OPTIMIZATION OF PROCESS VARIABLES FOR PREPARATION OF BLENDED PUFFED RICE BAR

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Dean, CAET

CERTIFICATE-I

This is to certify that the thesis entitled **"Optimization of process variables for preparation of blended puffed rice bar"** submitted in partial fulfillment of the requirements for the award of the degree of **Master of Technology (Agricultural Engineering)** in **Processing and Food Engineering** to the Orissa University of Agriculture and Technology, Bhubaneswar is a faithful record of bonafide and original research work carried out by **Indrajeet Sahu** under my guidance and supervision. No part of this thesis has been submitted for any other degree or diploma.

It is further certified that the assistance and help received by him from various sources during the course of investigation has been duly acknowledged.

Bhubaneswar
Date: 21 June, 2016

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CERTIFICATE-II

This is to certify that the thesis entitled **"Optimization of process variables for preparation of blended puffed rice bar"** submitted by **Indrajeet Sahu** to the Orissa University of Agriculture and Technology, Bhubaneswar in partial fulfillment of the requirements for the degree of **Master of Technology (Agricultural Engineering)** in **Processing and Food Engineering** has been approved by the students' advisory committee and the external examiner.

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ABSTRACT

India with divergent food habits is having a number of traditional foods, breakfast cereals, snack bars and rice cakes including puffed products. Puffed rice balls is one of the popular Indian traditional sweet snacks. It is mainly prepared using jaggery as sweetener and puffed rice. Sweets or confections with jaggery are gaining popularity due to the awareness of its health benefits. Since the product is popular among all sections of population in the country, an attempt was made to further enrich this product with nutraceuticals by incorporating flax seeds. In recognition of the above needs, the present investigation aimed at optimizing the process variables for preparation of blended puffed rice bar with respect to sensory evaluation and strength characteristics. Experiments were planned as per Box-Behnken response surface methodology (RSM). The three independent variables were jaggery % (80, 90 and 100), flaxseed % (10, 20 and 30) and tamarind juice in ml (5, 10 and 15). The plan consisted of 15 experimental runs with three experiments at centre point. The dependent quality attributes of bar considered were firmness and overall acceptability (OA). The experimental data were analyzed to develop response functions and the input variables were optimized for best outputs. A complete second order polynomial model of following form was fitted to the data of all responses using multiple regression technique. The adequacy of the model was tested considering R^2, F value and lack of fit. A puffed rice bar making device was proposed to be developed so that a number of puffed rice bar with uniform size and compaction could be prepared in one batch. The developed bar making unit consisted of stainless steel compartment unit and a wooden pressing unit. The performance of the device was compared to that of traditional method in terms of capacity and percentage uniformity in size. The effect of packaging material on sensory properties of prepared blended puffed rice bar was studied with respect to storage period. Four combinations of Cellophane wrapping and LDPE sealing were used and the bars were kept under ambient condition (33-37°C). The sensory attributes for the products under study considered were colour, flavour, taste, crispiness and stickiness. The overall acceptability was estimated using composite scoring.

The results of the investigation indicated that the traditional soft jaggery was more suitable for proper binding of the bar than the hard one. The end point temperature of the jaggery syrup was found out to be 120-122°C. The developed bar making device is useful in preparing puffed rice bar with a capacity 7.68 kg/h (400 numbers/h) with 90% uniformity in size and shape. The optimum operating conditions for preparation of blended puffed rice bar for multiple responses i.e. J%, FS% and TJ ml are -0.0303, -1, -0.0505 (coded values) and 90, 10 and 10 (uncoded values) respectively. Corresponding to this conditions values of responses i.e. firmness and overall acceptability were 21 N/mm and 7.5 respectively. The overall desirability was 0.859. Adequacy of 2nd order models developed for firmness and overall acceptability through regression analysis was confirmed by R^2 more than 0.95. The results revealed that all the process variables (J%, FS%, TJ ml) had significant effect on firmness and overall acceptability of blended puffed rice bar. Jaggery and tamarind juice content had most significant effect on both the responses. The surface profiles were drawn as a function of two process variables with the third one at optimum value and successfully interpreted. Overall analysis of the sensory evaluation of storage study revealed that the samples with both cellophane wrapping and LDPE sealing performed better than any other type upto 8 days of storage with overall acceptability of 7.74 by composite scoring.

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List of Symbols and Abbreviations

ρ_b	Bulk density
ρ_p	Particle density
%	Percent
°C	Degree centigrade
AICRP	All India Coordinated Research Project
ANOVA	Analysis of Variance
cm	Centimeter
conc.	Concentration
db	Dry basis
Dept.	Department
et al.	And other people
Fig.	Figure
FS	Flaxseed
g	Gram
g/cm^3	gram per centimeter cube
h	Hour
HDPE	High Density polyethylene
J	Jaggery
Kg	Kilo gram
Kg/h	Kilogram per hour
l	Litre
LDPE	Low density polyethylene
min	Minutes
ml	Milliliter
mm	Millimeters
N	Newton
N/mm	Newton per mm
No/h	Number per hour
OA	Overall Acceptability
PHT	Post Harvest Tecnology
ppm	Parts per million
pps	Points per second
RSM	Response Surface Methodology
s	Seconds

Temp.	Temperature
TJ	Tamarind Juice
Vs.	Versus
Φ	Porosity

Chapter I

INTRODUCTION

Chapter-1

INTRODUCTION

Cereal grains represent a major staple food source for a large proportion of the world's population. These grains are processed into a wide diversity of food products which provide various nutritional benefits and contribute to wellbeing for consumers. Industrially ready-to-eat puffed products are made from wheat, maize (corn), rice and various combinations of cereals and these foods are popular in Australia and many other countries. Although utilized extensively on a commercial scale, puffing of grains presents challenges and there are still major concerns regarding the quality of various puffed products made from the cereal grains.

The snack food is one of the most important areas of the food industry. Designing snack foods today can be a complex process to meet changing consumers taste and expectations to a wide variety of people. Most snack manufacturers use some form of existing technology as the basis for creating snack products and incorporate variations that increase the resulting snacks health image. Therefore, puffing and popping using advance technologies are processes, which can accomplish all these targets. As a simplest, inexpensive and quickest traditional method of dry heat application for preparation of ready-to-eat snacks products, puffing has been practiced since hundreds of years. Explosion puffing by sudden release and expansion of water vapour is a relatively well known and widely used process (Sullivan and Craig, 1984).

Puffing imparts acceptable taste and desirable aroma to the product. Popped/ puffed grain being a pre-cooked ready-to-eat material can be used in snack foods, specialty foods and as a base for development of supplementary foods. Examples of the use of the puffing process are the manufacture of expanded rice (Hoke *et al.*, 2005) or parboiled rice flour (Lai and Cheng, 2004). Convenient snack foods like popcorn, popped and puffed rice, popped sorghum, popped wheat roasted and puffed soybean and other legumes are very popular not only in Indian subcontinent, but also worldwide (Anderson, 1971; Jaybhaye *et al.*, 2014). Puffed cereal grains are commonly used as ingredients in a variety of food products, provide characteristics including crispiness which appeal to consumers. In addition to the traditional puffed breakfast cereals, newer developments have included healthy bars, confectionery and savoury foods.

Rice (*Oryza sativa* L.) is a major global crop and food source, especially in tropical and subtropical regions and this is increasingly popular for making breakfast cereals, snack bars and rice cakes and also as a light food when puffed as either brown or milled rice by processing at high temperatures. India with divergent food habits is having a number of traditional foods, including sweet products. Chikki or Bar is one of the popular Indian traditional sweet snacks. Puffed rice bar is mainly prepared using jaggery as sweetener and puffed rice. Sweets or confections with jaggery are gaining popularity due to the awareness of its health benefits. Jaggery or gur is a traditional, unrefined, non centrifugal, whole cane sugar consumed in Asia, Africa, Latin America and the Caribbean. It is obtained by concentrating sugarcane juice or date juice without separation of the molasses and crystals and can vary from golden brown to dark brown in color. It contains the natural goodness of minerals and vitamins inherently present in sugarcane juice & this crowns it as one of the most wholesome and healthy sugars in the world. It is a natural sweetener having a sweet winy flavour (Shahi 1999) and contains protein, minerals and vitamins and is a potent source of iron and copper (Manay and Swamy 2001). There are several different varieties of bar in addition to the most common peanut bar. Usually ingredients such as puffed Bengal gram, sesame, puffed rice, beaten rice and copra (desiccated coconut) are used and some bars are made using a combination of these ingredients. Special bars are made out of cashew nuts, almonds and pistachio. It has been reported that bar prepared with added sodium bicarbonate were lighter, more yellow than other products (McKee et al. 2003). Process of making chikki with added soda was patented (Shelesky and Anderson 2000). Peanut bar, peanut and sesame seed bar and peanuts and spices mixed with Bengal gram meal were developed and evaluated for sensory and nutritional properties with regard to their use as nutritional supplements for school children (Chahal and Sehgal 1996). Since the product is popular among all sections of population in the country, an attempt was made to further enrich with nutraceuticals by incorporating flax seeds.

According to market statistics, the global functional food and nutraceuticals market is increasing with a compound annual growth rate (CAGR) of 7.4% that is outpacing the traditional processed food market and is expected to reach USD 176.7 billion in 2013 (Ahmad et al. 2011). Canada is emerging as a leading world supplier in this growing market and the country boasts more than 300 companies - from small start-ups to multinational enterprises - many that are internationally recognized for the incorporation of bioactive ingredients, such as soluble fibre from oats, barley and pulses, omega- 3 fatty acids from fish and flax oil, unsaturated fatty acids from canola oil, plant sterols and stanols from vegetable boils, and protein from soy bean. Industry is also putting efforts to incorporate functional ingredients into food products, such as probiotic bacterial cultures, prebiotics (e.g. fructo-oligosaccharides) from corn, bio-actives concentrated from berries and flax, and novel fibres from pulses etc (Ahmad et al. 2011). The functional food industry in India is strong and is a growing force in the international health foods market. The health and wellness foods market is currently estimated to be in the vicinity of USD 1.6 billion and expected to reach USD 7.5–10 billion by the year 2015 (Palthur et al. 2009).

Flax seed (Linum usitatissimum) is one of the richest sources of n-3 fatty acids, mainly consisting of alpha linolenic acid in addition to 18:2 (linoleic acid). Unlike fish oil, flaxseed provides one of the non-animal sources of n-3 making it ideal for vegetarians. Flax seed contains approximately 40% oil, 30% dietary fiber, 20% protein, 6% moisture and 4% ash (Oomah and Mazza 1998, Bathena Ali et al. 2003). The traditional use of flaxseed in human health has been for higher protein and fibre content. Further discoveries of flaxseed fiber effects have been on blood glucose metabolism and hyperlipidemia. Other flaxseed constituents, oil and phyto-estrogens have been widely investigated in connection with cardiovascular diseases and cancer. In the present work flaxseeds were blended with puffed rice bar formulation to increase the essential fatty acids and the effect of blending of flax seeds with puffed rice for the optimization of bar was studied.

Response surface methodology (RSM) is a useful technique to handle complex process variables in research. The technique can be used in engineering process, industrial research and biological investigation with emphasis on optimizing the process system. RSM is mainly used to reduce the number of experimental runs needed to provide statistically significant information (Ravindra and Chattopadhaya, 2000). In recognition of the above needs and in order to explore the possibility of preparation of puffed rice bar the present investigation was carried out to standardize the relation between different process variables on bar preparation and to determine a set of optimum processing conditions suitable for better retention of therapeutic values.

Keeping all these facts in view the present work aimed at the following objectives:

1. To develop a device for preparation of puffed rice bar with uniform size and compaction.
2. To optimize the process variables for preparation of blended puffed rice bar with respect to sensory evaluation and strength characteristics using RSM.
3. To study the effect of packaging material on sensory properties of prepared blended puffed rice bar with respect to storage period.

Chapter II

REVIEW OF LITERATURE

Chapter-2

REVIEW OF LITERATURE

2.1 Introduction

Cereal grains are widely processed for ready-to-eat-breakfast cereals, snack food as well as puffed grain cakes. These products do not require further cooking by the purchaser and can provide nutritional advantages with some being high in fibre, low in fat and offering the benefits associated with whole grain products. The cereal grains which are most widely used are wheat, rice, corn, oats, and barley. The present investigation deals with preparation of puffed rice bar blended with flaxseed. Therefore this chapter deals with the review of literature on different aspects of production and processing of cereals product. It also includes the studies on value added products and the nutritional benefit of jaggery, puffed rice and flaxseed.

2.2 Types of cereal grains used for puffed products

Of the cereal grains, corn has been utilized for many years and continues to be widely used for making the popular breakfast cereal cornflakes and the puffed snack popcorn. Corn is followed closely by wheat which is commonly incorporated during production of breakfast cereals, puffed wheat snacks and wheat cakes. Whilst rice has been consumed as a staple food and in various forms for centuries it has gained considerable importance in recent years being processed, both alone and in combination with other cereals. Another cereal grain that has also attracted interest in recent times is oats which is typically used in the form of rolled oats and yet another cereal grain, barley, is also considered suitable for processing. Increasingly cereal grain foods are attracting attention and the demand for ready-to-eat food products made from cereal grains continues to expand (Wrigley 2004).

The basic steps in processing of each of the cereals grains into breakfast cereals and puffed food are similar. In recent times processes that have been used for other cereals have been applied to rice which is now used extensively in processing due to the unique flavour and textural properties it provides. Rice is increasingly being converted into flakes, shredded rice and multi-grain cereals as well as puffed products which can be prepared by a number of processing techniques. Puffing of rice can be carried out in hot sand, in hot oil, in an oven and by a puffing gun (Caldwell and Kadan 2004).

2.3 Scope of value added rice food products

There is a deep-rooted relation between the rice and the people of eastern India. In our society, morning starts with 'rice' and also ends with 'rice'. People use rice in eating and drinking and use its straw for sleeping. Always there is a great demand both from the researchers and the farmers for more productivity. Due to increased food grain production, now the growing population in India is able to consume rice in different value added forms according to their food habits. According to Trichopoulou et al. (2007) traditional foods are frequently palatable and this combined with reputed positive health effects, makes them attractive to the food industry. The agro-climatic condition in Odisha favors the rice cultivation and it has a great influence in the socio-cultural life of Odisha people. The farm women are very much acquainted with the value added rice food stuff in which traditional skill is required. But, their involvement in rice does not give any economic benefits. If we can enhance their skill for newer rice products then there is scope for commercial benefit. Puffed rice is very popular in many countries as a cereal breakfast component or as a light food. It is a whole grain puffed product from parboiled milled rice. It is prepared from hydrothermally treated or pregelatinized milled rice by heating in high temperature of air, oil and sand or by gun puffing method. Puffed rice is ready for consumption and easily digestible. It is commonly used in snacks, cereals drinks, Ready- to- Eat (RTE) breakfast cereals and infant foods.

2.4 Concept of Popping and Puffing

Popping of cereals has been practiced since hundreds of years. Popping is a type of starch cookery, where grains are exposed to high temperature for short time. Popping is a process in which kernels are heated until internal moisture expands and pops out through the outer shell of the kernel (Arkhipov et al., 2005), whereas, puffing is a process where, sudden release of water vapour and expansion of pre-gelatinized kernel (Sullivan and Craig 1984; Hoke et al., 2007) takes place. Superheated vapour is produced inside the grains by instantaneous heating, which cooks the grain and expands the endosperm while escaping with great force through the micropores of the grain structure. Most of the water in the kernel is superheated at the moment of popping and provides driving force for expanding the kernel once pericarp ruptures.

Hoseney et al. (1983) proposed that during the popping of popcorn the pericarp acts as a pressure vessel and popping occurs at about 177°C, which is equivalent to a pressure of 135psi inside the kernel. The electron scanning microscope image implied that in a translucent endosperm, the superheated water appears to vaporize in to the hilum, expanding the starch granules to a thin film. In the opaque endosperm large voids are produced and the starch granules remain birefringent. The voids around the starch provide an alternative site in to which the superheated water vaporizes. Thus, the starch granules are not expanded and retain their birefringence.

Hadimani (1994) reported that during popping the material practically gets sterilized and most of the seed microfloras are destroyed. Holm et al. (1985); Nyman et al., (1987) found that popping also improves the digestibility of starch as it involves gelatinization of starch and degradation of dietary fibres. Jaybhaye et al. (2014) studied that popping and puffing can be accomplished by using dry heat such as sand roasting, roasting using salt, gun puffing, hot oil frying, using heating medium such as hot air or microwave radiation. Hoke et al. (2005) reported that in India, the most frequent way is, puffing in hot sand (temperature of sand is about 250°C) or in oil (200-220°C).

2.5 Preparation of puffed rice

Regardless of the puffing process two important parameters should be taken into account: the selection of an appropriate sort of rice, and the use of a proper hydro-heat treatment of raw rice. Raw rice (paddy) is the rice in the husk. Raw rice wetted in water, heated in steam and dried is treated rice (special steamed rice). Wetted rice heated in sand is rice treated with dry heat. Milled rice is partially or fully free of the hull. The corresponding milled rice is regarded as treated by heat in steam or by dry heat.

Paddy rice grains are soaked in warm water overnight and the soaked grains are then roasted in sand on a Bhatti in small batches to produce dry-heat parboiled paddy rice grains. The paddy rice grains are allowed to dry in mild sun or in air after spreading out. The dried paddy grains are then milled in a huller. The milled parboiled grains are gently heated on the Bhatti without sand to reduce the moisture content to the appropriate level, then taken out and mixed with a proper amount of salt solution. After holding for some times, the parboiled rice grains are again roasted on the Bhatti in small batches with sand on a strong fire for a few seconds to produce the puffed rice.

Chinnaswamy and Bhattacharya (1983) founded that dry-heat parboiling gives better puffing expansion of rice than steam parboiling, and pressure parboiling gives better puffing expansion than dry-heat parboiling. This improved process has been developed by the Central Food Technological Research Institute, Mysore, India. Paddy rice grains are first washed with water, followed by pressure parboiling at 2.0–2.5 kg/cm2 for 15 min. The parboiled grains are then dried either in sun or mechanical drier and milled. Before puffing, the parboiled grains are mixed with saturated salt solution (3–4 mL of saturated salt solution per 100 g of rice grains), and thereafter the moisture content of parboiled grains is brought down to 10.5%–11.0% and puffed in 10 times of its weight with sand at 250 °C for 10–11 s. Pressure parboiled rice gives slightly coloured puffed rice. To reduce the colour, the paddy grains are washed with 2% sodium bisulfite solution. Hoke et al (2005) reviewed the optimum conditions set for different types of rice puffing (dry-heat, microwave and gun-puffing) from different works. Chinnaswamy and Bhattacharya (1983); Villareal and Juliano (1987) reported that effects of amylose and protein content are also evident in the quality of puffed rice, suggesting varietal differences to be considered for puffing rice. A more recent and sophisticated analysis on the same variety by Mahanta and Bhattacharya (2010) clarified the earlier doubts on the variable product qualities with processing conditions. The study indicated that the puffing is promoted by gelatinization and amylose-lipid complex formation, and retarded by amylase retrogradation and probable starch breakdown due to high temperature conduction heating. Addition of different salt solution increases the puffing ability of rice (Chinnaswamy and Bhattacharya, 1983; Murugesan and Bhattacharya, 1986). Presently, use of microwave for puffing has also gained much popularity. Maisont and Narkugsa (2010) studied the effects of salt, moisture content and microwave power on puffing qualities of a variety of waxy rice. The authors tried various combinations of the three parameters and found that the most suitable combination of 2% salt solution, 13% moisture content and microwave power of 700 or 800 W give the optimum product with high puffed yield and expansion volume with moderate hardness.

Juliano and Sakurai (1985) and Villareal and Juliano (1987) found that flaked or beaten brown rice and parboiled milled rice may be converted to puffed rice by heating in hot air or roasting in hot sand. During puffing, rice kernels increase their volume several times and a fully heat-treated crisp, porous, ready-to-eat product is created. Regardless of the puffing process two important parameters should be taken into account: the selection of an appropriate sort of rice, and the use of a proper hydro-heat treatment of raw rice. Murugen and Bhattacharya (1991); Hoke *et al.* (2005); Moisont *et al,* (2010) reported that the optimum moisture content for puffing of rice for puffing expansion in most of the studies found to be 13-14%. Salt solution is invariably added to milled rice before it is heat expanded in the industry. The effect on expansion was investigated (Chinnaswamy and Bhattacharya, 1983a). Salt appreciably increased the expansion ratio. Interestingly, not only sodium chloride but also other salts had the same effect. Gerkens and D'arnaud (1963) in his studies of the heat expansion of cooked starch postulated that salt helped the expansion by facilitating the heat conduction inward and the exit of moisture outwards. Murugen and Bhattacharya (1991) found that soaking paddy in 2 % common salt (NaCl) solution increased the expansion by about 15%. Their finding was supported by Chandrasekhar and Chattopadhyay (1991) and Hoke *et al.* (2005).

