DEVELOPMENT OF SEMI-AUTOMATED MULTIGRAIN CONTINUOUS HOT AIR PUFFING SYSTEM

THESIS

Submitted to
Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola
in partial fulfilment of the requirement
for the Degree of

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AGRICULTURAL ENGINEERING
(AGRICULTURAL PROCESS ENGINEERING)

By

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DECLARATION OF STUDENT

I hereby declare that the experimental work and its interpretation in the Thesis entitled **“DEVELOPMENT OF SEMI-AUTOMATED MULTIGRAIN CONTINUOUS HOT AIR PUFFING SYSTEM”** or part thereof has neither been submitted for any other degree or diploma of any University, nor the data have been derived from any thesis/ publication of any University or scientific organization. The source of materials used and all assistance received during the course of investigation have been duly acknowledged.

Place: Akola **(SURPAM TUKESH BALAJI)**

Dated: 19/08/2019 Enrolment No: CC-222

CERTIFICATE

This is to certify that thesis entitled **“DEVELOPMENT OF SEMI-AUTOMATED MULTIGRAIN CONTINUOUS HOT AIR PUFFING SYSTEM”** submitted in partial fulfillment of the requirement for the degree of “**Doctor of Philosophy in Agricultural Engineering (Agricultural Process Engineering)”** of Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola is a record of bonafide research work carried out by **SURPAM TUKESH BALAJI** under my guidance and supervision.

The subject of the thesis has been approved by the Student’s Advisory Committee.

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List of Abbreviations

°C	degree centigrade
Agril.	Agricultural
ANOVA	Analysis of Variance
Bn	Billion
Kcal	Kilo calories
CD	Critical Difference
CHAPS	Continuous Hot Air Puffing System
CL	Colour
Cp	Specific heat at constant pressure
CSP	Crispness
Db	Dry basis
Dm	Dry matter
Dr. PDKV	Dr. Panjabrao Deshmukh Krishi Vidyapeeth
ER	Expansion ratio
et.al.	and all
Etc	etceteras, and so forth
FCRD	Factorial Completely Randomized Design
Fig	Figure
HD	Hardness

Hp	Horse power
HTST	High Temperature Short Time
i.e.	that is
IIT	Indian Institute of Technology
In	Inch
INR	Indian Rupees
J	Journal
J	Jule
Kg	Kilogram
kW	kilo watt
Lb	Pound
LPG	Liquified Petrolium Gas
M	Mass
Max	Maximum
MC	Moisture content
Min	Minimum
Ml	mili liter
mm	Milimeter
MPa	Mega pascal
PP	Puffing percentage
Q	Heat load

Rs.	Rupees
RTE	Ready to Eat
viz	Namely
wb	Wet basis
Yr	Year
ρ_a	Density of air

THESIS ABSTRACT

a) **Title of the thesis** : **DEVELOPMENT OF SEMI-AUTOMATED MULTIGRAIN CONTINUOUS HOT AIR PUFFING SYSTEM**

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ABSTRACT

The puffing process can broadly be classified as the sand puffing, salt puffing, air puffing, oil puffing and roller puffing. Puffing is a simplest inexpensive and quickest traditional method of dry heat application, wherein grains are exposed to high temperature for short time (HTST).

The semi automated multigrain continuous hot air puffing system developed was operated with 1 hp electric power source for blower, 11 heater each with capacity of 0.75 kW with puffing capacity of 6 to 8 kg/h. The system consisted of electric heating assembly, continuous feeding system, continuous outlet system, cyclone separator and re-circulation of air unit. The optimized parameter for hot air puffing of sorghum and bajra were 0.025 and 0.22 kg/kg dm initial moisture content, 285°C and 355 °C puffing temperature, 5.5 and 4 m/s air velocity and 7982 and 8250 g/h feed rate, respectively. As moisture content of whole grain was too low to impart puffing, the moisture content of whole grain was increased to a predetermined level for maximum expansion effect and puffing yield. The sample of finger millet, kodo millet and kutki did not require additional moisture, because the whole grain moisture content was adequate for better puffing. The finger millet is not amenable for puffing in the form of whole grains, because, the seed coat of the finger millet grains, if not removed, it not only affects the puffing quality but also its expansion ratio. The endosperm of the millet is covered with the rigid seed coat. Since, the seed coat is firmly attached to the endosperm, the decortications becomes inevitable for puffing purpose.

The optimized parameter for hot air puffing of decorticated finger millet, kodo millet and kutki were 330, 270, and 380 °C puffing temperature, 2.5, 3.5 and 2.5 m/s air velocity and 6608, 6608 and 7686 g/h feed rate, respectively.

Since the process for hot air puffing of millet grains involved heat treatments, it is necessary to verify the changes occurring during hot air puffing of sorghum, bajra, finger millet, kodo millet and kutki grains. Therefore, the various bio-chemical composition *viz*., moisture content, protein, fat, carbohydrates, ash content, crude fiber, tannin and polyphenols content were determined. Moisture content, protein and tannin decreased due to the effect of higher air puffing temperature, while carbohydrates, crude fiber and iron increased. It could be observed that there was slight difference in fat, ash, and polyphenols content in hot air puffed millet grains.

