value Prob>F	
Model	1.11	9	0.12	0.36	0.00923	Significant
A: Pneumatic pressure	0.15	1	0.15	0.42	0.05359	
B: Speed of the piston	0.17	1	0.17	0.48	0.05098	
C: Jackfruit seed flour proportion in the blend	0.22	1	0.22	0.64	0.04485	
AB	0.13	1	0.13	0.38	0.05588	
AC	2.025E-3	1	2.025E-3	5.885E-3	0.09410	
BC	0.12	1	0.12	0.36	0.05684	
A2	0.17	1	0.17	0.48	0.05109	
B2	0.000	1	0	0	1.0000	
C2	0.17	1	0.17	0.50	0.05016	
Residual	2.41	7	0.34			
Lack of fit	0.92	3	0.31	0.82	0.5452	Not significant
Pure error	1.49	4	0.37			
Cor total	3.52	16				

R^2 - 96.62 Adj R^2 - 92.28

R^2 pred- 45.97 Adeq Precision- 17.36

APPENDIX 1I

Table 1: ANOVA for Energy

Source	Sum of squares	df	Mean square	F value	p-value Prob>F	
Model	4.966E-3	9	5.474E-4	0.33	0.00938	Significant
A: Pneumatic pressure	4.500E-4	1	4.500E-4	0.27	0.0061	
B: Speed of the piston	4.500E-4	1	4.500E-4	0.27	0.0619	
C: Jackfruit seed flour proportion in the blend	2.000E-4	1	2.000E-4	0.12	0.0073	
AB	6.250E-4	1	6.250E-4	0.38	0.05594	
AC	6.250E-4	1	6.250E-4	0.38	0.05594	
BC	6.250E-4	1	6.250E-4	0.38	0.05594	
A2	1.901E-3	1	1.901E-3	1.14	0.03206	
B2	6.579E-6	1	6.579E-6	3.953E-3	0.09516	
C2	5.921E-5	1	5.921E-5	0.036	0.08557	
Residual	0.012	7	1.664E-3			
Lack of fit	5.650E-3	3	1.883E-3	1.26	0.4013	Not significant
Pure error	6.000E-3	4	1.500E-3			
Cor total	0.017	16				

R^2 - 99.99 Adj R^2 - 99.97 R^2 pred- 99.58

Adeq Precision- 2.00

APPENDIX 1II

Table 1: ANOVA for Rate of extrusion

Source	Sum of squares	df	Mean square	F value	p-value Prob>F	
Model	1.04	9	0.12	0.19	0.00988	Significant
A: Pneumatic pressure	0.020	1	0.020	0.032	0.0086	
B: Speed of the piston	0.00	1	0.00	0.000	.0065	
C: Jackfruit seed flour proportion in the blend	0.020	1	0.020	0.032	0.08622	
AB	0.20	1	0.20	0.33	0.0584	
AC	0.12	1	0.12	0.20	0.0669	
BC	2.500E-3	1	2.5000E-3	4.056E-3	0.0951	
A2	0.24	1	0.24	0.39	0.0554	
B2	0.032	1	0.032	0.052	0.0825	
C2	0.35	1	0.35	0.56	0.0476	
Residual	4.31	7	0.62			
Lack of fit	1.45	3	0.48	0.68	0.6095	Not significant
Pure error	2.86	4	0.71			
Cor total	5.36	16				

R^2 - 94.63 Adj R^2 - 87.73

R^2 pred- 91.58 Adeq Precision-14.56

DEVELOPMENT AND EVALUATION OF A PNEUMATIC EXTRUDER FOR PRODUCTION OF FORTIFIED RICE NOODLES *(IDIYAPPAM)*

By

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ABSTRACT OF THESIS

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ABSTRACT

The traditional food products of various regions are now developing into food processing business. Marketing of these kind of culinary products will enhance the more income, jobs as well as minimizes post-harvest. Traditionally rice noodles or idiyappam is prepared by pressing the rice flour water mix through the die with holes of required diameter manually. It is a time consuming and energy intensive laborious process. There are motorized *idiyappam* machines are available. But such motorized extruders are complicated in design, energy intensive and lacking in precision with more moving parts and associated gear mechanisms. Pneumatic engineering is based on the compressed air or compressed inert gas. In this study a pneumatic extruder was developed for the production of fortified rice noodles, which composed of frame assembly, pneumatic cylinder, compressor, air filter regulator, double solenoid valve, pneumatic pipes/tubes, pneumatic fittings, timer, flow control valve, extruder die, dough cylinder , noodle collecting plate, plate holding section and DC motor. In order to evaluate the developed system towards extrusion fortified rice noodles, the effect of process parameters which would influence the capacity, energy and rate of extrusion such as pneumatic pressure of 600, 700 and 800 kPa, speed of the piston 0.05,0.06 and 0.07 m/s, jackfruit seed flour proportion in the blend of 5, 8 and 11% were studied. Physical properties, cooking properties, nutritional profile and sensory scores were analysed. The optimised operating condition of pneumatic pressure, speed of the piston and jackfruit seed flour proportion in the blend were found to be of 800 kPa, 0.07 m/s, 5 % respectively. From this study, it may be derived that the jackfruit seed flour fortified rice idiyappam prepared through the pneumatic extruder developed under this study at optimised operating condition of 800 kPa of pneumatic pressure, speed of the piston 0.07 m/s and 5% fortification of jackfruit seed flour in the rice powder resulted in production of higher capacity of noodles at lower energy level and higher rate of extrusion. These noodles were found to be on par with cooking and physico-chemical qualities, nutritionally rich and organoleptically superior with that of traditionally prepared rice idiyappam