Juliano and Sakurai (1985) reported that puffed and popped rices are traditional breakfast cereals and snack foods. Raw rice is traditionally popped by heating rough rice (13 to 17 percent moisture) at about 240°C for 30 to 35 seconds or at 275°C for 40 to 45 seconds or in an oil bath at 215 to 230°C. Srinivas and Desikachar (1973) found that the hull contributes to pressure retention before popping as evidenced by the lower popping percentage of brown rice. Good popping varieties have a tight hull and a significant clearance between hull and brown rice and when freshly harvested are free of grain fissures. Murugesan and Bhattacharya (1991) suggested that tightness of hull, grain hardness and degree of translucency could explain 80 percent of the variation in popping expansion among 25 rice varieties.

Chang and Chien (1997) found that the microwave popping ratio and expansion volume of dried rice increased with an increase of the storage time and also the amounts of alcohol or sodium chloride added. Mohapatra and Das (2011) have reported puffing of pre-conditioned rice using different levels of microwave energy (combination of power levels and time). It was reported that the puffing quality of rice depends on input energy and salt level in the kernels. An energy level of 29.21 kJ (880 W and 33.1 s) and salt concentration of 4.6 % was found to be optimum for puffing percentage and expansion ratio of 98.26% and 5.826, respectively. Chinnaswamy and Bhattacharya (1983a) gave the basic flowchart of puffing rice produced by traditional method (Figure 2.1).

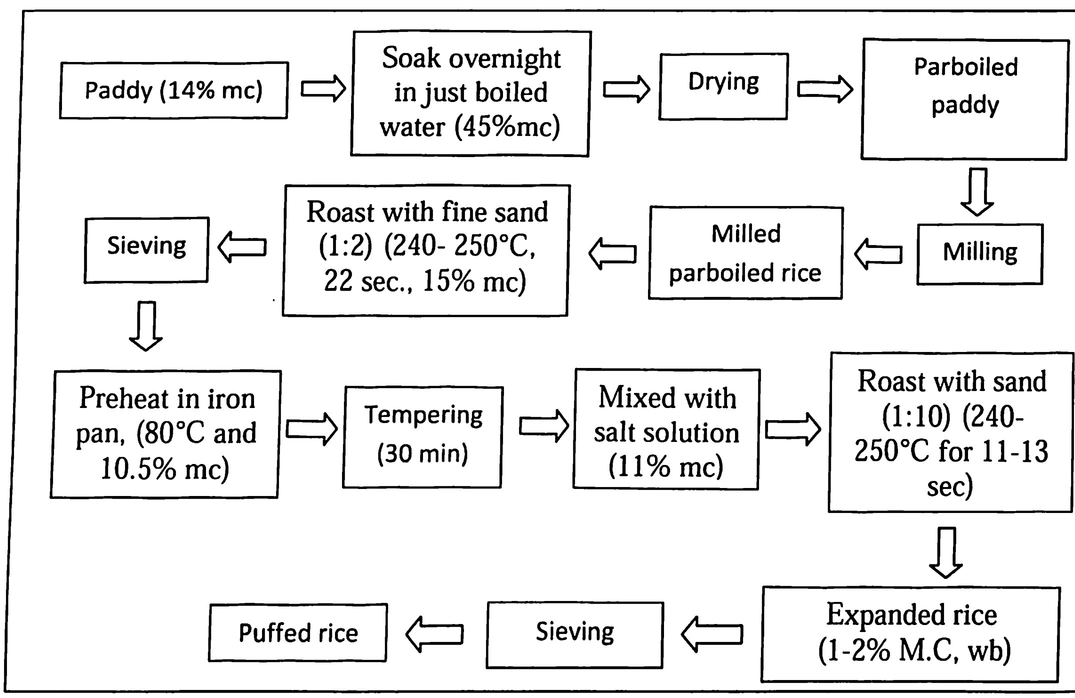

Figure 2.1 Process flow chart of expanded rice making in a local industry in Mysore (Chinnaswamy and Bhattacharya, 1983a)

2.6 Jaggery

Gur (Jaggery) is a natural, traditional sweetener made by the concentration of sugarcane juice and is known all over the world in different local names. It is a traditional unrefined non-centrifugal sugar consumed in Asia, Africa, Latin America and the Caribbean. Containing all the minerals and vitamins present in sugarcane juice, it is known as healthiest sugar in the world. India is the largest producer and consumer of jaggery. Out of total world production, more than 70% is produced in India.

In India, of the 300 Mt of sugarcane produced, 53% is processed into white sugar, 36% into jaggery and khandsari, 3% for chewing as cane juice, and 8% as seed cane. Jaggery and khandsari have withstood competition protecting farmers' interests besides meeting ethnic demands. Processes and equipments have been developed for quality solid, liquid and powder jaggery. Liquid jaggery has been commercialized. The organic clarificants developed help to retain jaggery as organic food.

Jaggery is prepared by concentrating the sugarcane juice and it is available in the form of solid blocks and in semi-liquid form. Besides this, the sap collected from some palm trees such as palmyra-palm (*Borassus flabellifer* L.), coconut-palm (*Cocos nucifera* L.), wild datepalm (*Phoenix sylvestris* Roxb.) and sago-palm (*Caryota urens* L.) is used for preparation of jaggery. For ease of handling, packaging and storage, jaggery in granular form is becoming popular. The hygroscopic nature of granulated jaggery product lead to stickiness and caking problems.

2.6.1 Processing of jaggery

Gur (jaggery) manufacturing starts from October and continues up to May, depending on the location and is stored both for marketing and human consumption during the remaining part of the year. However, the manufacturing process depends on the ultimate form to be produced. Also the processing of jaggery varies widely from state to state, in the state from one district to another and some cases within the district also. Jaggery making from sugarcane involves mainly four unit operations *viz.*, juice extraction, juice clarification, juice concentration by boiling/heating; cooling of concentrated juice followed by molding and storage, and the process flow is as shown in flow chart (Figure 2.2).

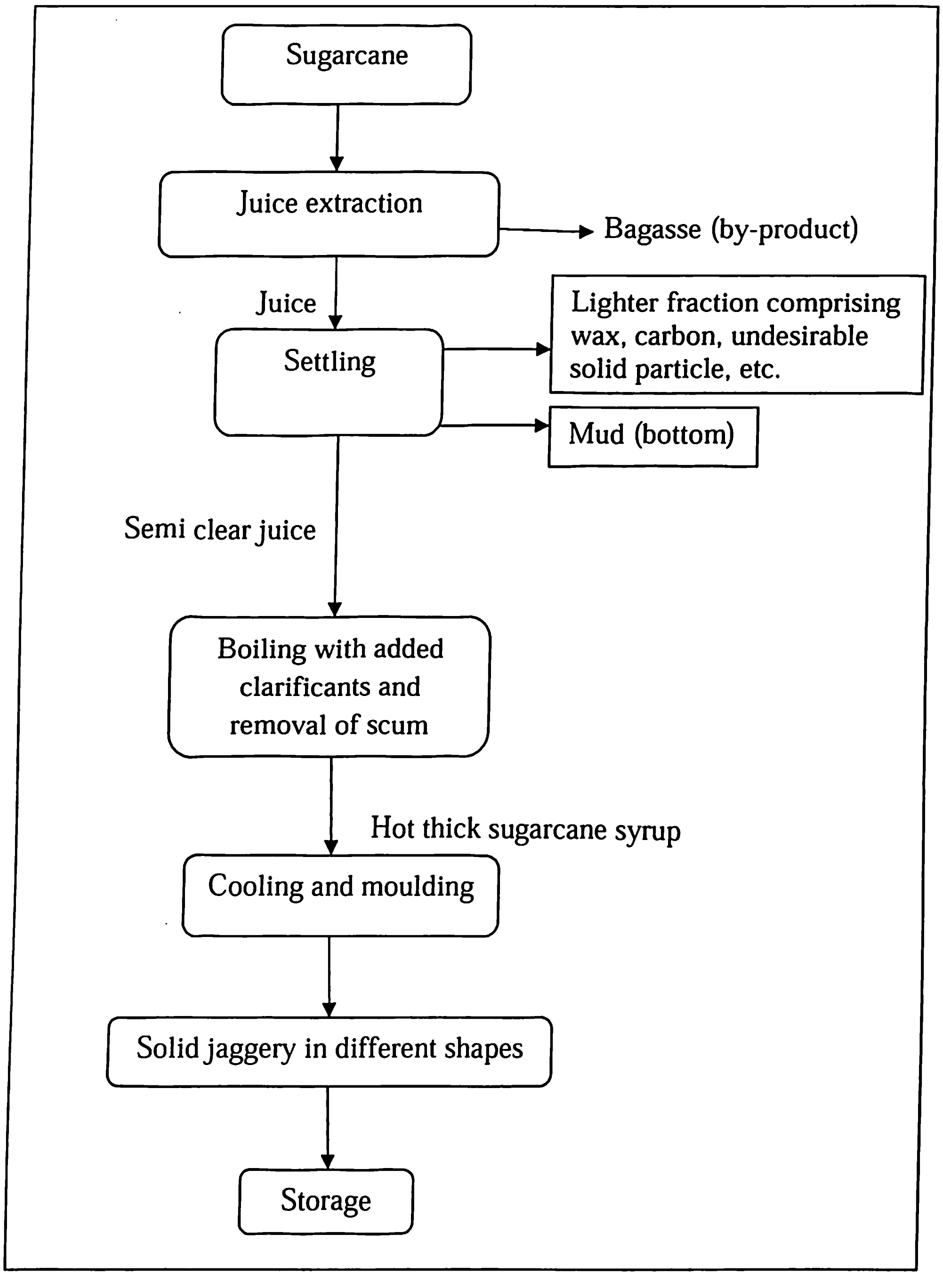

Fig 2.2 Process flow chart for solid jaggery manufacture (Rao et al., 2007 and Singh et al. 2011)

The unit operations involved in jaggery manufacturing is described as below:

Juice extraction

Juice extraction by crushing sugarcane is first step towards jaggery manufacturing. Usually, 2-5 roller crusher is used for extraction of juice which may be power operated (engine/electric) or animal driven vertical/horizontalcrusher. Vertical three roller crusher has the juice extraction efficiency of 50-55%, whereas same for horizontal crusher has 55-60%. Therefore, horizontal crusher is preferable. The juice extraction (%) depends upon crusher setting, crop parameter and operating conditions.

Juice clarification

The extracted juice collected through underground PVC pipeline into a masonry-settling tank covered with muslin cloth for removal of heavy impurities and rested for few minutes for separation of light and heavy particles. The clear juice is then drawn from a middle port of settling tank and pumped into boiling pan kept on furnace to fill 1/3rd of its capacity for concentration. In general, jaggery quality, storability and its acceptability depends on the clarity of the juice used in preparation. The clarification is mostly done during boiling stage. It is mostly done by using lime (Calcium hydroxide) which not only clarifies juice but also improves the consistency of jaggery by increased crystallization of sucrose, but at same time it darkens the colour if added in excess. Among the other chemical clarificant, hydros superphosphate, phosphoric acid, chemiflocks and alum are reported. Vegetative clarificants like mucilage's of *bhendi, chikani, kateshevari*, deola (*Hibiscus ficulneus*), etc. were used in early period. Out of these vegetative clarificants deola was found to be the most effective (Singh, 1998 and Banerji, 2008). The application of synthetic clarificants *viz.*, *Bhendi* powder or SN2 @ 2 mg/litre (2 ppm) with *bhendi* plant @ 2 kg per 100 litre of sugarcane juice is recommended for maximum removal of scum, improving the colour and higher jaggery recovery and also helpful in maintaining quality of jaggery during storage (Patil et al., 2005).

Juice concentration

The boiling of sugarcane is second important stage. After clarification, juice is boiled vigorously over the furnace. It is usually done using bagasse of cane as a fuel. A little quantity of oil (ground nut/mustard/coconut) is added to prevent excess frothing which facilitates easy flowing of hot syrup during transfer from one container to another. However, based on requirement of jaggery production, furnace design varies from place to place *i.e.* the furnace may have 1-5 pans. In coastal region of Andhra Pradesh, one pan is placed on the furnace, while 2 to 3 pans are placed in Rayalaseema and Telangana region, respectively. Such variation is also found in other states also. The overall heat utilization efficiency of the traditional type furnaces used by farmers is very low and needs drastic improvement. Indian Institute of Sugarcane Research (IISR), Lucknow has developed improved/efficient two and three pan furnace which saves bagasse (Singh *et al.*, 2009; Singh, 2009). The two pan furnace having fins at the bottom improves the efficiency and also saves fuel (28%) and juice processing time (17%) (Anwar, 2010; Anwar et al., 2009). The triple pan furnace developed by IISR, Lucknow has heat utilization efficiency of 34.3% which is obtained by trapping waste heat going along flue gases through chimney and is utilized for pre-heating of juice. The boiling is continued for 2-2.5 hr till the juice attains temperature of 118°C. The end point is judged by taking a small quantity of hot syrup from the pan, cooling it in cold water taken in a container, and finally shaping with finger. If shape is formed it means that the pan can be removed from the furnace. The moisture content of this syrup is somewhat higher than 10-12% (d.b.)

Molding

Properly concentrated juice with appropriate consistency i.e. hot syrup is worked out for some time and then allowed to solidify by transferring into a wooden tray and puddle using ladle. The concentrate is then transferred in to the mould of desired shape for shaping purpose. The shape of jaggery varies with place to place; some common shape preferred in different parts of country like, rectangular (0.25-1 kg), bucket shaped (10-20 kg), trapezoidal lumps (5 kg), round balls, etc. Some these shapes are complicated and create problem while molding, drying, packaging and distribution, etc. IISR lucknow has developed different molding frames and techniques for molding jaggery in to different shapes and sizes *viz.*, brick (250 and 500 g), cubes (20-25 g) and rectangular (10-11 g).

2.6.2 Methods of manufacturing

Jaggery is produced in three forms viz solid, liquid and powder or granular form, which is briefly dealt in as under. In India, approximately 80 per cent of jaggery prepared is solid jaggery (in the form of solid structure) and remaining 20 per cent includes liquid and granular jaggery.

Solid jaggery

The filtered cane juice is pumped into open pans kept on triple pan furnace (Figure 2.3), and heated with the begasse as fuel. The juice is clarified with herbal clarificant (deola extract @ 45 g/100 kg juice), to make light coloured jaggery by eliminating impurities in suspension, colloidal and colouring compounds by accumulation. The juice is then boiled and concentrated to make jaggery in desired shape and size (Figure 2.3 and 2.4).

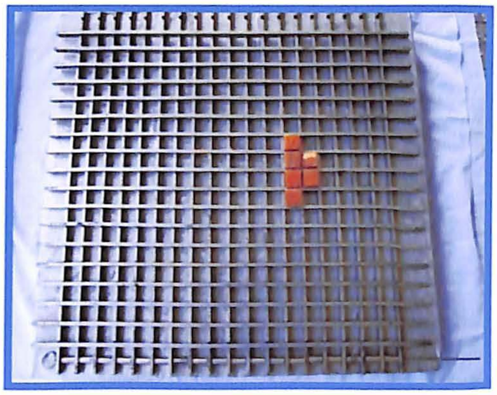

Plate 2.1 Triple pan furnaces in operation **Plate 2.2 Moulding frame**

Plate 2.3 Cubical jaggery

Liquid jaggery

It is an intermediate product obtained during concentration of purified sugarcane juice during jaggery making, and is semi liquid syrup like product. The quality of liquid jaggery largely depends upon quality and composition of cane juice, type of clarificants used, and striking temperature at which concentrating juice is collected. For quality liquid jaggery, the juice concentrate is removed from boiling pan, when it reaches striking point temperature of 103-106°C, depending upon the variety and agro-climatic zone. To avoid crystallization and to make liquid jaggery attractive in colour, citric acid is added @ 0.04% (400 mg/kg of liquid jaggery), whereas to improve shelf life of liquid jaggery without deterioration in quality, potassium metabisulphite @ 0.1% (1 g/ kg of liquid jaggery), or Benzoic acid @ 0.5% (5 g/kg of liquid jaggery), is added. Liquid jaggery is then allowed to settle for period of 8-10 days at ambient conditions. Later after filtration, it is properly packaged in sterilized bottles. Chemical composition of typical liquid jaggery could be: water 30-36%, sucrose 40-60%, invert sugar 15-25%, calcium 0.30%, iron 8.5-10 mg/100 mg, phosphorus 05/100 mg, protein 0.10/100 mg, and vitamin B 14/100 mg.

Granular jaggery

The process of making granular jaggery is similar up to concentration. The concentrating slurry is rubbed with wooden scrapper, for formation of grains. The granular jaggery is then cooled and sieved. Less than 3 mm sized crystals are found to be better for quality granular jaggery. Rising of pH of cane juice with lime, up to 6.0-6.2, and striking point temperature of 120°C was found to yield quality granular jaggery with high sucrose content of 88.6%, low moisture of 1.65%, with good colour, friability and crystallinity. Jaggery in the form of granules (sieved to about 3 mm), sun dried and moisture content reduced to less than 2%, and packed in polyethylene polyester bags or polyethylene bottles, can be stored for longer time (more than two years), even during monsoon period with little changes in quality. Colour of jaggery powder can range from golden yellow to golden brown dark brown like dark chocolate. The colour is often dependent on base ingredient used to make jaggery powder. It is softer than sugar and also amorphous. This is because vitamins proteins and ingredient of cane are not removed. It is made up of predominantly sucrose mineral salts iron.

2.6.3 Importance of jaggery

Jaggery is far complex than sugar, as it is made up of longer chains of sucrose. Hence, it is digested slower than sugar and releases energy slowly and not spontaneously. This provides energy for a longer time and is not harmful for the body. But this does not certify it fit for consumption by diabetics, because ultimately it is sugar. Jaggery also gathers a considerable amount of ferrous salts (iron) during its preparation, as it is prepared in iron vessels. This iron is also good for health, particularly for those who are anaemic or lack iron. Again, jaggery also contains of traces of mineral salts (you might have experienced this, that jaggery leaves a hint of salt on tongue) which are very beneficial for the body. These salts come from the sugar cane juice where it is absorbed from the soil. Furthermore, jaggery is very good as a cleansing agent. It cleans lungs, stomach, intestines, oesophagus and respiratory tracts. Those who face dust in their day to day life are highly recommended to take a daily dose of jaggery. This can keep them safe from asthma, cough & cold, congestion in chest etc. Gur is known to produce heat and give instant energy to a human body. In many parts of India, there is a tradition of serving a glass of water with gur to welcome the guests. Gur is also used as a cattle feed, in distillery, medicine manufacturing unit, ayurvedic medicines, ayurvedic sura and ayurvedic health tonics. Recently gur has also found a place in confectionary items. Another usage of gur is also seen in leather and tobacco industries. Besides, in cement industries and coalmines, gur is supplied to the workers in order to protect them from dust allergies. And at the time of natural calamities, the district administration purchases gur and distributes it to the victims for various health benefits.

Table 2.1: Composition of 100 g of jaggery

Carbohydrates g		**Vitamins mg**	
Sucrose	72-78	Provitamin	2.D
Fructose	1.5-7	Vitamin A	3.8
Glucose	1.5-7	Vitamin B1	0.01
Minerals mg		Vitamin B2	0.06
Calcium	40-100	Vitamin B5	0.01
Magnesium	70-90	Vitamin B6	0.01
Phosphorous	20-90	Vitamin C	7.00
Sodium	19-30	Vitamin D2	6.50
Iron	10-13	Vitamin E	111.30
Manganese	0.2-0.5	Vitamin PP	7.00
Zinc	0.2-0.4	Protein	280 mg
Chloride	5.3-0	Water	1.5-7g
Copper	0.1-0.9	Calories	312

2.6.4 Nutritional quality and uses of jaggery

It is rich in important minerals (*viz.,* Calcium-40-100 mg, Magnesium-70-90 mg, Potassium-1056 mg, Phosphorus-20-90 mg, Sodium-19-30 mg, Iron-10-13 mg, Manganese-0.2-0.5 mg, Zinc-0.2-0.4 mg, Copper-0.1-0.9 mg, and Chloride-5.3 mg per 100 g of jaggery), vitamins (viz., Vitamin A-3.8 mg, Vitamin B1-0.01 mg, Vitamin B2-0.06 mg, Vitamin B5-0.01 mg, Vitamin B6-0.01 mg, Vitamin C-7.00 mg, Vitamin D2-6.50 mg, Vitamin E-111.30 mg, Vitamin PP-7.00 mg), and protein-280 mg per 100 g of jaggery, which can be made available to the masses to mitigate the problems of mal nutrition and under nutrition. The micronutrients present in the jaggery possess antitoxic and anti-carcinogenic properties. It has moderate amount of calcium, phosphorous and zinc, so it helps to optimum health of a person along with all its benefits, purifies the blood and prevents rheumatic afflictions and bile disorders and thus helps to cure jaundice. Gur is high calorie sweetener and as it contains minerals, protein, glucose and fructose, it is known to be healthier in comparison to white sugar. A good quality Gur contains more than 70% sucrose, less than 10% of glucose and fructose, less than 5% minerals and less than 3% moisture.