Storage studies revealed that at very high humidity (95%) and temperature (45 °C) the hot air puffed sorghum, bajra, finger millet, kodo millet and kutki lost its shelf life within 20, 18, 22, 11 and 23 days in HDPE and 26, 27, 27, 20 and 26 days in Multi layer flexible film, respectively. It could be predicted that the hot air puffed grains if stored in Multi layer flexible packaging package at moderate RH (65 %) and ambient temperature of 30°C, considerably long shelf life of 182, 139, 190, 84 and 208 days in case of hot air puffed sorghum, bajra, finger millet, kodo millet and kutki, respectively, would be possible.

It is seen that 100 micron HDPE could protect about 4, 3, 4, 2 and 5 months at 30°C and 65 % RH and the 85 microns of Multi layer flexible could give the shelf life of 6, 5, 6, 3 and 7 months at 30°C and 65 % RH for hot air puffed sorghum, bajra, finger millet, kodo millet and kutki, respectively.

Key words: Millet, HTST, Hot air puffing, RTE

CHAPTER I

INTRODUCTION

1.1 Background Information and current status of millets

Cereals and millets play an important role in the human diet. Cereals belong to the family *Poaceae*, which include wheat, rice, barley, oats, rye, maize, sorghum and millets as major grain crops in the world market. Millets are small seeded cereals that are cultivated mainly in semiarid and tropical region of Asia and Africa.

Sorghum is the world fifth most important cereals and widely grown both for food and as a feed grain production. Roughly 90% of world sorghum area lies in the developing countries. India has the largest share (32.3%) of the world's area under sorghum and ranks second in production after the United State. The sorghum grain production of India in 2017-18 was 4.57 Million metric tonnes from an area of 5.10 Million hectares (Anonymous, 2018).

The nutrient composition of sorghum grain indicates that it is a good source of energy, protein, vitamins, and minerals including trace elements. Sorghum has 11.9 % of moisture and about 10.4 % of protein and a lower fat content of 1.9 %. The fibre and mineral content of grain sorghum is 1.6 %. It is a good source of energy and provides about 349 kcal and has 72.6 % of carbohydrates. Starch is the major carbohydrate of the grain. The other carbohydrates present are simple sugars, cellulose and hemicellulose. Sorghum is also rich in dietary fibre (14.3%). Calcium, phosphorous and iron content of sorghum is 25 mg, 222 mg and 4.1 mg (per 100 g of edible portion), respectively (Hosmani and Chittapur, 1997).

Millet is one of the oldest cultivated foods known to humans and possibly the first cereal grain used for the domestic purposes. Millet has been used in Africa and India as a staple food for thousands of years and out of 30 MT of millet produced in the world, about 90 % is utilized in developing countries and only a tiny volume is used in developed countries (Kundgol, 2012). The millet grain production of India in 2017-18 was 0.3909 MT from an area of 0.6499 Mha (Anonymous, 2018).

Millets are a group of small grained cereals and the smallest of them are collectively referred as small millets that include crops such as kodo millet (*Paspalum scrobiculatum*), finger millet (*Eleusine coracana*), little millet (*Panicum sumatrense*), foxtail millet (*Setaria italic*), proso millet (*Panicum milliaceum*) and barnyard millet (*Echino chloafrumentacea*) (Chandan Kumar, 2015).

Amongst minor millets finger, barnyard, foxtail, kodo, proso etc. are nutritionally rich, especially in micronutrient content. These are the most recognized nutritionally for being a good source of minerals like magnesium, manganese and phosphorus. Research has linked magnesium to a reduced risk for heart attack and phosphorus is important for the development of body tissue and energy metabolism. Millets are also rich in phytochemicals, including phytic acid (Shashi *et al.* 2007), which is believed to lower cholesterol, and phytate, which is associated with reduced cancer risk. Thus, millets are strategic in terms of their food, nutritional and livelihood security and their role in local agro-ecosystems (Joshi *et al.,* 2008). Millets also contains B vitamins, especially niacin, B6 and folic acid and minerals like calcium, iron, potassium, magnesium and zinc (Vachanth *et al.,* 2010).

Millet is a starchy food with a 75:25 amylopectin to amylose ratio and is a fairly good source of lipids (3-6 %) having about 50 % of the lipids in the form of polyunsaturated fatty acids (Sridhar and Lakshminarayana 1994). Although millet is known to contain amylase inhibitors, the carbohydrate digestibility of millet foods is not affected due to heat labile nature of the inhibitors (Chandrasekher *et al.,*1981).

Finger millet [*Eleusine coracana* (L) Gaertn] commonly known as ragi, nachni or nagli, is a small grain grown in the semi-arid and tropical regions of Africa and Asia where it is one of the cereal staples (Obilina and Manyasa 2002). Finger millet is cultivated mainly in eastern, central and southern Africa and in Asia it is produced in India, Nepal and china (House, 1995; Obilina and Manyasa, 2002). In India, the major finger millet growing states are Karnataka, Tamil Nadu, Andhra Pradesh, Orissa, Maharashtra, Uttar Pradesh, Bihar and Gujarat. Finger millet is the third most important millet in India next to sorghum and pearl millet, covering an area of 2Mha with annual production of 2.15 MT (Apoorva *et al.,* 2010).