In India, it is mainly used as an ingredient in sweet and savoury dishes. Further, its use in many herbal and traditional medicines. In Ayurvedic way of medicine, it is used as medicine, blood purifier and base material for syrups. Jaggery is among major agro processing industries in India. Nearly 20-30% of total sugarcane produced in the country is used for manufacture of about 7 million tonnes jaggery, which is known as most nutritious agent among all sweeteners. This sector provides employment to about 2.5 million people. It is therefore, imperative to expand the sector, as it provides higher food value jaggery at lower cost and boosts-up the rural economic system, involves low transportation cost of raw material, and non requirement of highly technical machinery and labour. Jaggery still dominates in preparation of various products like- reori, gazak, chikki, patti and ramdana, etc. of ancient origin. Kakavi (liquid jaggery) is part of daily diet in most parts of Maharashtra, and has been gaining commercial importance in India. Jaggery is rich in important minerals like salts: 2.8 g/100 grams, whereas only 300 mg/kg is obtained in refined sugar.

Singh et al. (2011) mentioned the importance of jaggery in India in their paper entitled 'Alternative sweeteners production from sugarcane in India: Lump Sugar (Jaggery). They stated that sugar and jaggery are the main sweetening agents which are added to beverage and foods for increasing palatability. Over the years, food habits of human beings have been greatly influenced by research and developmental activities and also due to their health consciousness. Despite witnessing pressure of industrialization, the jaggery industry has flourished in different states of the country viz., Uttar Pradesh, Tamilnadu, Karnataka, Maharashtra and Andhra Pradesh. The increasing trend of their production is of much significance to learn about peoples' liking towards jaggery in rural areas mainly due to its nutritional and medicinal values. Due to its nutritional and medicinal values, the jaggery has great export potential in the world.

Rama Rao and Babu (2011) studied to work-out costs and returns in value added products of sugarcane viz., sugar, jaggery and sugarcane juice, in order to suggest the sugarcane growers the profitable and sustained way to deal with sugarcane. The results revealed that cost of cultivation of sugarcane is the prime factor in the various value added products. Among the value added products, sugarcane juice production was found more profitable, which needs further study of technical and financial feasibility of keeping quality in order to produce on large scale. Lack of infrastructural facilities in jaggery production and insufficient price dissemination in jaggery marketing were major constraints faced by jaggery manufacturers in India.

Dwivedi (2010) reported that Kushinagar district of Uttar-Pradesh has large number of gur manufacturing units, mostly located in the rural areas and the manufacturers are following conventional methods for producing this. In the district the major clusters which are having more numbers of manufacturing units are Sukraouli, Kasia, Hata and Padarauna. Around half of the rural population is employed in gur making industry in this region. Although, there is no R & D assistance and marketing institutions for support. It is found that the manufacturers are producing majorly for distilleries and local licker producers, not for the food plate or common man's consumption. The study revealed that units of medium and large sizes were able to cover their operating expenses with significant level of profit but small size units were earning marginal profit. The profit earned by this category was very low as compared to other two sizes. The manufacturers are not interested in any new product of gur, they just want to earn more profit through gur only. This research urged the policymakers to streamline strategies that promote stabilization of sugarcane economy and make the nation credible supplier of gur in the international market, benefiting gur makers, sugarcane growers and related stakeholders.

Nain et al. (2002) reported that jaggery production was a major traditional enterprise in sugar cane producing areas. At times, jaggery making was profitable to cane producers, than supply to sugar factory. The cost of sugarcane was the major cost item in jaggery production. The investment in jaggery processing units was found to be profitable. Ramaswamy et al. (1999) stated that jaggery making is a traditional enterprise in Tamil Nadu and is more profitable to cane producers than supply to the factory. But, higher profitability is counter veiled by price risk in jaggery. Traditionally, jaggery making is under taken by cane growers in their own farm. The trend has changed with the entry of new enterprisers who venture jaggery manufacturing as a pure enterprise by procuring cane from the cane growers. The substantially higher price, immediate disbursements for the sale of cane, missing the registration in time with factory, delays in cutting order and complex procedure of transactions with the factory make the cane growers favour cane supply to jaggery making. Absence of price risk, labour shortage in the case of own jaggery making, financial and technical assistance extended by the factory are the major factors attracting supply of cane to factory.

2.6.5 Value addition in jaggery

Jaggery may be value added with different natural flavour (ginger, black pepper, cardamom, lemon etc.), nutrition (protein, vitamins and phytochemicals), texture (additives) and taste (additives like nuts, spices, cereal and pulses). Moreover, different value added products are prepared traditionally using jaggery instead of sugar viz., rosagolla, peda, curd, laddu (puffed cereal, nuts and sesame etc.) but no scientific literatures as well as process technologies are available for commercial exploitation.

Anwar et al. (2011) developed a vitamin C enriched jaggery powder by adding through a natural source *viz.*, cut pieces of amla fruits and dried up to 10% moisture content was found to be the best, followed by samples with grated and fine powder form of amla, as indicated through sensory evaluation. Replacement of sugar in the product formulation of "Bomboyson" by jaggery was studied by Gartaula and Bhattarai and they reported that replacing the sugar content by jaggery did not alter the overall acceptability (OA) of the product and there is increase in the mineral content of the product. The product could be stored safely up to 28 days at 5°C and 21 days at 25°C. Other uses include jaggery toffees and jaggery cake made with pumpkin preserve, cashew nuts, pea nuts and spices. Jaggery may also be used in the creation of alcoholic beverages like palm wine.

2.7 Flaxseed

Flaxseed, or Linseed (*Linum Usitatissimmum*), popularly known as Alsi (hindi), pesu, adasi (odia) in Indian languages, is a blue flowering rabi crop and a member of family Linaceae. Annual production of flax was 3.06 million tons and Canada is the world's largest producer of flax (about 38% of total production) (Anonymous, 2000). Globally, Flaxseed is grown as either oil crop or a fiber crop with fiber linen derived from the stem of fiber varieties and oil from the seed of linseed varieties (Diederichsen *et al.*, 2003; Vaisey-Genser *et al.*, 2003). The plant is native to west Asia and the Mediterranean. As the source of linen fiber flax has been cultivated since at least 5000 BC, today it is mainly grown for its oil (Berugland, 2002; Oomah, 2001). The spherical fruit capsules contain two seeds in each of five compartments. The seed is flat and oval with a pointed tip. It have smooth glossy surface. It varies in color dark brown to yellow (Freeman, 1995). The texture of flaxseed is crisp and chewy possessing a pleasant nutty taste (Carter, 1996). Beyond its oilseed crop ability, proximate composition of flaxseed makes it more promising for its utilization in different food products. Flaxseed is one of the richest vegetarian source of α- linolenic acid (omega 3 fatty acid) and soluble mucilage. In present era, consumer's trend towards functional food has increased significantly as health awareness rose. Use of flaxseed can be one step for novel high quality source of nutrition.

2.7.1 Functional elements of flaxseed

Flax typically has a small seed 3-6 mm in length and 2-3.5 mm width and 1 mm thickness. It is unique among cultivated seed plants with its contents of specific carbohydrates, proteins and lipids. By far the most human nutritional interest in this seed has focused on the carbohydrates, in the form of fibers, and on the lipids, especially the essential alpha-linolenic acid (ALA). The nutritional elements of flaxseed are presented in Table 2.2.Flaxseed contains a seed coat or true hull, an embryo or the germ, a thin endosperm and two cotyledons. The seed coat, together with endosperm form five layers and contributes 36 % of the total weight of the seed.

From outside to inside, there is the epidermis or the mucilage cells, round cells, fibers, crosscells, and pigment cells that give seeds their color. A thick shiny cuticle covers the seed coat. Flaxseed contains 35-45 % of fiber of which two-thirds is insoluble and one-third soluble. Insoluble fiber consists of cellulose, hemicellulose and lignin. Soluble fiber is in the form of mucilaginous material composed of polysaccharides. The majority of these polysaccharides are of non-starch type, similar to guar gum, with major relative composition of gel forming carbohydrates (rhamnose + fucose, xylose, galactose and uronic acids). The optimal pH range for viscosity of flaxseed mucilage is 6-8, the pH environment in human intestines.

Table 2.2: The composition of ground flaxseed (partly defatted, cold-pressed with 20% of oil left)

Compound/Property	Amount/100g of flaxseed
Water insoluble fiber	33.2 g
Water soluble fiber	11.0 g
Total pentosanes	8.1 g
Water soluble pentosanes	1.2 g
Beta-glucan	0.38 g
Total phosphatides	1.3 g
Lecithin	0.8 g
Protein	26 g
Fatty acids - α-linolenic acid - linoleic acid - oleic acid	20 g 13.2 g 2.8 g 2.0 g
Water binding capacity	8.3 ml/g

Source: Report of analysis. Technical Research Center of Finland, Biotechnology, 1995

2.7.2 Proximate composition of flaxseed

Morris(2003) reported that flax is rich in fat, protein and dietary fibre. An analysis of brown Canadian flax averaged 41% fat, 20% protein, 28% total dietary fibre, 7.7% moisture and 3.4% ash, which is the mineral-rich residue left after samples are burned. Daun et al. (2003) found that the composition of flaxseed can vary with genetics, growing environment, seed processing and method of analysis. Daun and DeClercq (1994) mentioned that the protein content of the seed decreases as the oil content increases. The oil content of flaxseed can be altered through traditional plant breeding methods, and it is affected by geography – the cool nights of northern Canada improve oil content and quality. Brown and yellow (Omega) varieties of flaxseed are virtually identical in their nutrient content (Morris, 2003). Seed coat colour is determined by the amount of pigment present, a feature that can be changed through normal plant breeding practices. Consumers can buy brown or yellow flaxseed based on price and appearance of the flaxseed containing food product, since the nutritional value of brown and yellow flax is similar. Flaxseed oil and canola oil have the lowest levels of the nutritionally undesirable saturated fatty acids. The level of the desirable monounsaturates in flax oil is modest.

2.7.3 Flaxseed as a source of ALA (Omega-3 fatty acid)

Hurteau (2004) suggested that there are two groups of omega fats: omega-3 and omega-6 fatty acids. Linolenic acid, eicosapentaenoic acid (EPA) and docosahexanoic acid (DHA) are three types of omega-3 fatty acids and are nutritionally important. All three fatty acids have been shown to reduce the risk of cardiovascular disease. Bozan and Temelli (2002) reported that flax contains a mixture of fatty acids. It is rich in polyunsaturated fatty acids, particularly ALA, the essential omega-3 fatty acid, and linoleic acid (LA), the essential omega-6 fatty acid. These two polyunsaturated fatty acids are essential for human i.e. the body needs them Supercritical CO_2 extraction gave a higher average ALA content (60.5%) compared to the soxhlet extraction method (57.7%). ALA and Linoleic acid constitutes 57% and 16.0 % of total fatty acids respectively in flax making the richest source of ALA. ALA from flaxseed exerts positive effect on blood lipids.

Reddy and Chetana (2010) experimented on preparation and quality evaluation of peanut chikki incorporated with flaxseeds and found the addition of flaxseeds to chikki increased PUFA content, especially n-3fatty acids, up to 9%, which were not present in chikki prepared only with peanuts. Thus the ratio of 18:2 to 18:3 increased with addition of flaxseed, which has significant health benefits. Byrappa et al. (2011) worked on processing, physico-chemical, sensory and nutritional evaluation of peanut chikki. They compared the storage stability and quality parameters of enriched chikki. Mala et al. (2014) studied the nutritional quality, storage stability and sensory evaluation of the pumpkin seed chikki incorporating flaxseed, oats and peanut.

Ranhotra et al. (1992) noted that flaxseed oil or blends of flaxseed oil and sunflower oil promoted cholesterol reduction in hypercholesterolemic rats compared to diets formulated with hard fats. These authors suggested that a diet with the appropriate balance of n-6 and n-3 fatty acids was preferred over diets high in n-6 fatty acids. Oomah and Maza (1998) reported that ground flaxseed is high in omega-3 fatty acids which have been shown to reduce hypertension, cholesterol and triglyceride level. Oikarinen et al. (2005) reported that flaxseed oil may be responsible for preventing colon carcinogenesis in multiple intestinal neoplasia (Min) mice. Dwivedi et al. (2005) also supported this finding that flaxseed oil prevented colon tumor development in rats. Presence of ALA in breast adipose tissue was inversely related to breast cancer risk (Maillard et al., 2002). ALA, being the essential fatty acid, requirement can be fulfilled by intake of flaxseed products (Morris, 2004).

2.7.4 Flaxseed as a source of protein

The protein content in flaxseed has been reported to between 10.5% and 31% (Oomah and Mazza, 1993). Khategaon cultivars grown in India had a protein content of 21.9% (Madhusudhan and Singh, 1983). Differences in protein can be attributed to both genetics and environment. The proximate protein content of dehulled and defatted flaxseed varied considerably depending upon cultivar growth location and seed processing. Hull fraction contains lower protein levels and that dehulling increases protein level of flaxseed protein level from 19.2% to 21.8% (Oomah and Mazza, 1997). Albumin and globulin type proteins are the major proteins in flaxseed. Flaxseed albumin comprised 20% of meal protein (Madhusudhan and Singh, 1983). Globulin fraction makes up to 73.4% and the albumin constitutes about 26.6% of total protein (Marcone et al., 1998). Flaxseed proteins are relatively high in arginine, aspartic acid and glutamic acid whereas lysine, methionine and cystine are limiting amino acid. Total amino acid content of the flaxseed after 8 days germination increased by 15 times with greatest increase (i.e. 200 times) being observed in glutamine and leucine compared to the original seed (Wanasundara et al., 1999). Oomah and Mazza (1995) compared the nutritional value of flaxseed meal with soybean meal and concluded that net protein utilization and protein efficiency ratio of flaxseed meal were slightly lower than soybean meal with the exception of protein scores, which were high in flaxseed meal.

2.7.5 Flaxseed as a source of dietary fibre (Mucilage or Gum)

Dietary fiber is a communal word used to describe a variety of plant substances that are not easily digested by the enzymes responsible for digestion in humans (Eastwood and Passmore, 1983). Diets rich in dietary fibre may help reduce the risk of heart disease, diabetes, colorectal cancer, obesity and inflammation (Morris, 2003). Flaxseed is a rich source of dietary fiber. Cui et al. (1994) reported that high amount of dietary fiber adds bulk to waste products in the gut and increases bile movement in the gastrointestinal movement. It exhibits natural laxative effect of dietary fiber. Flaxseed mucilage associated with hull of flaxseed is a gum like material composed of acidic and neutral polysaccharides. The neutral fraction of flaxseed contains xylose (62.8%) where as the acidic fraction of flaxseed is comprised mainly of rhamnose (54.5%) followed by galactose (23.4%).

2.7.6 Health benefits of flaxseed

The use of flaxseed as a dietary supplement is increasing in parallel with the research on its multitudinous effects on human health. Water-binding capacity of flaxseed insoluble fiber increases the intestinal bulk which is useful in the treatment of constipation, irritable bowel syndrome and diverticular disease. Soluble fiber from flaxseed mucilage delays gastric emptying, improves glycemic control, alleviates constipation and reduces serum cholesterol. Epidemiological studies show that the intake of dietary fiber and colorectal cancer correlate inversely. Flaxseed lignans and fatty acids have been investigated in several cohort studies for their effects on breast cancer risk and there is an association between elevated serum enterolactone and decreased incidence of breast cancer. The flaxseed diet has been shown to be beneficial on prostate cancer and benign prostate hyperplasia when defined by cell proliferation indexes and other cancer biomarkers. Alpha-linolenic acid seems to have an antiproliferative effect on prostate cancer cells. Elevated serum enterolactone level associates with a lower incidence of acute coronary heart disease. Respectively, low serum enterolactone enhances the risk for coronary deaths.

Chapter III

MATERIALS AND METHODS

Chapter-3

MATERIALS AND METHODS

The careful observation of literature on puffed rice value added products revealed that the research work conducted so far concentrated only on preparation of puffed rice laddu. Therefore, process parameters are required to be optimized for preparation of bar. Storage experiments for developed products were conducted and quality analysis was carried out to judge the storability. A low cost domestic level bar making unit has been planned to be designed and fabricated. The materials used and the methods followed for these studies have been described in this chapter.

3.1 Experimental plan layout

At the outset, the layout of the experimental plan has been prepared and presented in Figure 3.1.

3.2 Experimental design

In order to conduct the experiment in a systematic and efficient manner the entire experimental work was divided into various components. Before starting the experiment the independent variables and their levels were decided. The relevant parameters through which the inference of the experiment was to be predicted were selected as dependent parameters. Such plans were designed objective wise and are presented below.

3.2.1 Objective -1

Size of Bar: 5cm x 5cm x 3cm (fixed parameter)

Independent parameter:

1. Bar making device
2. Traditional
3. Individual mould

Dependent parameter:

1. Capacity, kg/h
2. Uniformity in size, %
3. Bulk density, g/cm^3

3.2.2 Objective -2

End point temperature (fixed parameter)

Independent variable:

1. Jaggery -80%, 90% and 100% of puffed rice (w/w)
2. Flaxseed - 10% , 20% and 30% of puffed rice (w/w)
3. Tamarind juice - 5ml, 10ml and 15ml per kg puffed rice

Dependent variable:

1. Mechanical properties- Firmness, toughness, compliance
2. Sensory properties- Taste, colour, flavour, crispiness, stickiness, overall acceptability

To optimize the process parameters Box-Behnken methods of response surface methodology has been used. Among mechanical properties firand among sensory overall acceptability have been considered as indices and used as response function. Total numbers of experimental combination were 15 and the design matrix has been provided in table 3.1 and 3.2 along with coded and uncoded values.