Proso millet (*Panicum miliaceum*) is also known as common millet, hog millet, white millet and baragu in Kannada. It is extensively cultivated in India, Russia, Ukraine, Turkey and Romania. Proso millet is well adapted to many soil and climatic conditions. It has a short growing season and requires little water. It is sold as health food and due to its lack of gluten content, it can be included in the diets of people who cannot tolerate wheat. The area covered under proso millet in India is about 0.0484 Mha with production of 0.0244 MT and productivity of 504 Kg/ha (Anonymous, 2006). In India, it is mainly grown in Andhra Pradesh, Maharashtra, Karnataka, Madhya Pradesh, Uttar Pradesh, Tamil Nadu and Bihar. In Bihar, it is cultivated throughout the year as a catch crop.

Kodo millet (*Paspalum scrobiculatum*), also known as varagu (Tamil) and haraka (Kannada), is harvested as a wild cereal in Western Africa and India. It grows abundantly along paths, ditches and low spots. The species was domesticated in India about 3000 years ago. It is known to be grown in the dry areas of West Bengal and hilly areas of Himachal Pradesh and Nepal (Sudha Devi, 2012).

Little millet (*Panicum sumatrense*) is also known as samai (Tamil) and saame (Kannada). It is grown in temperate zones of Asia, the Caucasus, China, East Asia and also in the tropics of India, Indochina and Malaysia. It can withstand both drought and water logging. It can be cultivated up to 2000 m above sea level. The largest cultivation is in central India. The yield is generally less than 500 kg/ha, but under favorable conditions, it may reach close to 1000 kg/ha. The average annual production is around 0.101 to 0.159 MT (Anonymous, 2007).

Small millets are tasty with a mildly sweet, nut-like flavour and contain a myriad of beneficial nutrients. Small millets contain 9–14%

protein, 70-80% carbohydrates and are rich source of dietary fibre (Malleshi and Hadimani, 1993). Even though the nutritional qualities of small millets have been well recorded (Hulse *et al.,* 1980), their utilization as food is confined to the traditional consumers in tribal population mainly due to non-availability of consumer friendly, Ready-to-use or Ready-to-eat products as in rice and wheat. In recent years, small millets have received attention, mainly because they are recognized as high fibre foods and efforts are underway to take them to consumers in convenient forms. Exploratory studies conducted on popping and milling of small millets has been promising (Malleshi and Desikachar, 1986).

1.2 Importance, need and scope of study

Food processing is employment intensive and creates 1.8 % jobs directly and 6.4 % indirectly across the supply chain of every Rs. 1 million invested for employment generation. It provides convenience & safe food to consumers and promotes diversification and commercialization of agriculture by providing effective linkage between consumers and farmers.

New food processing techniques can change the texture and taste of products made from millets and has a high potential for improvement of nutrient availability. Therefore, processing of millets to prepare Ready-to-use and Ready-to-eat products would enhance their food and economic value. Millets are claimed to be future foods for better health and nutrition security. They are recognized as important substitutes for major cereal crops to cope with the world food shortage and to meet the demands of increasing population of both developing and developed countries (Veena *et al.,* 2004). In recent years, millets have received attention, mainly because of their high fiber content and thus efforts are under way to provide it to consumers in convenient forms (Mansour, 2014).

The population of human being is ever increasing with vigorously changing lifestyle. This changing lifestyle is accompanied with changing demand, changing needs and habits. Newer technologies for processed food products have increased the demand for convenience foods.

Ready-to-eat (RTE), quick cooking and instant foods have become very common largely due to today's life style and the demand for quick-to-serve foods. Fast moving life of human demands convenience in food production, preparation and convenience in its consumption too. As a result, the convenience food sector has grown by 70 % over the past decade, creating a huge market. Convenience foods are designed to save consumers' time in the kitchen and reduce costs due to spoilage. These foods require minimum preparation, typically just heating, and can be packaged for a long shelf life with little loss of flavor and nutrients over time (Anonymous, 1998).

The food industry consists of segments like processed fruits and vegetables, cereal based RTE products, dairy products, meat, poultry and fishery products, beverages and confectionary. The RTE, quick cooking and instant foods are becoming very popular in this fast moving world. The food consumptive, which does not require domestic kitchen or cooking, is known as RTE (Kent and Evers, 1994). RTE breakfast cereals invented as corn flakes, and puffed rice by Dr. P. Anderson of USA (Brockington, 1950), revolutionized the food industry by providing a wide variety of tasty cereal products, representing the first of modern convenience foods. RTE food products include extruded snacks, puffed cereals, popcorn, rice-flakes and fried fryums.

Cereals and cereal based RTE foods being the cheapest of all the fuel foods for humans. All cereals and millets contain a large proportion of starch. In its natural form, starch is insoluble, tasteless and unsuited for human consumption. To make it digestible and acceptable it must be cooked. Breakfast cereals are products that are consumed after cooking and they fall into two categories, those made by a process that does not include cooking and which therefore have to be cooked domestically and those which are cooked during processing and which require no domestic cooking are described as RTE cereals (Kent and Evers, 1994).

Puffing is a simplest inexpensive and quickest traditional method of dry heat application, wherein grains are exposed to high temperature for short time (HTST). Super heated vapors is produced inside the grains by instantaneous heating, which cooks the grain and expand endosperm while escaping from with the great force through the microspore of the grain structure. This transformation occurs because of a high amount of natural moisture trapped inside the hull. Heating the grain immense pressure, which bursts open the hull, turning the kernel inside out. Each kernel of popcorn contains a certain amount of moisture and oil. Unlike most other grains, the outer hull of the puffed grain kernel is both strong and impervious to moisture and the starch inside consists almost entirely of a hard, dense type (Yenagi *et al*., 2005).

The puffing process can broadly be classified as the sand puffing, salt puffing, air puffing, oil puffing and roller puffing as example of atmospheric pressure process (Chandrashekar and Chattopadhya, 1989) while gun puffing is example of pressure drop process (Hoseney, 1986). The oil puffing adds oil to the puffed products thereby affecting shelf life besides health problems. The sand puffing imparts contamination of product with sand, while gun puffing demands extremely high working pressure. The extrusion puffing is highly sophisticated and required very high operating pressure and temperature. Puffing will ideally create an aerated, porous with added benefits of dehydration (Arya, 1992).

Generally, cereal grains are puffed with hot air, hot sand, frying in hot oil, microwave heating and by gun puffing methods. Roasting has a risk of burning and producing defects, while the oil from frying can be adsorbed and easily turns rancid. Moreover, the husk or wood chips fired furnace that is usually used in sand roasting method, based on conduction heating (Hoke *et al.,* 2005), presents environmental hazard as well as silica contamination. In comparison, high temperature short time (HTST) fluidized bed air puffing has better puffing efficiency as the product uniformly exposed to the heating medium (Brito-De La Fuente and Tovar, 1995).

The earlier researcher developed continuous hot air system which requires more space and feeding mechanism therein was manually operated (Babar 2011; Jadhav 2013) Large size of machine provides more area leading to more heat losses. Therefore, this system needs to be more compact and insulated with insulating material for minimizing heat losses, which will be more energy efficient. Hence some typical features like well insulated, semi automated, multigrain system, semi automated feeding arrangement for different grains, maintain feed rate for different grains need to be added in the present system to develop the semi-automated multigrain puffing system, so that user of this machine will have maximum benefits and involve in the production of such a food segment with low initial cost investment and with easily available agriculture produce as a raw material. Keeping in view the above, the present study will be undertaken with the above specific objectives.

1.3 Objectives

1) Development of semi-automated multigrain continuous hot air puffing system
2) Optimizing hot air puffing parameters for different grains
3) Biochemical analysis of product before and after puffing
4) Shelf life study of optimally puffed grains

1.4 Hypothesis

The semi-automated continuous multigrain puffing system was expected to have increased capacity, with ease of operation and safety, so that user of this machine will have maximum benefits. It will turn out a product, which will have more uniform quality and produced at much faster efficiency. This study leads to the development of a process technology for preparation of hot air puffed millets. This product would be highly crisp, stable and having longer shelf life in airtight containers, at room temperature.

The millets form a staple food for a large segment of the population, mainly those with low socio-economic status, especially during drought or famine. Conventionally, in India, the term coarse cereals cover all cereals except rice and wheat. At present, the small millets are consumed in traditional way and hardly any value added product is commercially produced except for some malted products. Small millets are known to be diabetic friendly and therefore can be perfectly employed for the development of new value added products. Such value added products are more acceptable to the modern day consumers and are more palatable. These millets are valuable in traditional food and feed. They are not usually traded in the international markets or even in local markets in many countries. So introducing puffing of millets can be involved in production of such a food segment with low initial cost investment and with easily available agriculture produce as a raw material. The quality of processed, final product of this gadget was expected to be competent with that of snack products available in market. Development of value added products using these grains may help the millet growing farmers to get better remunerative price for these produce. In order to get a good textural and nutritional property in the products.

CHAPTER II

REVIEW OF LITERATURE

A comprehensive review is mandatory in any research endeavor. This requires effort on the part of the investigator to select relevant subject matter, to organize and report it systematically. This chapter deals with the review of literary information required to formulate the research problem, carry out the work and to discuss the findings. The work, relevant to the development of RTE puffed grain snack foods from different grains viz., sorghum, bajra, finger millet, kodo millet and kutki, carried out by various investigators was reviewed extensively. The specific information availability and importance of puffed grain snack foods and puffing process are presented and discussed in brief. Review on different quality parameters associated with the development of puffed grain snack foods, estimation of chemical composition during process, changes occurring during their storage has been presented. Response surface methodology used by various researchers during the development of different puffed grain snack foods has also been reported in the following paragraphs.

2.1 Snacks

Matz (1993) has reported that the snack industry has been linked closely to the development and use of extrusion cookers for over sixty years. However, snack products predate extrusion cooking, having their origins in the traditional handmade products from earlier centuries. The classic examples of such products are puffed grains, prawn crackers and kerpok of the Far East and the tortilla snacks of South America.

2.2 Puffing methods

Matz (1970) reported the puffing process can be broadly classified as atmospheric pressure process with sudden application of heat and pressure drop process. The sand puffing, air puffing, oil puffing and roller puffing are examples of atmospheric pressure processes, while gun puffing is the example of pressure drop process. The key to the degree of puffing of the cooked grain is the suddenness of change in temperature or pressure (Hoseney, 1986).

Arya (1992) found that the sand or oven puffed/ popped products are quickly processed but they impart contamination of the product with sand while gun-puffing demands extremely high pressure for its working. The extrusion puffing is highly sophisticated and requires very high operating pressure and temperature. Puffing will ideally create an aerated, porous, snack-like texture with the added benefits of dehydration. Blending the puffed products with different flavours and marketing them in moisture impermeable plastic film pouches provide enormous opportunities for increasing acceptance and usage of puffed products.