3.2.3 Objective – 3

Independent variable:

- Packaging material:
    1. Cellophane wrapping
    2. Low Density Poly Ethylene (LDPE) packets

- P_1: Bar wrapped with only cellophane paper
- P_2: Cellophane wrapped with LDPE sealing
- P_3: Cellophane wrapped and kept inside LDPE (not sealing)

- P$_4$: Without cellophane wrapped but LDPE sealing

- Storage period:

  2 days, 4 days, 6 days and 8 days

Dependent variable:

1. Colour, Flavour, Taste, Crispiness and Stickiness
2. Overall Acceptability (OA)

   (By composite scoring)

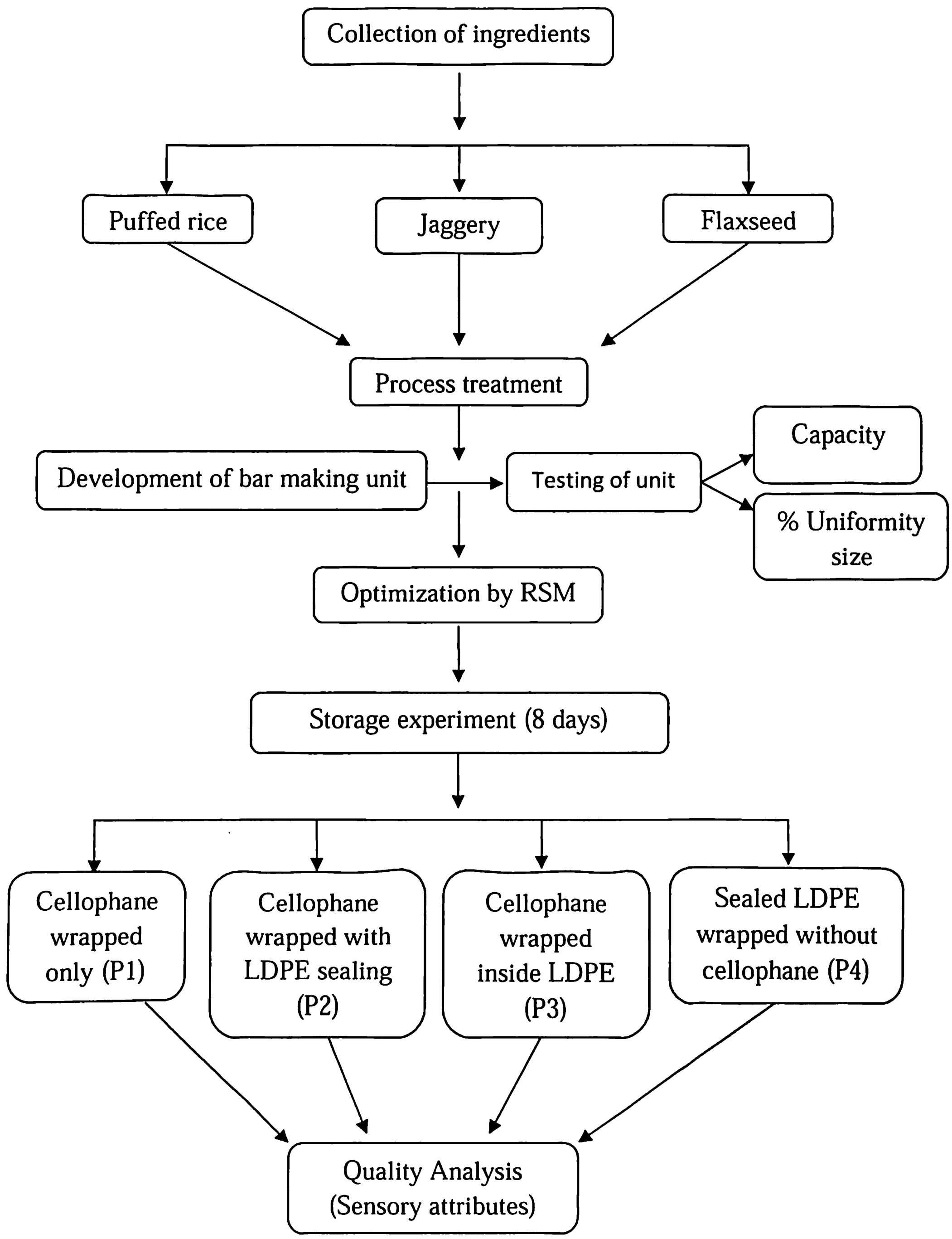

Figure 3.1 Layout of experimental plan

3.3 Experimental Procedure

3.3.1 Preliminary experiment

Before conducting the experiments information was collected from the traditional puffed rice laddu makers and the consumers. Traditional preparation method was noted down with respect to various unit operations, the ingredient composition and heat treatment requirements. Traditionally prepared laddu samples were collected and subjected to compression test in texture analyzer. The specific objective of these test were to determine the firmness of laddu and end point temperature of jaggery syrup during laddu preparation. Consumer preference was also analyzed for convenient size and shape of this value added products.

3.3.2 Design and Fabrication of bar making unit

A puffed rice bar making device was proposed to be developed so that a number of bars could be prepared in one batch. The developed bar making unit consisted of stainless steel compartment unit and a wooden pressing unit. The length, width and height of the device are 25.6×20.5×5cm respectively. The thickness of the sheet is 1mm. the device was composed of 20 compartments each with 5×5 cm internal dimension. One side of the unit has 5 compartments and the other side has 4. The height of each compartment is 5 cm out of which 2 cm is the extended portion on top in order to facilitate the required compaction (Figure 3.2). The wooden pressing unit was constructed out of a wooden sheet of (24.6×19.6 cm) with a thickness of 2 cm. the bottom side of the press was parted with mica so that it could be cleaned after each operation. The top of press was provided with a steel handle at the centre in order to apply uniform compaction throughout the unit (Figure 3.3). The capacity and percentage uniformity size are determined using the following formulae.

- $\text{Capacity (kg/h)} = \dfrac{\text{Number of bar} \times \text{Weight of each bar (kg)}}{\text{Time (h)}}$
- $\text{\% Uniformity size} = \dfrac{\text{Number of uniform shaped bar}}{\text{Total number of bar}} \times 100$

3.3 Experimental Procedure

3.3.1 Preliminary experiment

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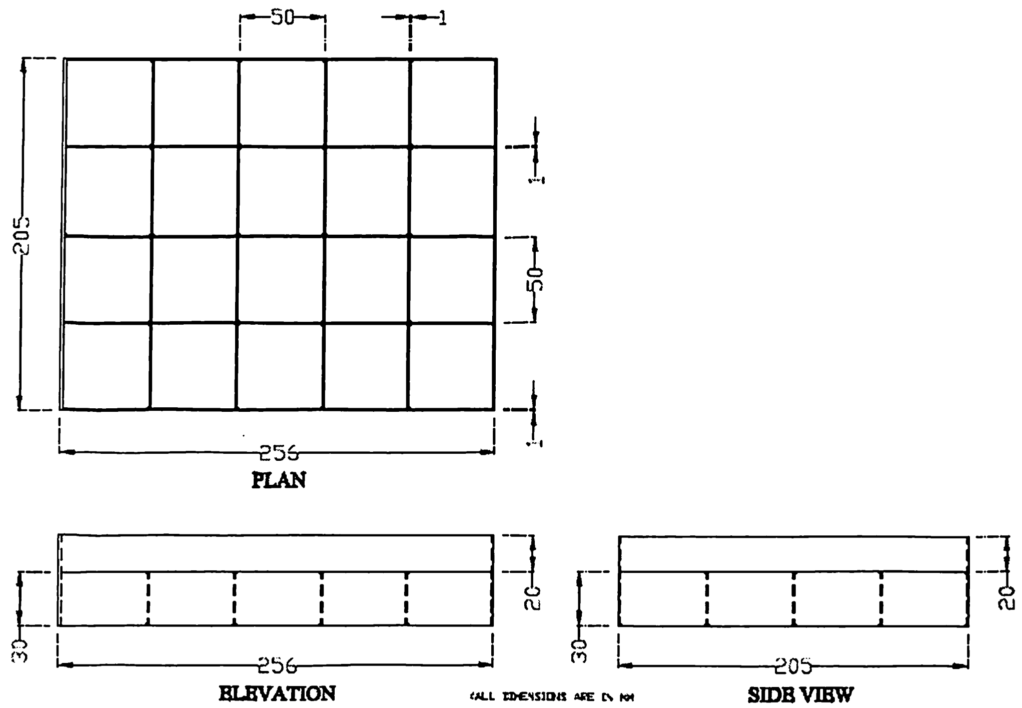


Figure 3.2 Design of stainless steel compartmental unit

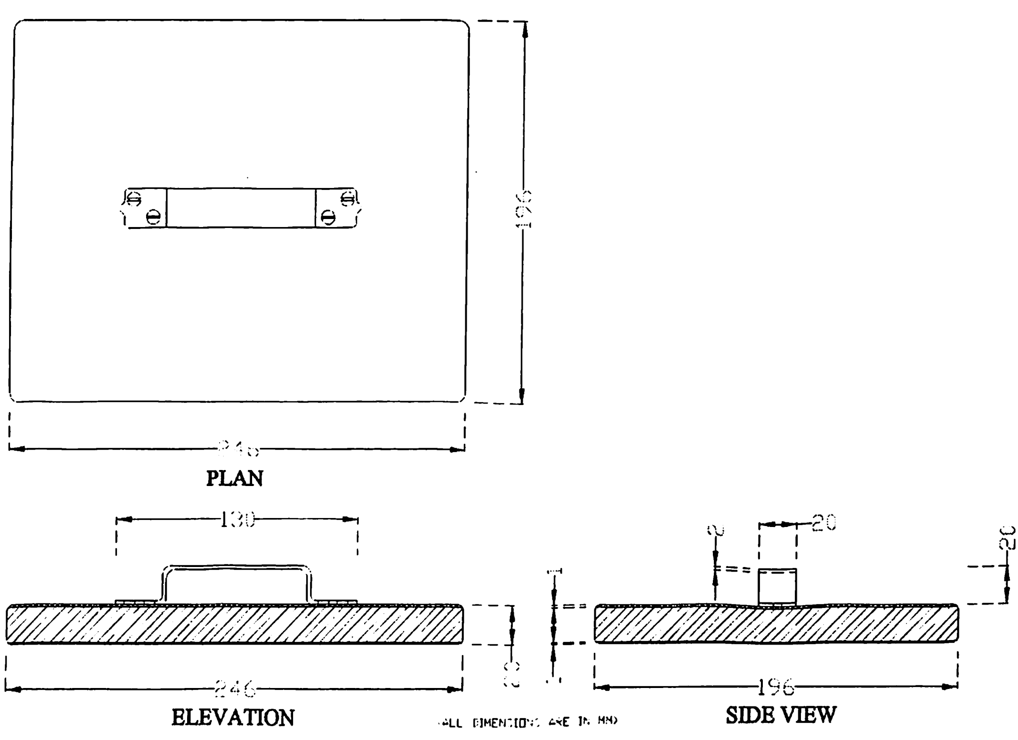


Figure 3.3 Design of Wooden pressing unit

3.3.3 Preparation of puffed rice bar

Puffed rice (patini) and jaggery (soft) were procured from local market and the flaxseed was purchased from a pharmaceutical store. Each ingredient was weighed as per the experimental runs provided in the experimental design. Initially the flaxseed was roasted in kadai for 2 to 3 minutes till the popping sound was observed after which the seeds are kept separately. Then weighed amount of jaggery was taken on the kadai and water was added to it in an amount little more than the jaggery on a (w/v) basis. After few minutes of boiling jaggery syrup got thickened. Stirring of the syrup was continued till the temperature reached to about (120-121°C) which is considered to be the end point of laddu preparation. However, traditionally the laddu makers test the consistency of jaggery syrup by putting a drop of syrup in normal water followed by observing its hardness. After the end point achieved the puffed rice mixed with jaggery followed by through mixing of flaxseed along with all the ingredients. In the mean time the bar making device is greased with oil and the hot mix ingredient is poured into it. The whole of the material is thoroughly spread into the compartments and uniform compaction is applied with the help of wooden press on it. The whole thing is allowed to be cooled for about 5 minutes. Thereafter the bars are pressed down with finger to be released out of compartments one by one. The process is repeated for all the experimental combination and the samples were subjected to quality analysis.

3.3.4 Optimization of blended puffed rice bar using Response Surface Methodology

Experiments were planned to optimize the process parameters of puffed rice bar using response surface method (RSM). RSM involves design of experiments, selection of levels of variables in experimental runs, fitting mathematical model and selecting variable levels by optimizing the response. Box-Behnlean design for three factors with three levels was used to design the experiments. The three independent variables were jaggery % (80, 90 and 100), flaxseed % (10, 20 and 30) and tamarind juice in ml (5, 10 and 15). The plan consisted of 15 experimental runs with three experiments at centre point. The design matrix and their uncoded values are shown in Table 3.1 and 3.2. The dependent quality attributes of bar considered were firmness and overall acceptability (OA). The experimental data were analyzed to develop response functions and the input variables were optimized for best outputs. A complete second order polynomial model of following form was fitted to the data of all responses using multiple regression technique. The adequacy of the model was tested considering R^2 (The coefficient of multiple determination), Fischer's F-test and residual graphs. The models were then used to interpret the effect of variables input parameters on the response.

$$y_k = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \sum_{i=1}^{n} \beta_{ii} x_i^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \beta_{ij} x_i x_j$$

Where _*i*, _*ii*, _*ij* are constant coefficient and *xi*, *xj* are coded independent variables.

$$Y=\beta_0+ \beta_1X_1+ \beta_2X_2+ \beta_3X_3+ \beta_4X_1^2+ \beta_5X_2^2+ \beta_6X_3^2+\beta_7X_1X_2+ \beta_8X_2X_3+ \beta_9X_3X_1$$

A commercial statistical package, MINITAB Version 13 (Minitab Inc, USA, Trial Version). The same software was used for the generation of response surface plots, superimposition (overlaying) of contour plots (design expert) and optimization of process variables. Such three-dimensional surface could give accurate geometrical representation and provide useful information about the behavior of the system within the experimental range (Montgomercy, 2004). The optimization of this puffed rice bar was aimed at finding levels of J%, FS% and TJ ml at maximum overall acceptability with a targeted firmness.

Table 3.1 Process variable and their coded values

Process variables	**Code**	**Coded level**		
		-1	**0**	**+1**
Jaggery (%)	**X_1**	**80**	**90**	**100**
Flaxseed (%)	**X_2**	**10**	**20**	**30**
Tamarind juice (ml)	**X_3**	**5**	**10**	**15**

Table 3.2 BOX – BEHNKEN method of design matrix for optimization of blended puffed rice bar

SE.NO.	CODED VALUE			UNCODED VALUE		
	X_1	X_2	X_3	J (%)	FS (%)	TJ (ml)
1	-1	-1	0	80	10	10
2	+1	-1	0	100	10	10
3	-1	+1	0	80	30	10
4	+1	+1	0	100	30	10
5	-1	0	-1	80	20	5
6	+1	0	-1	100	20	5
7	-1	0	+1	80	20	15
8	+1	0	+1	100	20	15
9	0	-1	-1	90	10	5
10	0	+1	-1	90	30	5
11	0	-1	+1	90	10	15
12	0	+1	+1	90	30	15
13	0	0	0	90	20	10
14	0	0	0	90	20	10
15	0	0	0	90	20	10

3.3.5 Packaging and storage studies

Two types of packaging material viz. cellophane and LDPE pouch were used. After getting the bar, the bars were wrapped with cellophane paper and put it in a LDPE pouch in different categories. i.e. bar wrapped with only cellophane paper (P1), cellophane wrapped with LDPE sealing (P2), cellophane wrapped and put it inside the LDPE pouch without sealing (P3), direct put it in the LDPE pouch and sealed without wrapping cellophane (P4).

After packaging of the bars were kept under ambient condition (33-37°C). The stability of the products was evaluated by texture and sensory quality. Storage studies were carried out for 8 days due to summer season.

3.4 Quality analysis

3.4.1 Sensory evaluation

Sensory evaluation offers the opportunity to obtain a complete analysis of the various properties of food as perceived by human sense. Sensory evaluation is an important and the best method for evaluating the level of acceptance of any new food products developed. This also provides a light on quality and production control measures. The sensory evaluation was done using a nine point hedonic scale following the procedure of ISI (1997). The 9-point hedonic scale used the descriptive scoring i.e. like extremely 9, like very much 8, like moderately 7, like slightly 6, neither like nor dislike 5, dislike slightly 4, dislike moderately 3, dislike very much 2 and dislike extremely as 1. The attributes for the products under study considered were colour, flavour, taste, crispiness and stickiness. However, the overall acceptability was estimated using composite scoring. A panel of 12 semi trained members evaluated the prepared the blended puffed rice bar.

Composite scoring test: The investigating attributes were given some weightage based on the judge's opinion regarding the importance given to a particular investigating attribute. The weightages given to a particular subjective attribute was in such a way that the sum of the weightages for all the investigating attribute was 1. In composite scoring the scores allotted to each investigating attribute was multiplied by corresponding weightage and then the average of all cumulative summation was considered to be the score of overall acceptability.

3.4.2 Textural analysis

Texture is essentially the effect of physical and chemical properties on our senses of sight, hearing and touch and is an important attribute in our perception of food. If texture is not right, we do not like the food even if the other parameters are acceptable. The maximum force required to penetrate a sample at a certain displacement rate is interpreted as the textural quality of hardness, crispiness, or crunchiness.

The textural hardness of bar sample was measured using a texture analyzer (model: TA-XT plus, Make: Stable Micro systems, UK) with texture exponent software. The study was conducted by using 50 kg load cell. The samples were tested by using 75mm compression platen (P/75) probe which was operated at the speed of 2mm/sec. Position samples centrally with the core at right angles to the direction of force, on the blank plate of the Heavy Duty Platform or directly on the machine base. The samples were compacted by 66.67% from initial height of 30mm to final height of 20mm. The maximum force indicated was measured as the compaction force which was measured in kg or N. Once a trigger force of 100g has been achieved the compression platen proceeds to move down onto the puffed rice bar and a rapid rise in force is observed. During this stage the sample is deforming under the applied force but there is no apparent breakdown of the product. As the compression distance increases small peaks are seen on the graph profile, each peak indicating a compressive failure of the sample which contributes to the formation of a crack. This stage ends abruptly when the sample splits or cracks and is indicated by a large decrease in force. The greater the distance this occurs, the greater is the ability to withstand compression without sample breakage.

The test may be modified to compress samples to a greater distance. This will subsequently increase the 'hardness' values if this is the case a 250kg load cell would be recommended for higher force range. Any values obtained are only relative at the specified distance to which they are compressed. The following specification was taken at the time of testing.

Pre-test speed – 1mm/sec

Test speed – 2mm/sec

Post-test speed – 10mm/sec

Distance of compaction – 20mm

Trigger type – auto 100 g

Tare mode – auto

Data acquisition – 25 pps (points per second)

Firmness: The average slope of load displacement curve from zero to the point of rupture or failure. Therefore, the curve slope will be calculated from the puncture force (F) and the displacement (D) induced by this force:

$$\text{Firmness (N/mm)} = \frac{\text{Force (F)}}{\text{Displacement (D)}}$$

Toughness: Mechanical energy or work required for rupture is calculated from the area under load displacement curves from zero up to the point of rupture or failure.

$$\text{Toughness (N.mm)} = \frac{1}{2} \times \text{Force (F)} \times \text{Displacement (D)}$$

Compliance: Property of a material of undergoing elastic deformation or change in volume when subjected to an applied force. It is equal to the reciprocal of stiffness.

$$\text{Compliance (mm/N)} = \frac{\text{Displacement (D)}}{\text{Force (F)}}$$

3.4.3 Physio - chemical properties

Bulk density

It is the property of granules, powders & other solids or any other masses of corpuscular or particulate matter. It is defined as the mass of many particles of the materials divided by the total volume they occupy .The total volume includes particle volume, inter particle void volume & internal pore volume. It can change depending on how the materials handled (Mohsenin, 1986).

$$\rho_b = \frac{M}{V_t}$$

Where, ρ_b= bulk density

M = mass of the product

V_t= total volume of the product

Particle density

The particle density of granular material (ρ_p, kg/m^3) is defined as the ratio of its mass to its actual volume and hence was calculated by dividing the unit mass of each sample to its particle volume. It was determined by using the toluene (C_7H_8) displacement method. Toluene was used in place of water because it is absorbed by grains to lesser extent. The volume of toluene displaced was found by immersing a weighted quantity of flaxseed in the toluene (Mohsenin, 1986; Singh and Goswami, 1996).

$$\rho_p = \frac{M}{V_p}$$

Where, ρ_p = particle density

M = mass of the product

V_p = particle volume of the product

Porosity

Porosity may be defined as relationship between volume of the inter-grain space to the total volume of grain bulk. Porosity depends upon the shape, dimension and roughness of the grain surface. The porosity can be determined by the relationship between particle density and bulk density of the material.

$$\Phi = 1 - \frac{\rho_b}{\rho_p}$$

Where, Φ = porosity, %

ρ_b = bulk density of the product, kg/m^3

ρ_p = particle density of the product, kg/m^3

Moisture content

Hard jaggery and soft jaggery of 5 g samples each were taken in two different petridish. The initial weights of both samples were measured in a digital weighing balance. Then the weighed samples were dried in a hot air electric oven at 105°C for 24 hr. After drying of 24 hr, the sample was cooled in a desiccator and reweighed. The moisture content was expressed either in percent (wet basis) or in kg moisture per kg dry matter (dry basis). The experiment was conducted in replicates and the average values were written in table 4.1.

$$\text{Moisture content (\%)} = \frac{M_1 - M_2}{M_1} \times 100$$

Where, M_1 = Mass of sample before drying, g

M_2 = Mass of sample after drying, g

Reducing sugar

Lane and Eynon method was used to estimate reducing sugar which is based on principle of reduction of Fehling's solution by reducing sugar. First, 10-50 g jaggery (both soft and hard) measured and transferred to the 500 ml volumetric flask. 100 ml water was added and then it was neutralized with NaOH solution to phenolphthalein end point. Thereafter 5 ml each of Fehling A and B was pipette out into 250 ml volumetric flask. 40 ml water was added and then it was mixed. The sugar solution was dispensed from burette and heated to boiling. 3 drops of methylene blue indicator was added. Addition of sugar solution was continued drop wise until the blue colour disappeared to a brick-red end point.

Final titration was carried out with 5 ml each of Fehling A and B, which was pipette out into 250 ml conical flask. Sample solution was added to about 0.05 to 1.0 ml less than titre value of preliminary titration. Flask was heated to boiling. In between 3 drops of methylene blue indicator was added. Titration was completed within 1 min by adding 2 to 3 drops of sugar solution at a time, until the indicator was decolourized. At the end point, the boiling liquid assumed the brick red colour. Titration was formed in duplicate and average was taken.