Pardeshi and Chattopadhyay (2014) reported that the soy-fortified rice-based cold extrudate, after requisite steaming, was puffed in whirling bed of hot air using the HTST whirling bed puffing system. The hot air puffing of product was conducted at five different hot air temperatures from 200 to 240 °C at constant whirling air velocity of 3.97 m/s from its initial moisture of 0.53711 kg/kg dm.

Gayatri *et al.* (2014) observed that popping is a simple and less expensive processing method which improves textural and sensory qualities of cereals and also there are minimum changes with respect to nutrient composition in the processed product. Traditionally, popped products are prepared only during few specific occasions. This type of home processed ready-to-eat snacks has a great market potential as value added health products, convenient food, as consumer needs are changing towards more convenient foods as well as less refined or polished grains.

2.2.1 Sand puffing

In India, work on puffing of paddy has been carried out by Srinivas and Desikachar (1973) and Srinivas *et al.* (1974) they standardized a laboratory procedure for preparing small puffed paddy samples by sand roasting for the purpose of evaluation. Their study revealed that maximum expansion in puffing of paddy could be achieved by using fully mature, crack free grains having moisture content of 14 % (wb) and roasted at an optimum sand temperature of 275 °C.

Chinnaswamy and Bhattacharya (1983) has reported optimum conditions for sand puffing of rice at 250 °C for 2.5 min. for best expansion. Chandrasekhar and Chattopadhyay (1989) reported that the hydro thermally treated rice at 10.5-11 % moisture content can be puffed in sand at 250-260 °C temperature.

2.2.2 Oven puffing

Hoseney (1986) experimented as oven puffed rice made from raw or parboiled milled rice, which was cooked with the adjuncts for 1 h at 15-18 lb/in^2 in a rotary cooker until uniformly translucent. It was dried to 0.4286 kg/kg dm moisture content, tempered for 24 h and again dried to 0.25 kg/kg dm moisture content. The dried rice was subjected to radiant heat to plasticize the outside of the grain. The grain was ‘bumped’ through smooth rolls, just sufficiently to flatten and compress it and then surface dried to about 0.1765 kg/kg dm moisture content and tempered for 12-15 h at room temp. The bumped rice then passed to the toasting oven, where it remained for 30-90 s. The temperature in the oven was about 300 °C in the latter half of the oven-cycle. He reported, due to the bumping, which has compressed the grains, and the high temperature, the grains immediately puff to 5-6 times their original size.

2.2.3 Gun puffing

Fast and Caldwell (1990) reported that large grain size wheat preferred for puffing on account of its higher expansion during puffing, but durum wheat may also be used. The wheat is pre-treated with about 4 % of a saturated brine solution (26 % salt content) to toughen the bran during preheating and make it cohesive, so that the subsequent puffing action blows the bran away from the grain, thereby improving its appearance.

Explosion puffing includes initial air drying of the product to moisture content of 0.175 to 0.538 kg/kg dm, heating under pressure in a steam gun and quickly releasing the pressure which causes rapid release of vaporizing moisture, resulting in expansion of the product (Hailand *et al.,* 1977).

2.2.4 Extrusion puffing

Karve and Tikekar (2007) developed a continuous technique for puffing of amaranth seeds using single screw extruder with a tapered screw without die. It was found that the puffing efficiency of amaranth seeds was a function of temperature and screw speed. The maximum efficiency of 86% was achieved at barrel temperature of 290 °C and screw speed of 125 rpm.

2.2.5 Oil puffing

Oil puffing, especially deep fat frying, has become the most popular food preparation technology during the last five decades. The reason is that the preparation is easy even for less experienced cooks and the finished product is highly palatable. Frying is basically a dehydration process. During deep fat frying, the fat acts as heating medium and it is immiscible with water. Most of the food materials contain a lot of water. Because of high temperature, water within the food material gets heated and pumped out into the surrounding oil in the form of steam (Varela *et al.,*1988).

The increasing consumption of fried foods contributes to a high intake of fats and oils. Because consumers wish to reduce their consumption of fats and oils, pans are offered on the market that does not require any fat. When these are used the heat transfer medium is not oil and therefore, the process should not be regarded as frying but as roasting. During frying, fat or oil is preheated to temperatures of 150–180 °C. In contact with oil, fried food is heated rapidly in the surface layers to the temperature of the frying oil. The temperature reaches only 80–100 °C in inner layers (Nath, 2006).

Chattopadhyay *et al.* (2004) reported that the maximum expansion ratios of 1.980 and 1.962 and maximum mean sensory scores of 6.8333 and 6.5833 at frying temperature of 255 °C and 180 °C with frying time of 4.5 s and 14 s for cylindrical fryums and star shaped fryums, respectively. They also found that potato flakes could be fried satisfactorily at 205 to 255 °C with decreasing frying time from 4 to 2 s, giving Expansion ratio (ER) ranging from 1.654 to 1.798. The ER along thickness always remained higher than the longitudinal ER of cylindrical fryums and diametrical ER of star shaped fryums and potato flakes at all the frying temperatures.

2.2.6 Microwave puffing

The experiment was conducted to develop cold extrudate, followed by microwave puffing and subsequently by oven toasting to prepare Ready-to-eat (RTE) fasting foods. The microwave puffed product was well comparable with products available in market as per the sensory evaluation. The fat and ash content were least affected due to processing while protein content was found to be decreased due to oven toasting. The oil content in microwave puffed product was considerably less as compared to that in oil fried product (Dhumal 2010; Dhumal *et al.,* 2014).

Bhatt and Joshi (2014) observed that there was improvement in the puffing quality of the rice in terms of puffing yield, volume expansion ratio and overall acceptability score when the milled rice was treated with salt. As the concentration of the salt was increased from 0 to 3%, the quality parameters improved. The guar gum and soy protein treatment interfered in puffing of the pretreated rice resulting in poor puffing quality of the end product.

2.2.7 HTST Air puffing

Nath *et al.* (2007) developed HTST air puffed potato snacks. The cold extrudate was prepared from potato powder at moisture content of 0.581 kg/kg dm and puffed optimally in whirling bed HTST air puffing system at air velocity of 3.99 m/s at temperature of 235.46 °C in 51.11 s.

Pardeshi and Chattopadhyay (2008) analyzed that the heating of wheat based cold extrudates in HTST whirling bed of air at 215°C, up to first 8 to 10 s, caused surface moisture removal and case hardening.

The further heating caused phase conversion of entrapped moisture into vapors. These vapors could not be escaped till sufficient pressure was not built up. The further expansion of vapors inside the product led to impart puffing effect, upto 15 s of puffing time. During this period rate of moisture removal were drastically reduced. The continual heating caused development of cracks along puffing wall and escaping of vapors with further expansion.

Pardeshi (2008) has reported that the time required to attain the temperature, required to initiate puffing varied from 20 s at 200 °C to 10 s at 240 °C for wheat-soy and 15 s at 200 °C to 9 s at 240 °C for rice-soy snacks. The average material temperature attained for wheat-soy and rice-soy snacks to reach the optimum puffing effect reduced with increase in puffing air temperature.

2.3 Cereal puffing

Yenagi and Bhuvaneshwari (2004) studied the effect of bulgarisation on popping quality of wheat varieties. The process of bulgarisation increased the expansion of popped wheat grains preferable in dicoccum wheats than durum and bread wheat. Significant difference in expansion ratio of raw and bulgarised wheat varieties was observed.

Zapotoczny *et al.* (2005) studied the effect of temperature on the physical, functional, and mechanical characteristics of hot-air-puffed amaranth seeds. Amaranth seeds were puffed with hot air at 290, 330 and 370 °C. Selected temperature-dependent properties of raw and puffed amaranth seeds, namely seed size, shape, color, water and fat absorption, resistance to compression and back extrusion energy were determined. These properties are required for designing apparatus for puffing cereals with hot air. It was postulated that 290 °C is the optimum temperature for hot-air-puffing of amaranth seeds. A temperature of 330 °C may bring the expected results only when high water holding capacity of seeds is desirable.

Murthy *et al.* (2006) studies the modelling of heat and mass transfer during puffing and popping of grains by fluidization. The process parameters such as air flow rate, temperature of hot air, initial moisture content, residence time and bed height are optimized for various grains such as maize, jowar, paddy and rice in order to achieve high popping efficiency. The fluidization velocity of maize, jowar paddy and rice were found to be in the range of 4.18-5.78 m/s and the carry over velocity was found to be in the range of 2.15- 6.18 m/s. The convective heat and mass transfer coefficients were estimated and found to be in the range of 103.84 to 186.81 W/m^2 °C and 0.131 to 0.194 m/s, respectively.

2.4 Hot air puffing system

Mukharjee (1997) developed whirling bed hot air puffing system for puffing of potato cubes and reported maximum expansion ratio as 2.605 at temperature of 209.2°C and air velocity 3.67 m/s. The system is batch type and operated using LPG.

Babar (2011) developed continuous hot air puffing system that was found safe and easy to operate. The continuous hot air puffing system enables continuous feeding of raw material and continuous exit of puffed product, hence frequent resetting of temperatures and air velocities was not required. The continuous hot air puffing system had the five to six folds increased capacity over existing batch type hot air puffing systems besides reduced requirement of energy due to recirculation of used hot air. The continuous hot air puffing system could be set to any puffing temperature from 175 to 300°C and air velocity of 2.5 to 6 m/s. The optimum conditions for puffing of wheat based triangular shaped commercial fryums were found to be puffing temperature of 250 °C and feed rate of 100 g/min puffing fryums with 6 kg/h capacity. The moisture content and protein content of fryums were observed to be reduced due to hot air puffing as compared to raw material and air puffed fryums are found to be free of oil.

Kambale (2011) developed hot air puffing system for amaranth seeds and evaluated the performance by considering parameters like different moisture contents (11.65- 20.83) and different temperatures and determined the parameters like puffing time, expansion ratio, puffing efficiency and he concluded that puffing time was highest for sample with highest moisture content and vice versa. Highest time of 4.75 second was observed at the moisture content of 20.83% (w.b.), highest expansion ratio of 10.2 was found at moisture content of 15.73% (w.b.), highest puffing efficiency 97.77% was observed at moisture content of 15.73% (w.b.)