The % reduction sugar in the sample is given as

$$\text{Reducing sugar, \%} = \frac{0.0025 \times V_1 \times V_2 \times 100}{W \times V_3}$$

Where, W= Weight of the sample, g

V_1 = Titre volume, ml

V_2 = Dilution volume of sample, m

V_3 = Volume of clarified sample solution required for Fehling's reaction, (ml). Based on the factors for Fehling's solution, V_3 ml sample contain 0.0025 V_1 g reducing sugar.

Non- reducing sugar

Total sugar represents reducing sugar and non reducing sugars di and oligo saccharides, which can be hydrolysed into reducing sugar with dilute acids. For the determination of non reducing sugars 50 ml of sample was taken in 100 ml volumetric flask. 5 ml of conc. HCL was added and allow to stand at room temperature for 24 hours. Neutralization with conc. HCL solution followed by 0.1N NaOH using phenolphthalein as end point indicator was done. Volume was made up and transferred to 50 ml burette having an off-set tip. Titration was performed against Fehling's solution similar to the reducing sugars.

Based on the factor for Fehling's solution, total reducing sugars in

V_4 ml = 0.0025 × V_1 g

As 50 ml of the clarified and de-leaded solution was diluted twice after hydrolysis, dilution volume of the sample = 2 × V_2

Therefore,

$$\text{Total sugar, \%} = \frac{0.0025 \times V_1 \times 2 \times V_2 \times 100}{W \times V_4}$$

% Non reducing sugar in sample = (Total sugar - % Reducing sugars) × 0.95

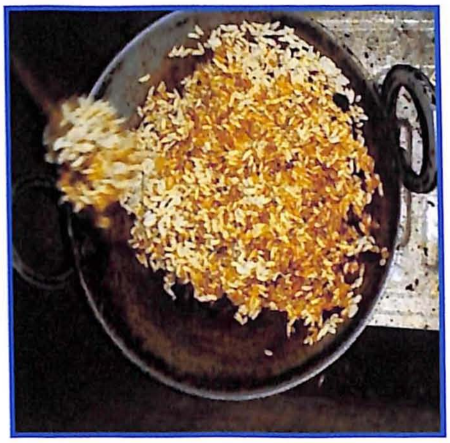
Ascorbic acid

Ascorbic acid or vitamin C content of jaggery was estimated by volumetric method. 5 ml of standard ascorbic acid (100µg/ml) was taken in a conical flask containing 10ml 4% oxalic acid and was titrated against the 2,6-dichlorophenol indophenols dye (Dye solution). The appearance and persistence of pink colour was taken as end point. The amount of dye consumed (V_1 ml) is equivalent to the amount of ascorbic acid. 5 ml of sample (prepared by taking 5 ml of sample in 40 ml of 3% meta phosphoric acid) was taken in a conical flask having 5 ml of 3% meta phosphoric acid and titrated against the dye (V_2 ml). The amount of ascorbic acid was calculated using formula:

$$\text{Mg of ascorbic acid/100 ml} = \frac{\text{titre} \times \text{dyefactor} \times \text{vol.made up (50 ml)} \times 100}{\text{extract taken} \times \text{vol.of sample}}$$

Where, Dye factor = 0.5/titre

a) Thickening of jaggery syrup (traditional)

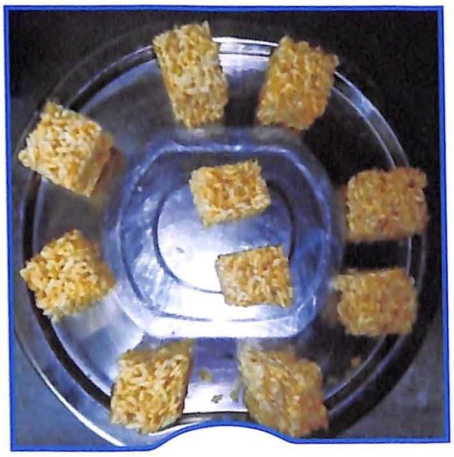


b) Adding of puffed rice

c) Making of puffed rice ball

d) Prepared puffed rice ball

e) Puffed rice cube by individual mould



f) Prepared puffed rice cube

Plate 3.1 Preparation of puffed rice ball and cube by Traditional method and Individual mould

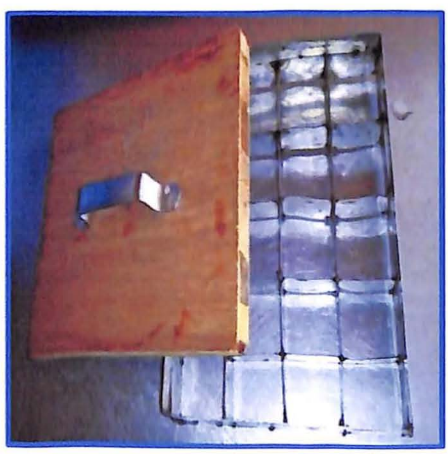
a) Cutting of stainless steel sheet

b) Fabrication of compartmental unit

c) 1st stage of compartmental unit

d) 2nd stage of compartmental unit

e) Bottom view of pressing unit



f) Complete bar making unit

Plate 3.2 Development of bar making unit

a) Collection of ingredients

b) Weighing of jaggery

c) Roasting of flaxseed

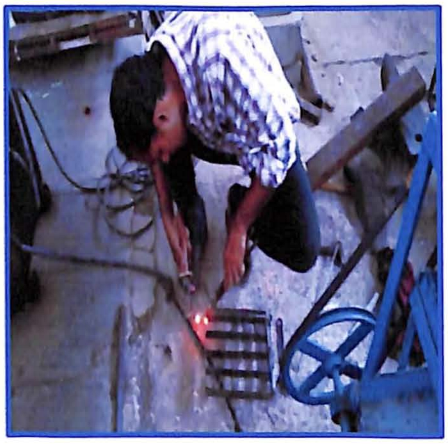
d) Pouring of jaggery into kadai

e) Thickening of jaggery syrup

f) Pouring of puffed rice in jaggery syrup

Plate 3.3 Preparation of material for blended puffed rice bar

a) Cutting of stainless steel sheet

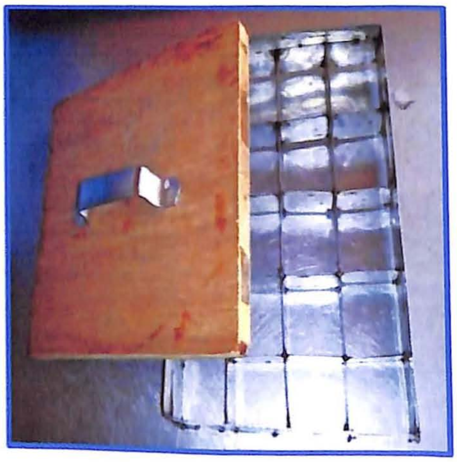


b) Fabrication of compartmental unit

c) 1st stage of compartmental unit

d) 2nd stage of compartmental unit

e) Bottom view of pressing unit



f) Complete bar making unit

Plate 3.2 Development of bar making unit

a) Pouring material into compartmental unit

b) Compaction by pressing unit

c) Take out of bar from device

d) Prepared blended puffed rice bar

e) Close view of bar

f) Finished product

Plate 3.4 Compaction and removal of bar from bar making unit

a) Wrapping of cellophane material

b) Wrapped blended puffed rice bar

c) Cellophane wrapped only (P_1)

d) Cellophane wrapped with LDPE sealing (P_2)

e) Cellophane wrapped inside LDPE (without sealing) (P_3)

(f) Only sealed with LDPE (P_4)

Plate 3.5 Packaging of blended puffed rice bar

a) Hardness test of bar by Texture analyzer

b) Side view testing operation

b) Data analysis for texture test

c) Hardness test of puffed rice ball

Plate 3.6 Hardness tests of puffed rice bar and ball by Texture analyzer

(a) (b)

(c) (d)

Plate 3.7 Sensory evaluation by panelists

Chapter IV

RESULTS AND DISCUSSION

puffed rice laddus have been found out to be 20 to 22N/mm. This range can consider as an index of process variables in preparation of puffed rice bars.

(e) Traditionally the puffed rice laddus are prepared by binding the hot puffed rice mix between two palms which poses drudgery and sometimes injury if continuously done. Very often the laddus prepared are not of uniform size and shape which fetch lesser price in the market. Therefore it was decided to fabricate a low cost small device to prepare a number of puffed rice bar in a batch without imposing drudgery to hands.

4.2 Performance evaluation of the puffed rice bar making device

Figure 4.2 depicts the isometric view of the device. The plan and elevation with dimensions along with the description is presented in section 3.3.2. The bars were prepared using the device and performance was compared to that of traditional and the individual mould. Table 4.3 shows that per batch 20 number of bars can be prepared using the device where as the other two methods can have only one at a time. Therefore, the capacity of these three methods found out to be 7.68 kg/h, 2.64 kg/h, and 3.75 kg/h respectively. Percent uniformity in shape and size which is important for marketing was found out to be 90%, 40% and 100%. Since the traditional method is manual, a poor percent of uniformity in size and shape was observed. The individual mould was offering 100% size and shape but the cube size was not acceptable by the consumers. The bulk densities of bars produced by the three methods were 0.21, 0.22 and 0.24 g/cm^3 respectively. The higher bulk densities are due to the obvious reason of preparing the bar individually. It is summarized that puffed bar making device is useful in preparing puffed rice bar of 7.68 kg/h (400 numbers/h) with 90% uniformity in size and shape.

4.3 preparation of blended puffed rice bar

Table 4.4 presents the values of various responses i.e. firmness and overall acceptability at different experimental combination of Box-Behnken design metrix. A wide variation in all the responses is observed i.e. 12.4 to 28.0 N/mm for firmness and 5.7 to 7.5 for overall acceptability. The maximum and minimum values of those parameters were achieved for the run order of 8, 5 and 13, 5 respectively.

Chapter-4

RESULTS AND DISCUSSION

Optimized conditions for blended puffed rice bar have been determined. A device was fabricated to prepare a number of bars in one batch. Storage studies for the bars have also been carried out. The result obtained and the discussions made are presented in this chapter.

4.1 Preliminary experiments

Preliminary experiments have been conducted based on the information and samples collected from the traditional puffed rice laddu makers. The following inferences have been drawn:

(a) As per the consumer's convenient eating requirement, the brick shaped bar is preferred over spherical laddus. Among different sizes suggested, a bar size of 5cm×5cm×3cm was preferred most.

(b) The traditional soft jaggery was found to be more suitable for proper binding than the hard one. Table 4.1 indicated that there is a difference in moisture content, reducing and non reducing sugar and sucrose content among the soft and hard jaggery. The method of preparation or variation in temperature may be the probable reasons for this ability.

(c) The end point temperature of the jaggery syrup was found out to be 120-122°C. Beyond this temperature the puffed rice became hard and the desired shape could not be formed.

(d) In order to determine the desirable firmness/ crispiness of the traditional puffed rice laddu, samples were collected and subjected to texture analysis. Table 4.2 and Figure 4.1 indicated the texture parameters and the forces vs time and forces vs displacement graph. It is observed that the force requirement varied from 403 to 405N for a constant displacement of 20 mm with a time variation of 10.01 to 10.015 seconds. From this the acceptable firmness requirement for puffed rice laddus have been found out to be 20 to 22N/mm. This range can consider as an index of process variables in preparation of puffed rice bars.

(e) Traditionally the puffed rice laddus are prepared by binding the hot puffed rice mix between two palms which poses drudgery and sometimes injury if continuously done. Very often the laddus prepared are not of uniform size and shape which fetch lesser price in the market. Therefore it was decided to fabricate a low cost small device to prepare a number of puffed rice bar in a batch without imposing drudgery to hands.

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4.3 preparation of blended puffed rice bar

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4.3.1 Regression models and effect of variables on various responses

The regression coefficients of complete second order polynomial models for both the responses along with the R^2 value are shown in Table 4.5. Both the models were tested for their adequacy using ANOVA technique. F value for the lack of fit were non-significant (P>0.05 i.e. 0.202 and 0.118 respectively) there by confirming the validity of models (Table 4.6). Adequacy of both the models were confirmed by R^2 more than 0.95 (0.976 and 0.983) for firmness and overall acceptability respectively. Residual graphics representing normal probability, frequency histogram etc. also depicted the close fitness of the models (Appendix A3 and A4).

4.3.2 Effect of variables on various responses

The individual and combined effect of process variables are presented in the Table 4.6. The probability of predictor's coefficient indicated the extent of its effect on the response. The nature of the effect could be explained by the sign and the magnitude of the coefficient. Negative sign at linear level indicated decrease in response when the level of predictor is increased while positive sign indicated increase in response. Significant negative interaction suggested that for constant value of the response, the level of one of the predictors can be increased while that of other decreased. Positive interaction means the response is minimum at centre point and it increases both ways from centre point. Negative coefficient of the quadratic terms shows the maximum response at the centre value and it decrease with increase or decrease in parameter level. The list of complete second order models developed are as follows:

$$Y_{firmness} = 20.934 + 3.91*J + 0.91*FS + 3.16*TJ - 1.59*J^2 + 0.95*FS^2 - 0.25*TJ^2 - 0.15*J*FS + 1.87*FS*TJ + 1.12*J*TJ$$

$$Y_{overall\ acceptability} = 7.45 + 0.08*J - 0.10*FS - 0.01*TJ - 0.70*J^2 + 0.02*FS^2 - 0.50*TJ^2 - 0.07*J*FS - 0.07*FS*TJ - 0.50*J*TJ$$

The simplified models deleting the non-significant terms are as follows:

$$Y_{firmness} = 20.934 + 3.91*J + 0.91*FS + 3.16*TJ - 1.59*J^2 + 1.87*FS*TJ + 1.12*J*TJ$$

$$Y_{overall\ acceptability} = 7.45 + 0.08*J - 0.10*FS - 0.70*J^2 - 0.50*TJ^2 - 0.50*J*TJ$$

Results reveal that all the process variables (J %, FS %, TJ ml) had significant effect on firmness and overall acceptability of blended puffed rice bar. Jaggery and tamarind juice content had most significant effect on both the responses.

a) **Effect of variable on firmness:** Firmness was greatly ($P<0.01$) influenced by J% and TJ ml at linear level. This is attributed due to the fact that both these components were primarily functionary as binding agents. A negative quadratic coefficient of J% indicated that after a critical value of J%, the firmness of the bar reduced. Incorporation of flaxseed did not have much effect on firmness except at linear level ($P<0.1$) and an interaction with TJ ml at ($P<0.05$). However, combined linear and combined interaction was more prominent than the quadratic effect.

b) **Effect of variables on overall acceptability:** Though jaggery and tamarind juice was basically used as binding agent, they influenced the taste and flavor of the bars as well. Therefore a profound quadratic and interactive effect ($P<0.01$) of both these variables was found on overall acceptability. A negative linear influenced of flaxseed blending was observed indicating less consumer appeal. This could be due to the fact that addition of flaxseed was imparting dark colour to the finished product.

4.3.3 Optimization of process variables

In order to optimize the process conditions for puffed rice bar preparation by numerical optimization techniques, some levels were to be decided for all the three process variables. Based on their relative contribution to quality of final product different weightage was given to different responses. In the process study, desirability function was developed for the criteria to maximize the overall acceptability while keeping the firmness at a target value. This was done to keep the characteristic and desirable crispy texture such that it is brittle on the first bite. The optimum operating conditions (both coded and uncoded) for multiple responses along with their desirability function is presented in Figure 4.4. Since the product preparation aimed at having the maximum desirable qualities, it was essential to work out the multiple response optimization. Under this, the set of compromised responses within acceptable range was obtained at optimum process conditions of J%, FS% and TJ ml at -0.0303, -1, -0.0505 (coded values) and 90, 10 and 10 (uncoded value) respectively.

Corresponding to these values of process variables, the value of firmness and overall acceptability were 21 N/mm and 7.5 respectively. The overall desirability was 0.859. These conditions were experimentally verified for the response values and were found to be acceptable with deviation of within ±5%.

4.3.4 Surface plotting

The surface profiles for different responses were drawn as a function of two process variables with the third one at optimum level which are presented in Figure 4.5 and 4.6.

a) **Firmness:** Figure 4.5 (a, b and c) depicted that the firmness increased with increase in any of the variables with the third variable at optimum. However, a very slow and gradual increase in firmness was observed (Figure 4.5 a, c) with increase in FS% as compared to those of J% and TJ ml.

b) **Overall acceptability:** It is observed from Figure 4.6 (a, b and c) that overall acceptability increased up to centre point and thereafter decreased with increase in J% at any given FS% and TJ ml. A similar trend was observed with variation in TJ ml with other two variables kept at constant. However, incorporation of flaxseed did not show much significant change in overall acceptability with change in variables within the experimental range under study. This infers that addition of flaxseed did not show significance difference in sensory attributes. Chetna et al. (2011) also found similar results in preparation of flaxseed blended peanut chikki. Though flaxseed imparted slight dark colour to the puffed rice bar, the product was acceptable with respect to all quality arttributes.

4.4 Effect of packaging materials on blended puffed rice bar during storage

The blended puffed rice bars were prepared and subjected to storage with wrapping and packaging. For this two kinds of packaging material (LDPE and cellophane) were used. The pieces were wrapped with cellophane material and sealed inside LDPE pouches. Four variant of packaging systems have been used (Table 4.8). The samples were subjected to sensory evaluation at an interval of 2 days. The sensory attributes colour, flavor, taste, crispiness and stickiness contributed to composite scoring of overall acceptability.

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It is observed that sensory scores of all desirable attributes decreased for the samples under different packaging systems at the end of eight days when compared to the initial values (Figure 4.8). But the overall acceptability of samples wrapped only with cellophane materials reduced drastically 2 days onwards (Figure 4.8a). So observations were not recorded for those samples after 2nd day onwards. Careful observation on data revealed that the samples stored in LDPE with or without cellophane material fetched higher sensory score.

Traditionally the puffed rice laddus are prepared in winter months only. This is because during that period, both temperature and relative humidity are lesser than those in summer season. Therefore the shelf life of the laddus is significantly better in winter days. The present investigations are carried out in summer months during which both temperature and relative humidity are high.

Moisture of dry puffed rice is very critical as it determines the quality and stability of the product. The puffed rice bar product has a moisture content of 3% (db) at the time of preparation. The initial crispy texture was attributed due to this. With storage period the sensory scores reduced at different rates depending on the packaging material used. Increased moisture content or higher atmospheric temperature (35 to 40 °C) might have rendered the product soft for which the bars lost their characteristic crispy texture. However, the reduction in sensory score varied with packaging system used for the products. Samples kept in P_2 system could retain the sensory score to a greater extent up to 8 days of storage indicating less moisture migration due to the low moisture permeability (Figure 4.8b). P_3 and P_4 systems lost the sensory acceptability after 4 and 6 days respectively. Examination on individual sensory attributes indicted that there samples mostly failed to get good scores in flavor and crispiness. The impact of this resulted in low overall acceptability due to composite scoring.

Overall analysis of the sensory evaluation of the storage study revealed that P_2 (cellophane wrapped with LDPE sealing) performed better than any other type upto 8 days of storage with overall acceptability of 7.74 (Figure 4.9). This was followed by P_3 (cellophane wrapped inside LDPE without sealing) upto 6 days (overall acceptability). Samples stored inside LDPE without cellophane wrapping (P_4) became soft only after 6 days of storage (overall acceptability). This indicated that both the packaging materials were combined effective than that with individual packaging. However, trails with HDPE packaging material and storage at low temperature and low relative humidity will elaborate the appropriate storage requirement of blended puffed rice bars during summer season.