Korin (2012) developed hot-air popcorn machine especially with a seasoning coater. A popcorn making machine includes a main unit comprising a fan pumping air into chamber, enclosing a heater and a bowl. The bowl has sidewalls tapered downwardly with mini-nozzles attached thereto. Hot airflows are introduced from the chamber through the mini-nozzles into the bowl tangentially to its inner surface, forming a main hot airflow circulation. A central nozzle is mounted at the bowl's bottom, including slots, introducing additional airflows, tangential to the nozzle's surface, from the chamber into the bowl, forming an additional hot airflow circulation surrounding the nozzle, co-directed with the main circulation. The main unit comprises a receptacle collecting popcorn coming from the bowl. The claimed machine optionally includes a coater unit for coating popcorn with oil, salt, etc., and a compact cabinet enclosing the main and coater units. They concluded that the design provides fast and essentially even heating of corn kernels for efficient popping.

2.5 Properties of puffed product

2.5.1 Volume Expansion of Puffed product

Chandrasekhar and Chattopadhyay (1991) studied 12 Indian rice varieties for varietal effect and found that varieties like *Palmoi, Panloi, Kavirajsal,* etc. were expanded in hot air with expansion ratio of about 9. The expansion ratio was measured as bulk volume of puffed product to bulk volume of unpuffed product.

Case *et al.* (1992) reported that specific bulk volume of the frying-puffed product was increased as the gelatinization level of the pellets increased. They suggested also that the gelatinization level of the pellets could predict texture of the expanded products.

Singh *et al.* (2003) measured specific volume, of extruded snack foods by sand displacement method, which was used to determine bulk density (g/100 ml).

Segnini *et al.* (2004) quantified the volume of potato chips, before and after frying, by measuring the displaced volume of a fine granular material (rape seeds) by the volume of the chips. Compaction of the seeds was studied to evaluate the reproducibility and accuracy of the technique.

2.5.2 Hardness and crispness of puffed product

For freeze-thaw-dehydrated instant potato cubes, Khodke (2002) considered hardness value as mean peak compression force and measured crispness in terms of major positive number of peaks obtained by Stable Micro Systems Texture Analyzer (using cylindrical probe of 35 mm). For Biscuit, cereal based products and Potato chips, she reported the acceptable values of hardness and crispness ranging between 3000 to 4000 g and 35 to 40 (+ve peaks), respectively, were reported.

Nath and Chattopadhyay (2007) prepared hot air puffed potato snacks and observed that process temperature and time influence the crispness, hardness and colour of the finished product which decide the sensory and organoleptic qualities.

Pawar *et al*. (2014) developed RTE foods with HTST microwave puffing process. Linear and quadratic models were developed using response surface methodology (RSM) to study the synergy between process parameters and responses in terms of moisture content (MC), hardness (HD), expansion ratio (ER) and crispness (CSP).

Winopal *et al*. (2015) carried out study on instrumental sensory testing in the food industry. The mechanical texture properties like hardness, crispness and flavour of foods were studied.

2.5.3 Colour Measurement

Nsonzi and Ramaswami (1998) measured the colour of osmo-convective dried blueberries as L, a and b, directly on the product surface, using a Minolta Chroma meter. They computed colorimetric ratio (a/b) to represent the blueness and redness of the blueberries. The total colour difference (ΔE) was determined using the following equation:

$$\Delta E = \left[\Delta L^2 + \Delta a^2 + \Delta b^2\right]^{1/2}$$

Hunter Lab colour meter was used to determine the colour of freeze-thaw-dehydrated instant potato cubes (Khodke,2002). The L-values, which denotes degree of whiteness (black=0 and white=100), was chosen to represent the colour of samples.

Yam and Papadakis (2004) presented a simple method that uses a combination of digital camera, computer, and graphics software to measure and analyze the surface color of food products. The method has also the advantages of being versatile and affordable. The images of the food products can be displayed on computer screen or printed on paper for qualitative analysis of colour and structure. Quantitative information such as colour distribution and averages (in terms of L*, a* and b* values) can also be determined readily. Sawant *et al*.(2013) used the mix containing the least amount of finger millet flour (10%) had the lightest colour (highest L value) as indicated by Hunter Colour Flex Meter.

Katherine *et al*. (2006) given that RGB digital cameras obtain information in pixels, this article presents a computational solution that allows the obtaining of digital images in L*a*b* color units for each pixel of the digital RGB image. On the basis of the construction of models, it is possible to find a L*a*b* color measuring system that is appropriate for an accurate, exacting and detailed characterization of a food item, thus improving quality control and providing a highly useful tool for the food industry based on a color digital camera.

2.6 Response Surface Modelling and Optimization Technique

Myers (1971) studied central composite rotatable design (CCRD) is a response surface methodology for fitting a second order model to a data set without needing to use a complete 3*k* factorial experiment. After the necessary experiment is created, multiple linear regressions are performed. Coded variables are to be used in this method. A rotatable central composite surface response design with four variables and five levels was used to characterize the corn fibre and corn starch extrudates by Artz *et al.* (1990). A second order polynomial was used to analyse the data and three dimentional graphs were generated from regression equations over the range of variables tested.

Ravindra and Chattopadhyay (2000) optimized process parameters for osmotic preconcentration and fluidized bed drying to produce dehydrated quick-cooking potato cubes by using response surface methodology. A solution of 50 % sugar and 10 % salt at 47 °C for 4 h was found for osmotic preconcentration of potato cubes and drying at 140 °C for 10 min at 5.3 m/s followed by thin layer air drying at 50-60 °C and 0.75 m/s for about 7 h were found to be optimum condition.