Table 4.1 Properties of ingredients used in puffed rice bar

Physical properties	**Puffed rice**	**Flaxseed**
Bulk Density (g/cm^3)	0.078	0.638
Particle Density (g/cm^3)	0.177	1.675
Porosity (%)	56	61
Chemical composition	**Hard jaggery**	**Soft jaggery**
Moisture content (%)	15.11	26.34
Reducing sugar (%)	9.69	20.22
Non reducing sugar (%)	28.81	17.40
Sucrose content (%)	27.37	16.53
Total sugar (%)	38.51	37.62
Vitamin C (mg/ 100gm)	369.92	94.22

Table 4.2 Mechanical properties of puffed rice bar from texture analyzer data

Sample	Force (N)	Displacement (mm)	Compaction (%)	Time (sec)	Firmness (N/mm)	Toughness (Nmm)	Compliance (mm/N)
T1	420.10	20	66.67	10.015	21.005	4201.01	0.047
T2	403.53	20	66.67	10.015	20.17	4035.3	0.05
T3	425.25	20	66.67	10.015	21.26	4252.5	0.047
S1	309.36	20	66.67	10.005	15.46	3093.6	0.065
S2	474.06	20	66.67	10.005	23.70	4740.6	0.042
S3	343.55	20	66.67	10.01	17.17	3435.5	0.058
S4	497.24	20	66.67	10.005	24.86	4972.4	0.04
S5	246.97	20	66.67	10.005	**12.34**	2469.7	0.081
S6	358.89	20	66.67	10.005	17.94	3588.9	0.056
S7	360.55	20	66.67	10.01	18.02	3605.5	0.055
S8	570.99	20	66.67	10.02	**28.54**	5709.9	0.035
S9	399.79	20	66.67	10.01	19.99	3997.9	0.05
S10	369.63	20	66.67	10.005	18.48	3696.3	0.054
S11	421.65	20	66.67	10.01	21.08	4216.5	0.047
S12	540.49	20	66.67	10.015	27.02	5404.9	0.037
S13	424.93	20	66.67	10.015	21.24	4249.3	0.047
S14	405.18	20	66.67	10.01	20.25	4051.8	0.049
S15	427.28	20	66.67	10.005	21.36	4272.8	0.047

Table 4.3 Comparative performance evaluation of device

	Bar making device	Traditional	Individual mould
No. of bar / batch	20	1	1
Capacity, kg/h (No/h)	7.68 kg/h (400 No/h)	2.64 kg/h (176 No/h)	3.75 kg/h (150 No/h)
Size and shape	5×5×3 cm (brick shaped)	5cm dia (spherical shaped)	5×5×5 cm (cubical shaped)
% Uniformity shape	90%	40%	100%
Storage	8 days	3 days	8 days
Bulk density (g/cm^3)	0.21	0.22	0.24

Table 4.4 Experiment results for the Box- Behnken three factors response surface analysis

SE.NO.	X_1	X_2	X_3	J (%)	FS (%)	TJ (ml)	Firmness (N/mm)	OA
1	-1	-1	0	80	10	10	15.46	6.6
2	+1	-1	0	100	10	10	23.70	7.0
3	-1	+1	0	80	30	10	17.18	6.7
4	+1	+1	0	100	30	10	24.80	6.8
5	-1	0	-1	80	20	5	12.40	5.7
6	+1	0	-1	100	20	5	17.94	6.8
7	-1	0	+1	80	20	15	18.02	6.7
8	+1	0	+1	100	20	15	28.00	5.8
9	0	-1	-1	90	10	5	19.99	7.1
10	0	+1	-1	90	30	5	18.48	6.9
11	0	-1	+1	90	10	15	21.02	7.2
12	0	+1	+1	90	30	15	27.02	6.7
13	0	0	0	90	20	10	21.20	7.5
14	0	0	0	90	20	10	20.20	7.4
15	0	0	0	90	20	10	21.40	7.45

Table 4.5 Regression Coefficients of second order model for different responses

Predictors	Coefficient	Firmness	OA
Intercept			
	β_0	20.93***	7.45***
Linear			
X_1	β_1	3.91***	0.08*
X_2	β_2	0.91*	-0.10*
X_3	β_3	3.16***	-0.01
Quadratic			
X_1*X_1	β_4	-1.59**	-0.70***
X_2*X_2	β_5	0.95	0.02
X_3*X_3	β_6	-0.25	-0.50***
Interaction			
X_1*X_2	β_7	-0.15	-0.07
X_2*X_3	β_8	1.87**	-0.07
X_1*X_3	β_9	1.12*	-0.50***
R-sq		0.976	0.983

X_1= J% (Jaggery percentage), X_2= FS% (Flaxseed percentage), X_3= TJ% (Tamarind juice percentage), OA= Overall Acceptability, ***Significant at 1% level, **Significant at 5% level, *Significant at 10% level.

Table 4.6 Analysis of variance of process variables as linear, quadratic and interactive terms of different responses

Parameter	DF	Firmness			Overall acceptability		
Source		SS	F	P	SS	F	P
Regression	9	242.479	22.75	0.002	3.78	33.62	0.001
Linear	3	209.402	58.94	0.000	0.14	3.80	0.092
Square	3	13.863	3.90	0.088	2.59	69.18	0.000
Interaction	3	19.214	5.41	0.050	1.04	27.87	0.002
Residual error	5	5.921			0.06		
Lack-of- Fit	3	5.094	4.11	0.202	0.05	7.67	0.118
Pure error	2	0.827			0.005		
total	14	248.400			3.84		

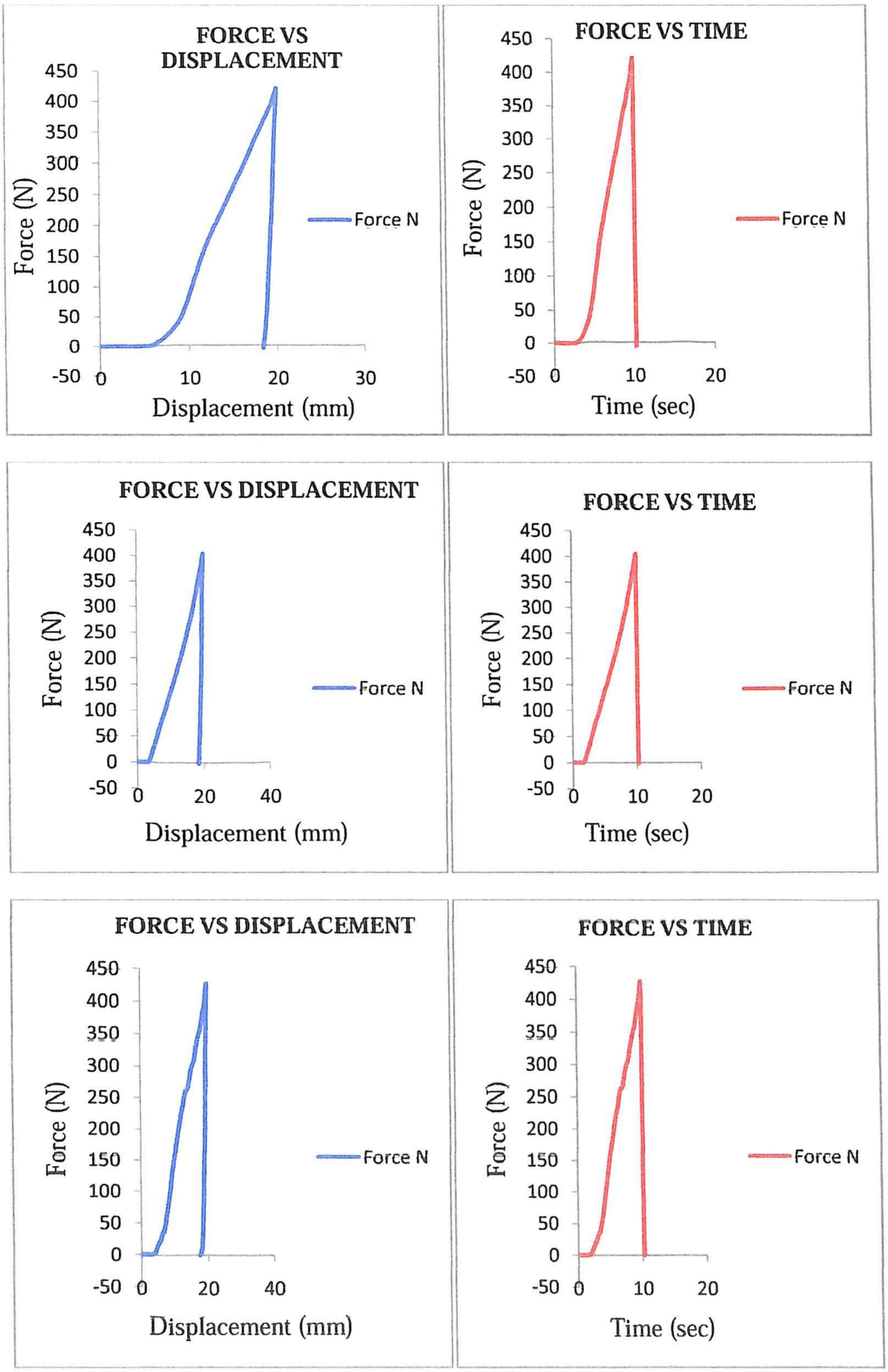


Figure 4.1 Texture profile graph (Force Vs Displacement and Force Vs Time) for traditionally prepared puffed rice ball in compression test for 3 replication

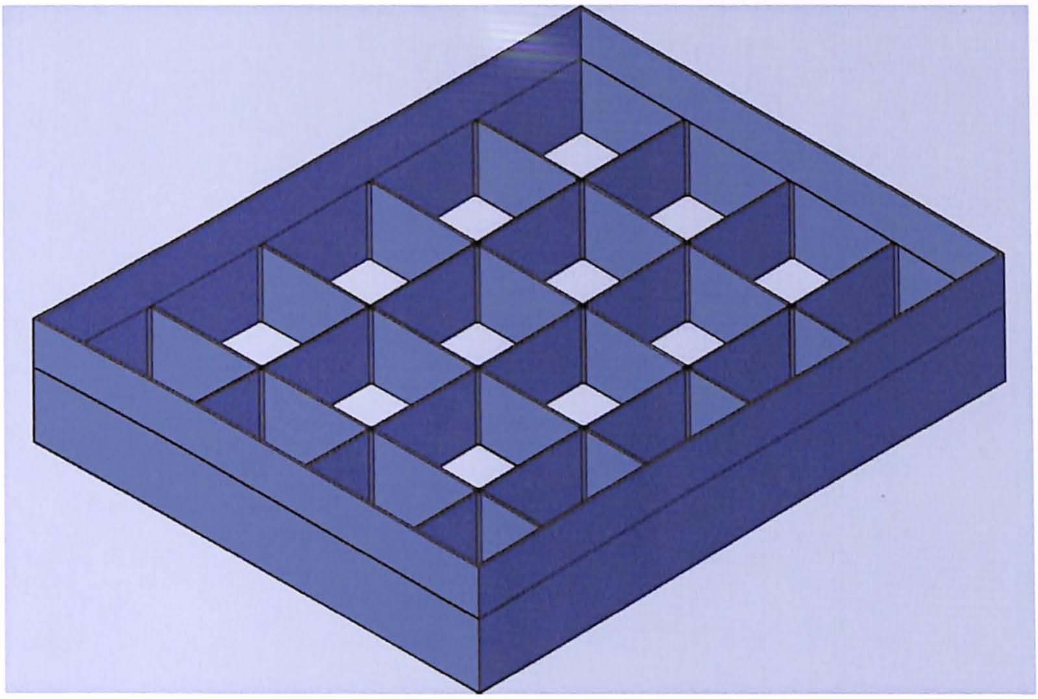


Figure 4.2 Isometric view of compartmental unit

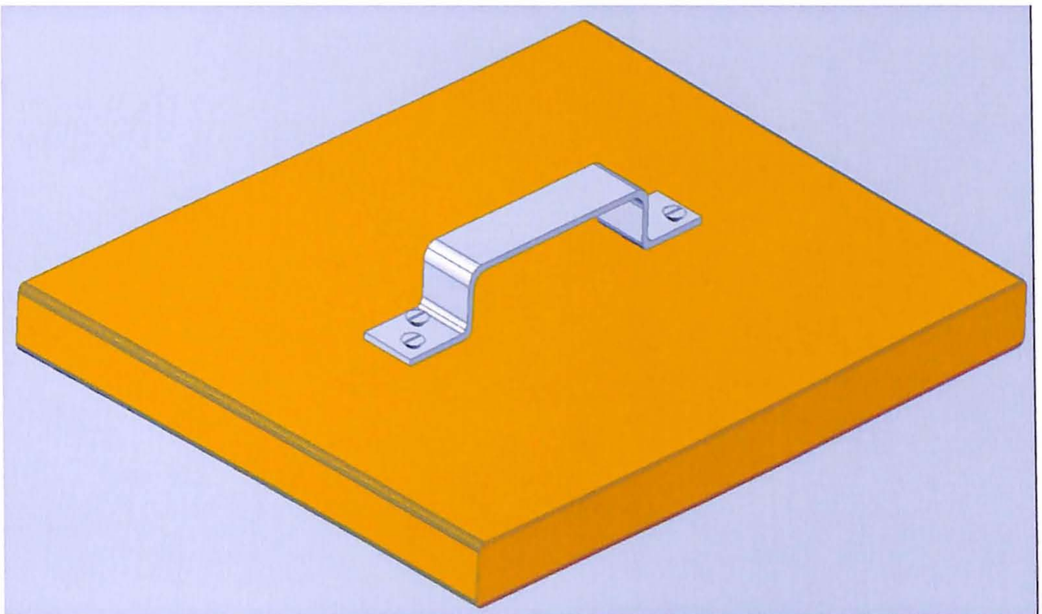


Figure 4.3 Isometric view of wooden pressing unit

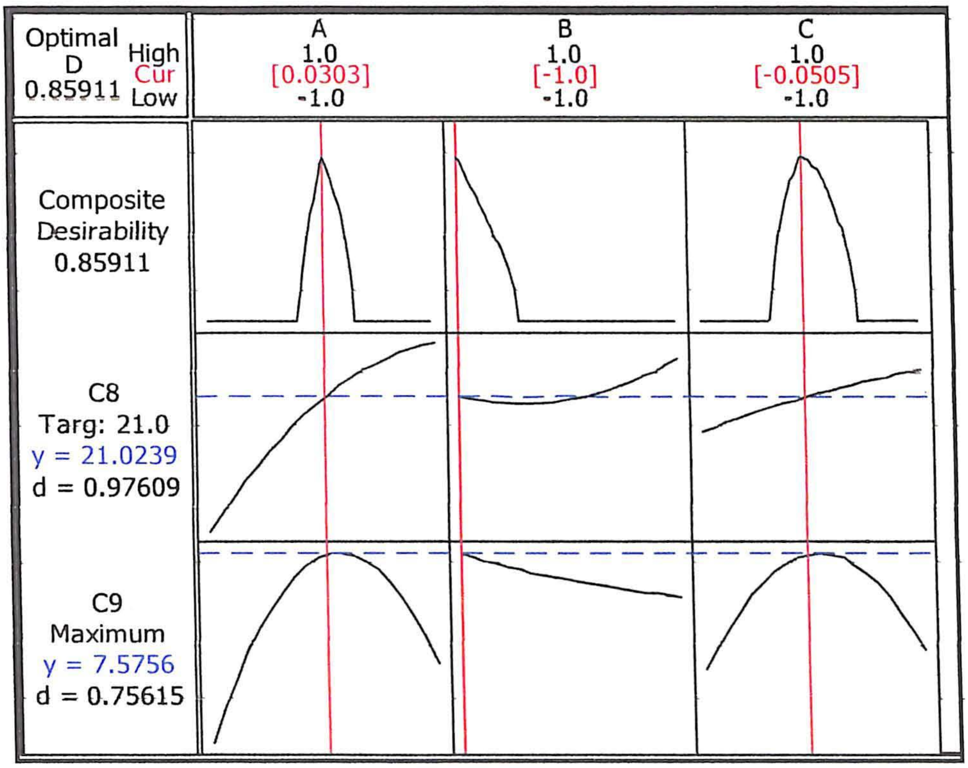
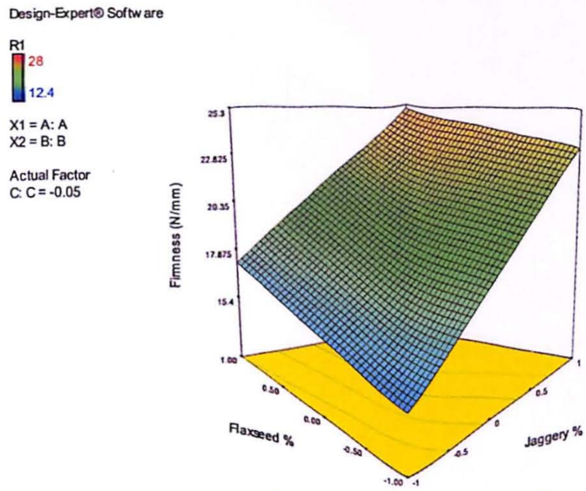
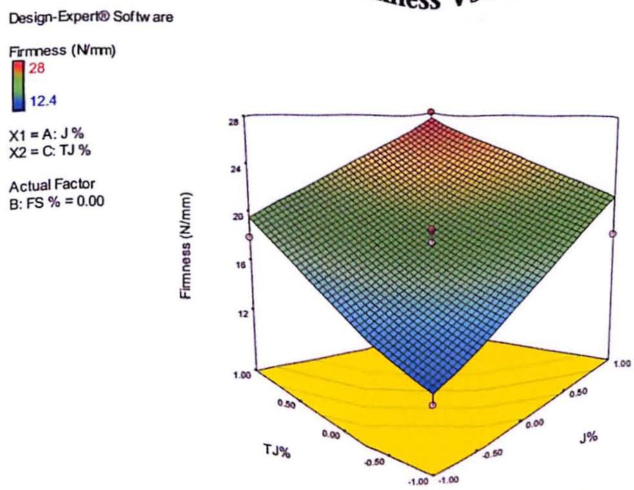


Figure 4.4 Optimization Plot of Firmness and OA

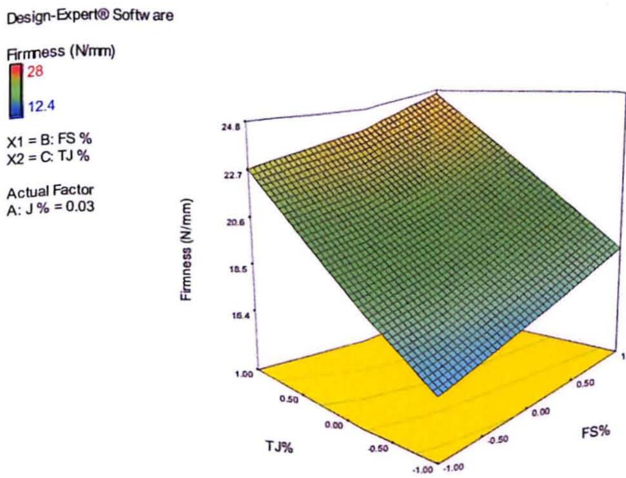
(Here C8 = Firmness, C9 = Overall acceptability, D = Desirability, A = J%, B = FS% and C = TJ ml)



(a: Firmness Vs X_1, X_2)

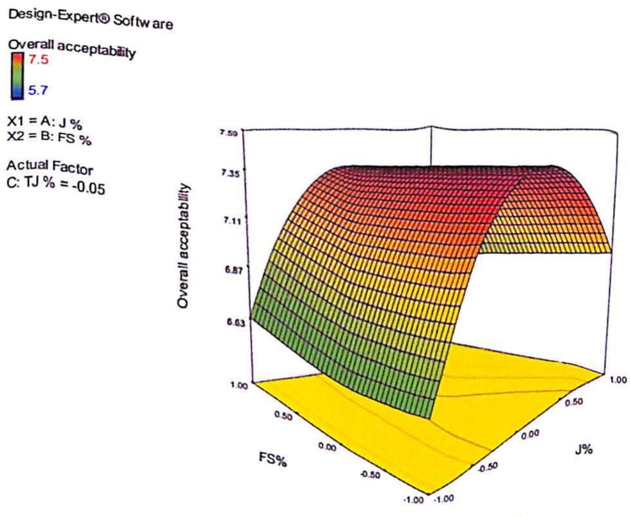


(b: Firmness Vs X_1, X_3)

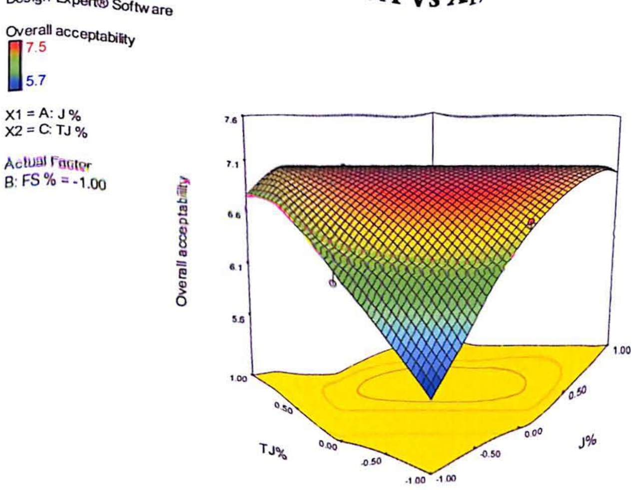


(c: Firmness Vs X_2, X_3)

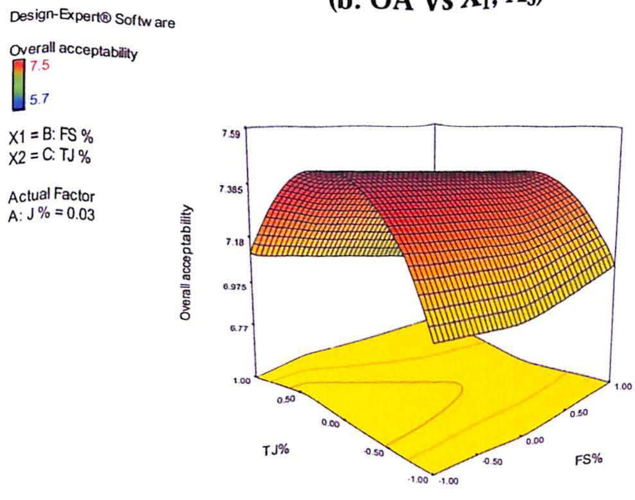
Figure 4.5 Surface plots for Firmness Vs X_1X_2, X_1X_3 and X_2X_3 input parameters



(a: OA Vs X_1, X_2)



(b: OA Vs X_1, X_3)



(c: OA Vs X_2, X_3)

Figure 4.6 Surface plots for OA Vs X_1X_2, X_1X_3 and X_2X_3 input parameters

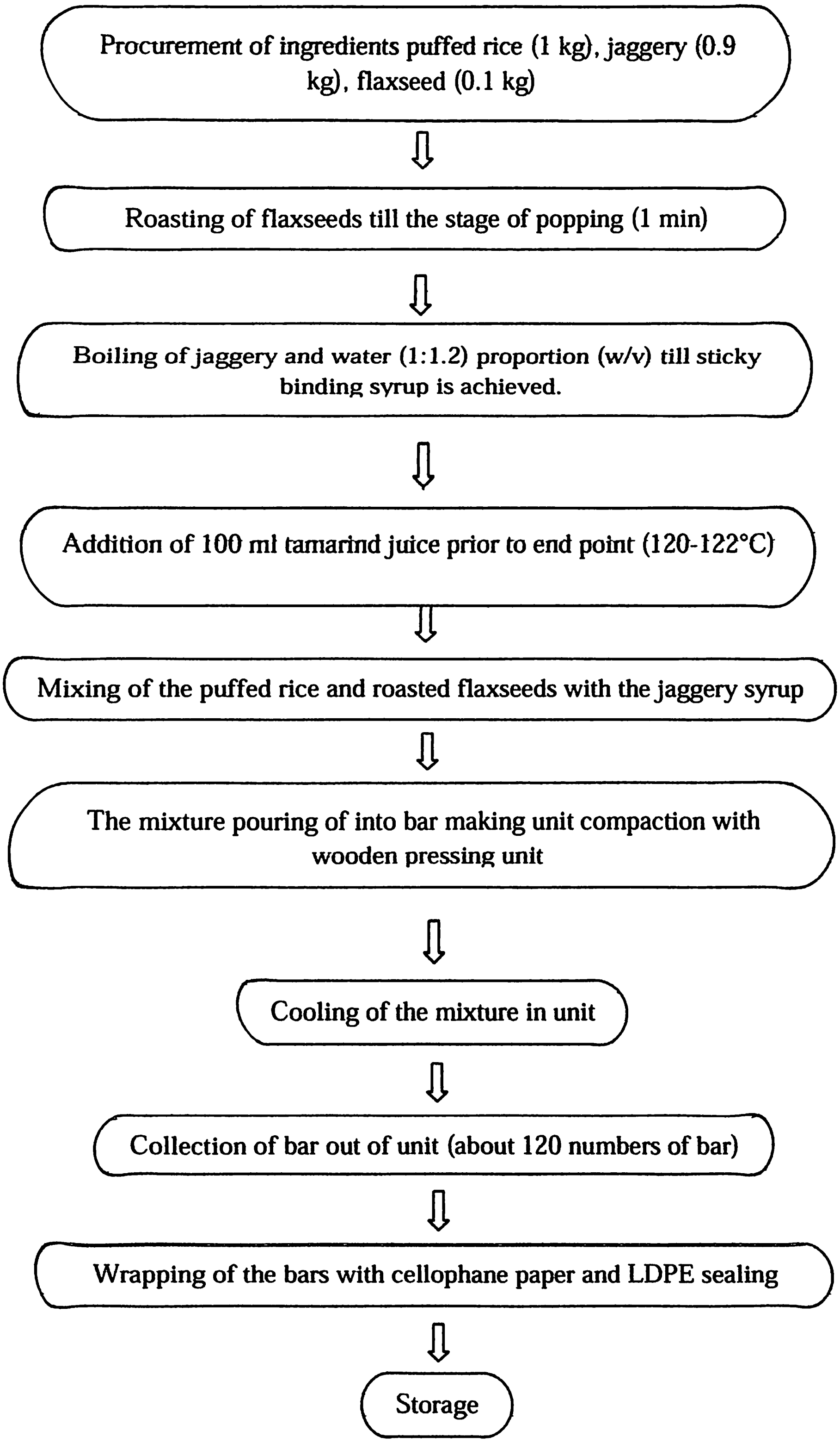
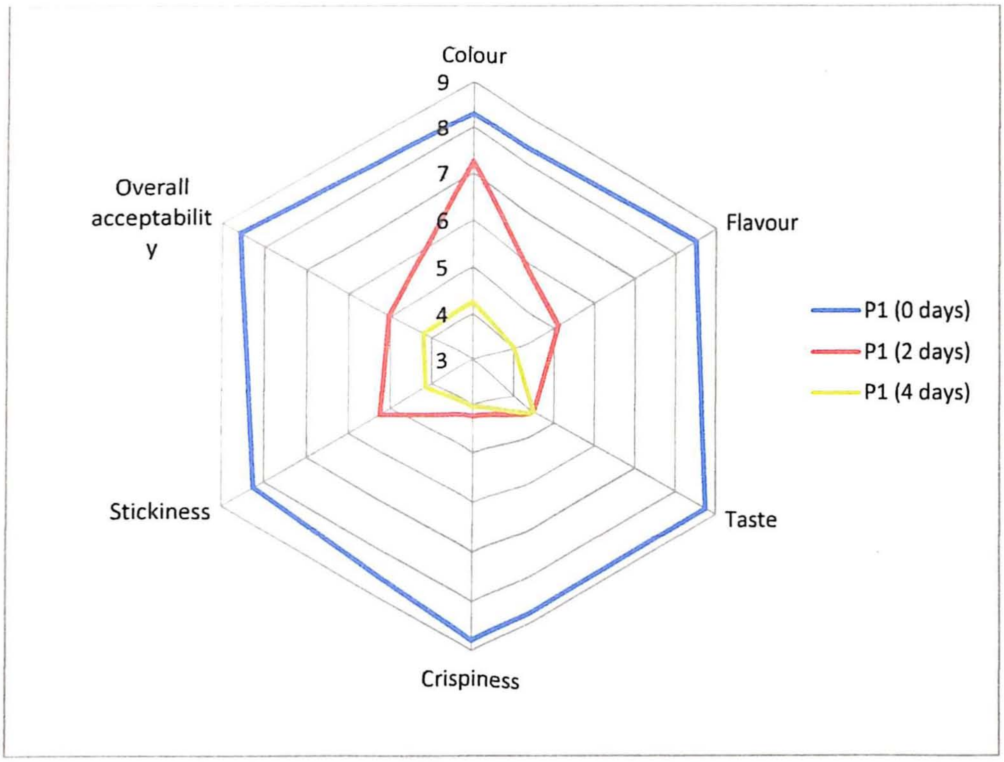
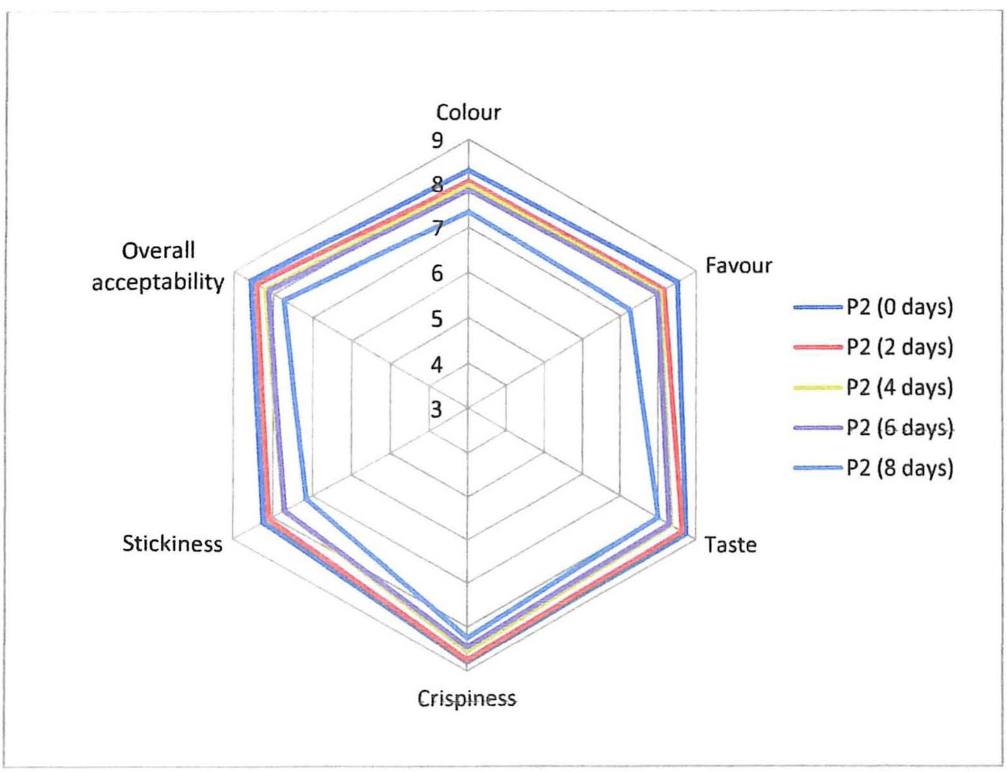


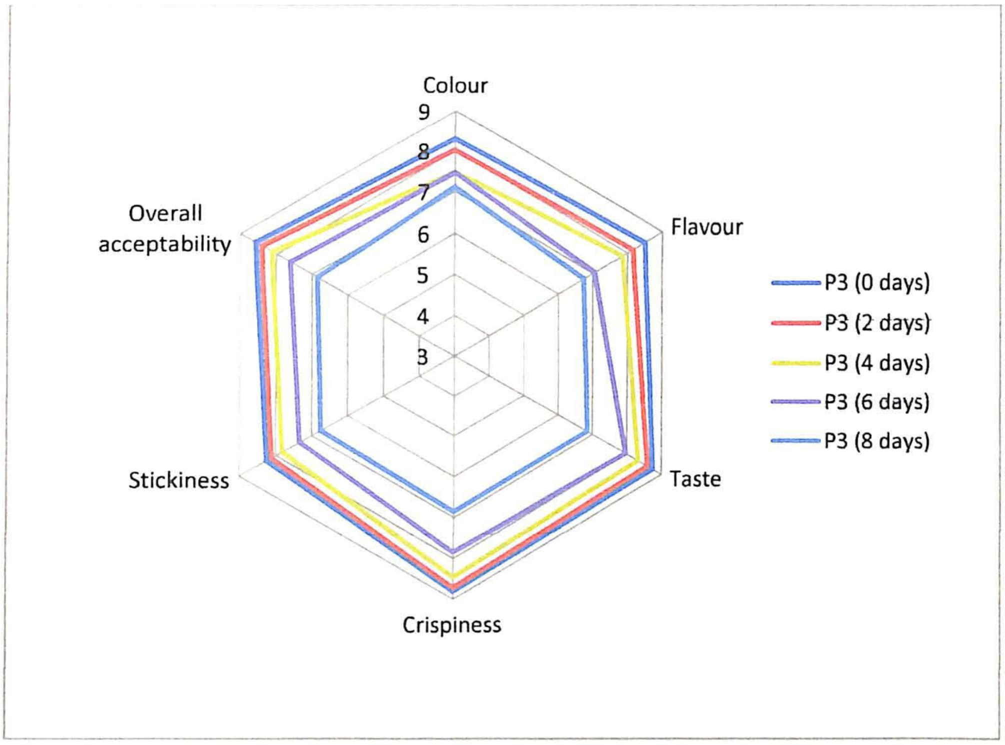
Figure 4.7 Mass flow chart for blended puffed rice bar preparation


Colour
Flavour
Taste
Crispiness
Stickiness
Overall acceptabilit y
9
8
7
6
5
4
3
P1 (0 days)
P1 (2 days)
P1 (4 days)

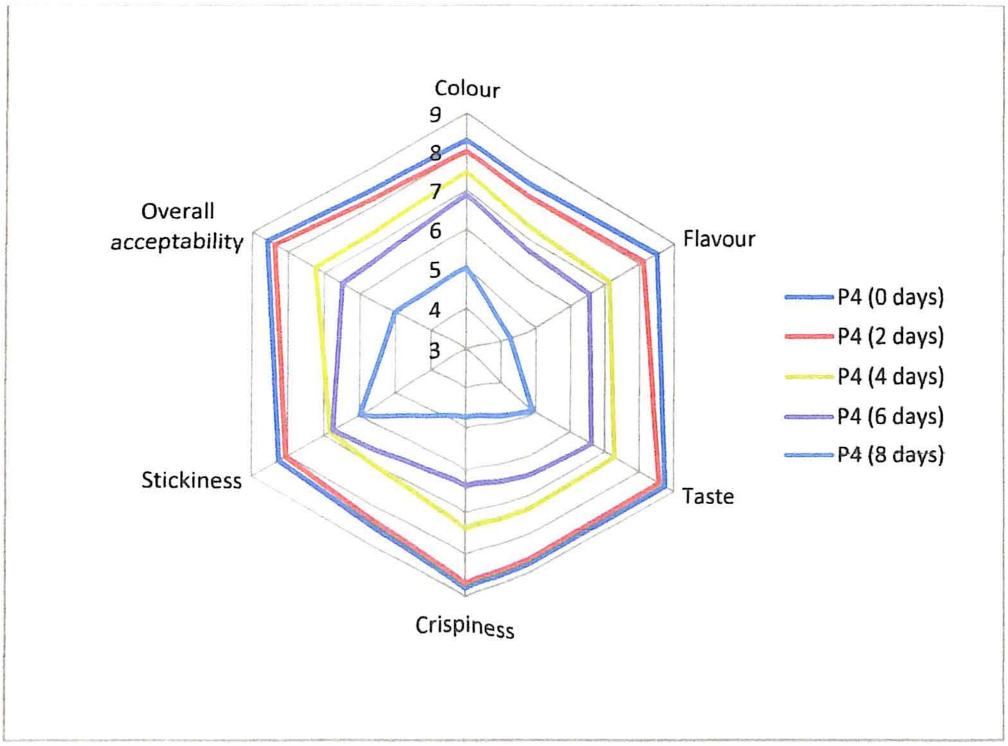
(a)


Colour
Favour
Taste
Crispiness
Stickiness
Overall acceptability
9
8
7
6
5
4
3
P2 (0 days)
P2 (2 days)
P2 (4 days)
P2 (6 days)
P2 (8 days)

(b)



(c)



(d)

Figure 4.8 Effect of storage periods and packaging material on sensory properties

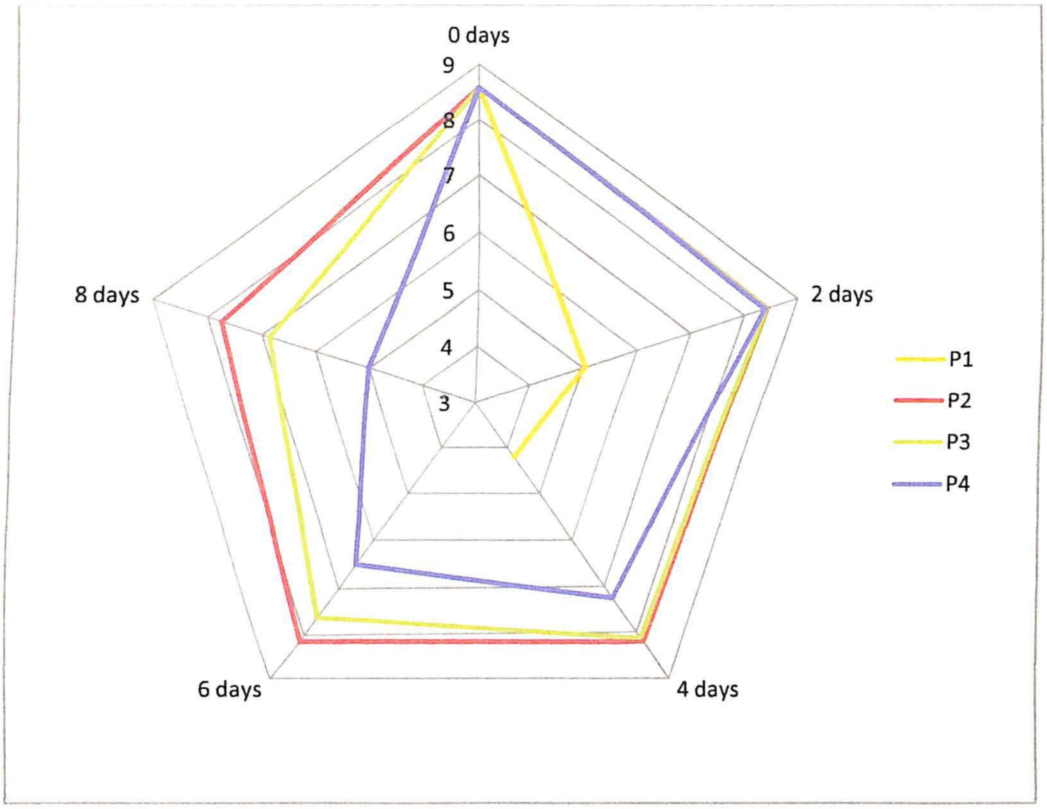


Figure 4.9 Effect of storage periods and packaging material on overall acceptability

Chapter V

SUMMARY AND CONCLUSION

Chapter-5

SUMMARY AND CONCLUSION

The snack food is one of the most important areas of the food industry. Designing snack foods today can be a complex process to meet changing consumers taste and expectations to a wide variety of people. Most snack manufacturers use some form of existing technology as the basis for creating snack products and incorporate variations that increase the resulting snacks health image. Therefore, puffing and popping using advance technologies are processes, which can accomplish all these targets. As a simplest, inexpensive and quickest traditional method of dry heat application for preparation of ready-to-eat snacks products, puffing has been practiced since hundreds of years. Convenient snack foods like popcorn, popped and puffed rice, popped sorghum, popped wheat roasted and puffed soybean and other legumes are very popular not only in Indian subcontinent, but also worldwide (Anderson, 1971; Jaybhaye *et al.*, 2014). In addition to the traditional puffed breakfast cereals, newer developments have included healthy bars, confectionery and savoury foods.

Rice (*Oryza sativa* L.) is a major global crop and food source, especially in tropical and subtropical regions and this is increasingly popular for making breakfast cereals, snack bars and rice cakes and also as a light food when puffed as either brown or milled rice by processing at high temperatures. India with divergent food habits is having a number of traditional foods, including sweet products. Chikki or Bar is one of the popular Indian traditional sweet snacks. Puffed rice bar is mainly prepared using jaggery as sweetener and puffed rice. Sweets or confections with jaggery are gaining popularity due to the awareness of its health benefits. It contains the natural goodness of minerals and vitamins inherently present in sugarcane juice & this crowns it as one of the most wholesome and healthy sugars in the world. Since the product is popular among all sections of population in the country, an attempt was made to further enrich with nutraceuticals by incorporating flax seeds. In the present work flaxseeds were blended with puffed rice bar formulation to increase the essential fatty acids and the effect of blending of flax seeds with puffed rice for the optimization of bar was studied. In recognition of the above needs and in order to explore the possibility of preparation of puffed rice bar the present investigation was carried out to standardize the relation between different process variables on bar preparation and to determine a set of optimum processing conditions suitable for better retention of therapeutic values.

Keeping all these facts in view the present work aimed at the following objectives:

1. To develop a device for preparation of puffed rice bar with uniform size and compaction.
2. To optimize the process variables for preparation of blended puffed rice bar with respect to sensory evaluation and strength characteristics using RSM.
3. To study the effect of packaging material on sensory properties of prepared blended puffed rice bar with respect to storage period.

In order to conduct the experiment in a systematic and efficient manner the entire experimental work was divided into various components. Before starting the experiment the independent variables and their levels were decided. The relevant parameters through which the inference of the experiment was to be predicted were selected as dependent parameters. Such plans were designed objective wise and are presented below.

Objective -1

Size of Bar: 5cm x 5cm x 3cm (fixed parameter)

Independent parameter:

1. Bar making device
2. Traditional
3. Individual mould

Dependent parameter:

1. Capacity, kg/h
2. Uniformity in size, %

3. Bulk density, g/cm^3

Objective -2

End point temperature (fixed parameter)

Independent variable:

1. Jaggery -80%, 90% and 100% of puffed rice (w/w)
2. Flaxseed - 10% , 20% and 30% of puffed rice (w/w)
3. Tamarind juice - 5ml, 10ml and 15ml per kg puffed rice

Dependent variable:

1. Mechanical properties- Firmness, toughness, compliance
2. Sensory properties- Taste, colour, flavour, crispiness, stickiness, overall acceptability

To optimize the process parameters Box-Behnken methods of response surface methodology has been used. Among mechanical properties firmness and among sensory overall acceptability have been considered as indices and used as response function. Total numbers of experimental combination were 15.

Objective – 3

Independent variable:

- Packaging material:

    1. Cellophane wrapping
    2. Low Density Poly Ethylene (LDPE) packets

- P_1: Bar wrapped with only cellophane paper
- P_2: Cellophane wrapped with LDPE sealing
- P_3: Cellophane wrapped and kept inside LDPE (not sealing)
- P_4: Without cellophane wrapped but kept and sealed by LDPE

- Storage period:

  2 days, 4 days, 6 days and 8 days

Dependent variable:

1. Colour, Flavour, Taste, Crispiness and Stickiness
2. Overall Acceptability (OA)
   (By composite scoring)

Before conducting the experiments information was collected from the traditional puffed rice laddu makers and the consumers. Traditional preparation method was noted down with respect to various unit operations, the ingredient composition and heat treatment requirements. Traditionally prepared laddu samples were collected and subjected to compression test in texture analyzer. The specific objective of these test were to determine the firmness of laddu and end point temperature of jaggery syrup during laddu preparation. Consumer preference was also analyzed for convenient size and shape of this value added products.

The developed bar making unit consisted of stainless steel compartment unit and a wooden pressing unit. The length, width and height of the device are 25.6×20.5×5cm respectively and thickness of the sheet is 1mm. the device was composed of 20 compartments with 5×5 cm internal dimension and the height of each compartment is 5 cm out of which 2 cm is the extended portion on top in order to facilitate the required compaction. The wooden pressing unit was constructed out of a wooden sheet of (24.6×19.6 cm) with a thickness of 2 cm. the bottom side of the press was parted with mica so that it could be cleaned after each operation. The top of press was provided with a steel handle at the centre in order to apply uniform compaction throughout the unit. The capacity and percentage uniformity size are determined using formulae.

Experiments were planned to optimize the process parameters of puffed rice bar using response surface method (RSM). The three independent variables were jaggery % (80, 90 and 100), flaxseed % (10, 20 and 30) and tamarind juice in ml (5, 10 and 15). The plan consisted of 15 experimental runs with three experiments at centre point. The dependent quality attributes of bar considered were firmness and overall acceptability (OA). The experimental data were analyzed to develop response functions and the input variables were optimized for best outputs. A complete second order polynomial model of following form was fitted to the data of all responses using multiple regression technique. The adequacy of the model was tested considering R^2 (The coefficient of multiple determination), Fischer's F-test and residual graphs. The models were then used to interpret the effect of variables input parameters on the response. The optimization of this puffed rice bar was aimed at finding levels of J%, FS% and TJ ml at maximum overall acceptability with a targeted firmness.

Cellophane and LDPE packaging materials are used for the storage study with four different conditions which is explained in the experimental design

Quality analysis was performed by the textural analysis and sensory evaluation The sensory evaluation was done using a nine point hedonic scale following the procedure of ISI. The attributes for the products under study considered were colour, flavour, taste, crispiness and stickiness. However, the overall acceptability was estimated using composite scoring. A panel of 12 semi trained members evaluated the prepared the blended puffed rice bar. The textural hardness of bar sample was measured using a texture analyzer with texture exponent software. The study was conducted by using 50 kg load cell. The samples were tested by using 75mm compression platen (P/75) probe which was operated at the speed of 2mm/sec. The samples were compacted by 66.67% from initial height of 30mm to final height of 20mm. The physio- chemical properties of puffed rice, jaggery and flaxseed were conducted and the values are given in results section.

The data obtained during the course of investigation were analyzed and the salient conclusions are given below:

1. Among the hard jaggery and the soft jaggery, the traditional soft jaggery was found to be more suitable for proper binding of the bar than the hard one.
2. The end point temperature of the jaggery syrup was found out to be 120-122°C.
3. The developed bar making device is found to be useful in preparing puffed rice bar with a capacity 7.68 kg/h (400 numbers/h) with 90% uniformity in size and shape.
4. The optimum operating conditions for preparation of blended puffed rice bar for multiple responses i.e. J%, FS% and TJ ml are -0.0303, -1, -0.0505 (coded

values) and 90, 10 and 10 (uncoded values) respectively. Corresponding to this conditions values of responses i.e. firmness and overall acceptability were 21 N/mm and 7.5 respectively. The overall desirability was 0.859.

5. Adequacy of 2^{nd} order models developed for firmness and overall acceptability through regression analysis were confirmed by R^2 more than 0.95 (0.976 for firmness and 0.983 for overall acceptability).
6. The results revealed that all the process variables (J%, FS%, TJ ml) had significant effect on firmness and overall acceptability of blended puffed rice bar. Jaggery and tamarind juice content had most significant effect on both the responses.
7. The surface profiles were drawn as a function of two process variables with the third one at optimum value and successfully interpreted.
8. Overall analysis of the sensory evaluation of storage study revealed that the samples with both cellophane wrapping and LDPE sealing performed better than any other type upto 8 days of storage with overall acceptability of 7.74 by composite scoring.

values) and 90, 10 and 10 (uncoded values) respectively. Corresponding to this conditions values of responses i.e. firmness and overall acceptability were 21 N/mm and 7.5 respectively. The overall desirability was 0.859.

5. Adequacy of 2nd order models developed for firmness and overall acceptability through regression analysis were confirmed by R^2 more than 0.95 (0.976 for firmness and 0.983 for overall acceptability).
6. The results revealed that all the process variables (J%, FS%, TJ ml) had significant effect on firmness and overall acceptability of blended puffed rice bar. Jaggery and tamarind juice content had most significant effect on both the responses.
7. The surface profiles were drawn as a function of two process variables with the third one at optimum value and successfully interpreted.
8. Overall analysis of the sensory evaluation of storage study revealed that the samples with both cellophane wrapping and LDPE sealing performed better than any other type upto 8 days of storage with overall acceptability of 7.74 by composite scoring.

Chapter VI

SUGGESTIONS FOR FUTURE WORK

Chapter-6

SUGGESTIONS FOR FUTURE WORK

The following suggestions are made for the future work.

1. The bar making unit may be modified to make it flexible to have higher capacity for preparation of puffed rice bar of different size at a large scale.
2. The blending of bar with different ingredients like peanut, walnut, cashew, almonds, pistachios, Bengal gram, sesame and copra etc. would enhance the flavor and taste of bar. So further work is recommended for the blending of these ingredients to puffed rice bar.
3. Attempt may be made to enhance the shelf life of the product in summer season by using HDPE packaging material and different storage environment.

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APPENDICES

Appendix A: Regression and optimization results

A1: Response Surface Regression: Firmness versus J, FS and TJ

The analysis was done using coded units.

Estimated Regression Coefficients for Firmness

Term	Coef	SE Coef	T	P
Constant	20.9333	0.6283	33.318	0.000
A	3.9175	0.3847	10.182	0.000
B	0.9138	0.3847	2.375	0.064
C	3.1613	0.3847	8.216	0.000
A*A	-1.5979	0.5663	-2.822	0.037
B*B	0.9496	0.5663	1.677	0.154
C*C	-0.2554	0.5663	-0.451	0.671
A*B	-0.1550	0.5441	-0.285	0.787
A*C	1.1200	0.5441	2.058	0.095
B*C	1.8775	0.5441	3.451	0.018

S = 1.08822 PRESS = 83.3716
R-Sq = 97.62% R-Sq (pred) = 66.44% R-Sq (adj) = 93.33%

Analysis of Variance for Firmness

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	242.479	242.479	26.9421	22.75	0.002
Linear	3	209.402	209.402	69.8007	58.94	0.000
Square	3	13.863	13.863	4.6211	3.90	0.088
Interaction	3	19.214	19.214	6.4046	5.41	0.050
Residual Error	5	5.921	5.921	1.1842		
Lack-of-Fit	3	5.094	5.094	1.6982	4.11	0.202
Pure Error	2	0.827	0.827	0.4133		
Total	14	248.400				

A2: Response Surface Regression: OA versus J, FS and TJ

The analysis was done using coded units.

Estimated Regression Coefficients for OA

Term	Coef	SE Coef	T	P
Constant	7.45000	0.06455	115.415	0.000
A	0.08750	0.03953	2.214	0.078
B	-0.10000	0.03953	-2.530	0.053
C	-0.01250	0.03953	-0.316	0.765
A*A	-0.70000	0.05818	-12.031	0.000
B*B	0.02500	0.05818	0.430	0.685
C*C	-0.50000	0.05818	-8.593	0.000
A*B	-0.07500	0.05590	-1.342	0.237
A*C	-0.50000	0.05590	-8.944	0.000
B*C	-0.07500	0.05590	-1.342	0.237

S = 0.111803 PRESS = 0.93125
R-Sq = 98.37% R-Sq (pred) = 75.78% R-Sq (adj) = 95.45%

Analysis of Variance for OA

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	3.78183	3.78183	0.420204	33.62	0.001
Linear	3	0.14250	0.14250	0.047500	3.80	0.092
Square	3	2.59433	2.59433	0.864778	69.18	0.000
Interaction	3	1.04500	1.04500	0.348333	27.87	0.002
Residual Error	5	0.06250	0.06250	0.012500		
Lack-of-Fit	3	0.05750	0.05750	0.019167	7.67	0.118
Pure Error	2	0.00500	0.00500	0.002500		
Total	14	3.84433				

A2: Response Surface Regression: OA versus J, FS and TJ

The analysis was done using coded units.

Estimated Regression Coefficients for OA

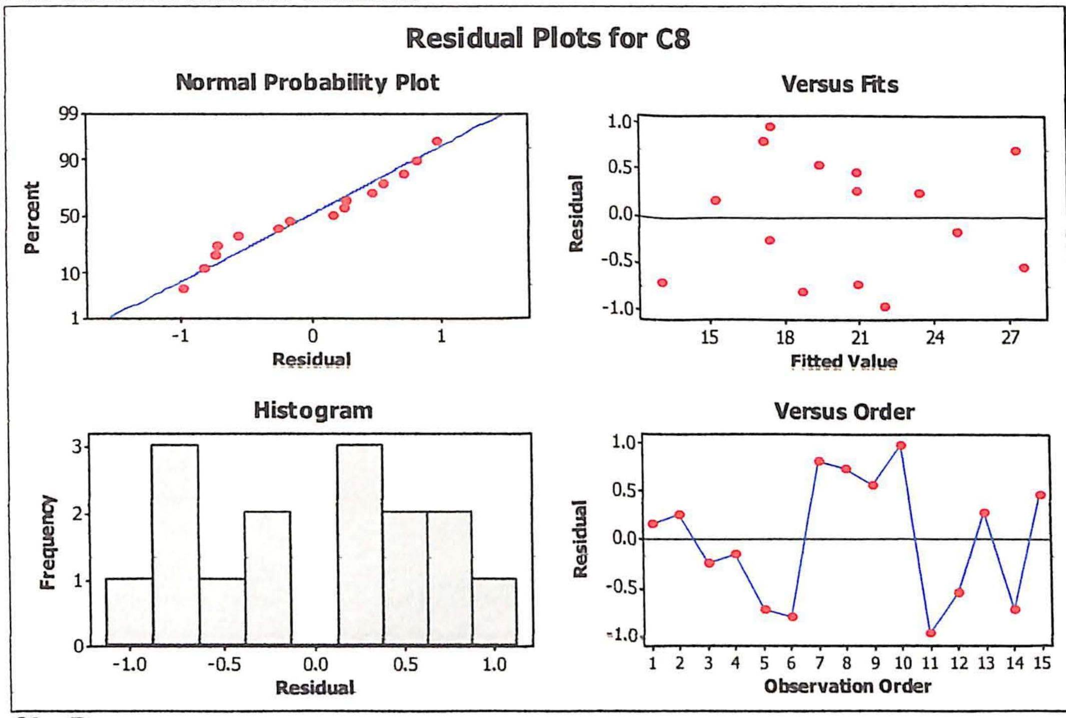
Term	Coef	SE Coef	T	P
Constant	7.45000	0.06455	115.415	0.000
A	0.08750	0.03953	2.214	0.078
B	-0.10000	0.03953	-2.530	0.053
C	-0.01250	0.03953	-0.316	0.765
A*A	-0.70000	0.05818	-12.031	0.000
B*B	0.02500	0.05818	0.430	0.685
C*C	-0.50000	0.05818	-8.593	0.000
A*B	-0.07500	0.05590	-1.342	0.237
A*C	-0.50000	0.05590	-8.944	0.000
B*C	-0.07500	0.05590	-1.342	0.237

S = 0.111803 PRESS = 0.93125
R-Sq = 98.37% R-Sq (pred) = 75.78% R-Sq (adj) = 95.45%

Analysis of Variance for OA

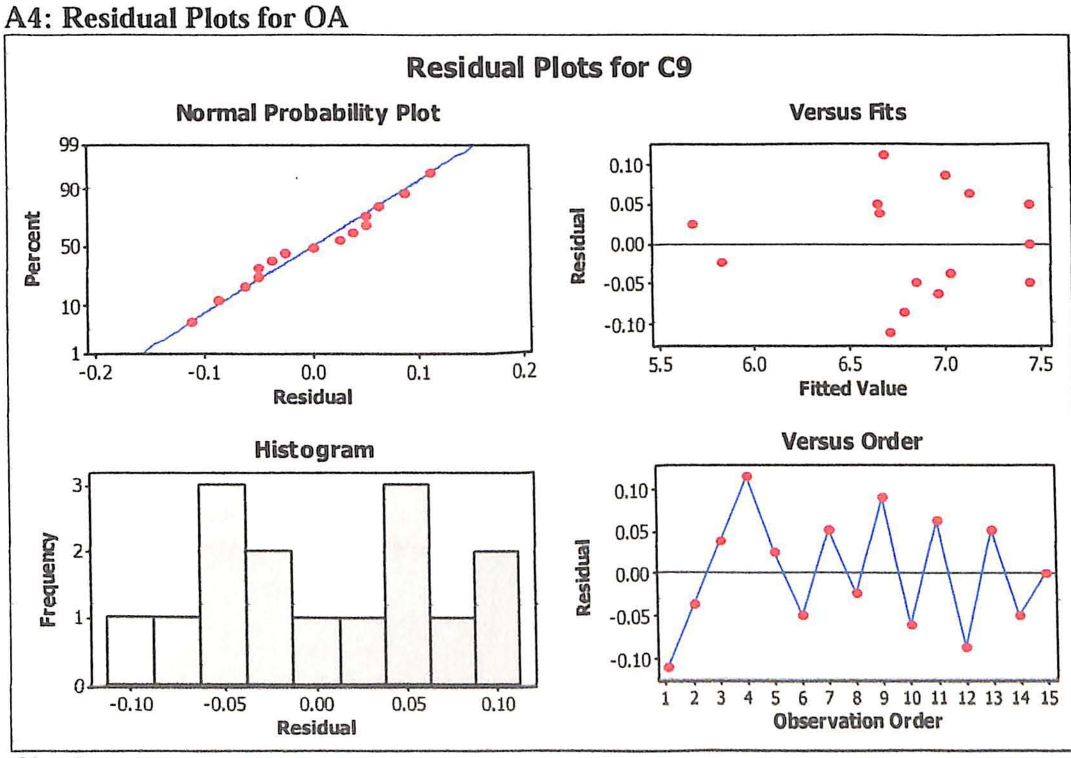
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	3.78183	3.78183	0.420204	33.62	0.001
Linear	3	0.14250	0.14250	0.047500	3.80	0.092
Square	3	2.59433	2.59433	0.864778	69.18	0.000
Interaction	3	1.04500	1.04500	0.348333	27.87	0.002
Residual Error	5	0.06250	0.06250	0.012500		
Lack-of-Fit	3	0.05750	0.05750	0.019167	7.67	0.118
Pure Error	2	0.00500	0.00500	0.002500		
Total	14	3.84433				

A3: Residual Plots for Firmness



C8 = Firmness

A4: Residual Plots for OA



C9 = Overall acceptability

A5: Response Optimization

Parameters	Goal	Lower	Target	Upper	Weight	Import
C8	Target	20.0	21.0	22.0	1	1
C9	Maximum	7.5	7.6	7.6	1	1

Starting Point
A = -1
B = -1
C = -1

Global Solution
X_1 = 0.0303030
X_2 = -1
X_3 = -0.0505051

Predicted Responses
Firmness = 21.0239, desirability = 0.976093
OA = 7.5756, desirability = 0.756147

Composite Desirability = 0.859110

Appendix B: Average data for sensory evaluation of blended puffed rice bar by 9-point hedonic scale

Sample	Attributes					
	Colour	Flavour	Taste	Crispiness	Stickiness	Overall acceptability
S1	7.13	6.74	6.55	6.21	6.8	6.6
S2	7.03	7.11	7.13	6.95	7.2	7.0
S3	6.84	6.92	6.71	6.58	6.84	6.7
S4	6.48	7.15	6.86	6.74	7.12	6.8
S5	6.41	6.05	5.46	5.22	6.21	5.7
S6	6.84	7.08	6.65	6.87	7.02	6.8
S7	7.01	6.73	6.85	6.38	6.77	6.7
S8	6.62	6.72	5.35	5.16	6.19	5.8
S9	7.73	6.94	7.13	6.97	7.2	7.1
S10	6.44	7.04	6.94	7.05	7.12	6.9
S11	7.33	7.27	7.33	7.26	6.93	7.2
S12	6.81	6.87	6.34	6.91	6.83	6.7
S13	7.66	7.26	7.74	7.73	7.21	7.5
S14	7.36	7.11	7.25	7.76	7.32	7.4
S15	7.52	7.12	7.36	7.64	7.48	7.45
Weightage factor	15/100	15/100	25/100	30/100	15/100	-

Appendix C: Weightage factor of blended puffed rice sensory attributes

Panelists	Colour	Flavor	Taste	Crispiness	Stickiness
P1	10	10	20	40	20
P2	20	20	35	15	10
P3	20	10	30	30	10
P4	10	20	35	25	10
P5	20	10	30	30	10
P6	15	15	30	30	10
P7	10	20	35	25	10
P8	10	15	30	35	10
P9	15	15	25	35	10
P10	10	15	25	30	15
P11	15	10	30	35	20
P12	10	20	10	40	20
Average	13.75	15	27.916	30.83	12.916

Appendix D: Effect of storage periods on sensory attributes of puffed rice bar

Sample	Storage periods (days)	Sensory attributes					
		Colour	Flavour	Taste	Crispiness	Stickiness	Overall acceptability
Initial	0	8.3	8.5	8.75	8.8	8.25	8.58
P1	2	7.25	5.1	4.50	4.25	5.25	5.03
	4	4.25	4.02	4.5	4.05	4.15	4.2
P2	2	8.05	8.15	8.65	8.75	8.1	8.43
	4	7.95	8.05	8.35	8.55	7.72	8.21
	6	7.84	7.98	8.3	8.45	7.7	8.13
	8	7.35	7.25	8.01	8.25	7.15	7.74
P3	2	8.02	8.15	8.6	8.73	8.12	8.41
	4	7.78	7.85	8.32	8.46	7.82	8.13
	6	7.46	7.05	7.96	7.85	7.34	7.62
	8	7.11	6.74	6.85	6.86	6.75	6.86
P4	2	8.01	8.11	8.58	8.69	8.06	8.38
	4	7.48	7.12	7.28	7.38	6.82	7.25
	6	6.88	6.54	6.62	6.36	6.74	6.5
	8	5.02	4.26	4.91	4.74	5.98	5.01