The importance of breakfast cereal is gaining significance in an era of changing life-style, rapid urbanization, convenience and above all, a health-conscious society. The convenience as ready-to-eat (RTE) foods is also becoming popular among the people. Convenience foods as defined by Franzese (1981) are “those that are ready-to-serve in that the manufacture has added services to the basic ingredients to eliminate all the requirements for preparation activities onsite, except when appropriate reheating and seasoning to taste”. However, the balanced and sufficient nutrition content of available ready-to-eat foods is major issue of verification.

Millets play a major role in the food security and economy of many less developed countries in the world. They are commonly cultivated in India, Africa and China. Millet is thought to be one of the first grains cultivated by man. The first recorded reports on the cultivation of millet dates back to about 5,500 BC in China (Crawford 2006). They are extremely important crops in semi-arid regions where other crops normally do not survive. Millets ranks as the sixth most important cereal and feeds one third of the total world population (Saleh *et al.,* 2013).Another attributes of millets that make them a preferred choice in areas where they are cultivated, are their short harvest period (45-65 days) (Bukhari *et al.,* 2011).

Millet is a generic term used for the grains from the heterogeneous group of forage grasses. They are small sized grains and are grouped along with maize and sorghum as 'coarse cereals' perhaps because of their typical grain texture, which makes them difficult to process as well as cook in convenience form similar to rice and wheat. They assume significance for food and nutritional security in most of the Asian and African countries because of their hard nature and ability to grow in rain-fed lands with very little agricultural inputs as compared to most of the cereals. The annual production of the millets worldwide is about 32 MT, of which a little more than half the quantity is produced in India. Indian food grain production in 2012-13 has been over 255.36 MT, out of which millets has been 17.67 MT and soybean 18.45 MT. India is the top consumer and producer of millet in the world and Indian eat 42% of millets produced globally (Anonymous, 2013).

2.7 Nutritional profile of millets

By any nutritional parameter, millets are far ahead of rice and wheat in terms of their mineral content, compared to rice and wheat. It has been reported that millets are rich source of nutrients and contain 60–70% dietary carbohydrates, 6–19% protein, 1.5–5% fat, 12–20% dietary fibre, 2–4% minerals, and several other phytochemicals (Hadimani*et al.,*1995). Millet is a starchy food with 25:75 amylose to amylopectin ratio and is a fairly good source of lipids (3–6%), having about 50% of the lipids in the form of polyunsaturated fatty acids (Sridhar and Lakshminarayana, 1994). Although millet is known to contain amylase inhibitors, the carbohydrate digestibility of millet foods is not affected because of heat-labile nature of the inhibitors (Chandrasekher *et al*., 1981).The free sugars found in millet are glucose, fructose, sucrose and raffinose and their contents ranges from 1-1.4% with sucrose (0.3-1.2%) being the predominant sugar (Malleshi and Desikachar,1986). Total sugars in small millets ranged from 1.4-2% with proso having highest contents. Millets have total starch ranging from 64-79 % (Geervani and Eggum, 1989). Amylose contents in millets ranges from 26-30% and amylopectin 69-74% (Kumari and Thayumanavan, 1998).Among the millets, pearl millet (*bajra*) has the highest content of macronutrients and micronutrients such as iron, zinc, Mg, P, folic acid and riboflavin. Finger millet (*ragi*) is an extraordinary source of calcium. Though low in fat content, it is high in PUFA (polyunsaturated fatty acids) (Antony *et al.,* 1996). It is also rich in essential amino acids, like lysine, threonine, valine, sulphur containing amino acids and the ratio of leucine to isoleucine is about 2 (Ravindran, 1992; Antony *et al.,*1996; Indira and Naik, 1971). The chemical score (percentage of the most limiting amino acid compared to a standard protein like egg protein) of finger millet is about 50 which is relatively better than other millets, *Jowar* (34) and pearl millet (43) (FAO,1970; Eggum *et al.,*1982).

Table 2.1: Dry matter profile of millets

Millets	Energy (kcal)	Carbohydrate (gm)	Protein (gm)	Fat (gm)	Fiber (gm)
Pearl	363	67	11.8	4.8	20.4
Foxtail	351	63.2	11.2	4	17.62
Finger	336	72.6	7.7	1.5	18.8
Barnyard	300	55	11	3.9	13.7
Wheat	348	71	11.6	2.00	12.9
Rice	362	76	7.9	2.70	5.2
Sorghum	329	70.7	10.4	3.10	14.2

(Source: Anonymous, 2015)

Foxtail millets have antioxidant activity and barnyard millets are rich in iron. In this fashion, nutrient to nutrient, every single millet is extraordinarily superior to rice and wheat and therefore is the solution for the malnutrition that affects a vast majority of the Indian population

(Anonymous, 2015). Following tables shows the comparison of nutritional profile of millets with big cereals.

Table 2.2: Vitamin profile of millets (mg/100gm)

Millets	Vit.A	Vit. B Complex				Vit.E
		Thiamin	Ribofl-avin	Niacin	Folic acid	
Pearl	132	0.41	0.28	4.5	45.5	19.0
Foxtail	32	0.59	0.11	3.2	15.0	9.3
Finger	42	0.42	0.19	1.1	18.3	22.0
Barnyard	-	0.33	0.10	4.2	-	-
Wheat	64	0.410	0.100	5.10	36.6	-

(Source: Anonymous,2015)

Table 2.3 A: Micronutrient profile of major nutrients (mg/100gm) of millets

Millets	Calcium	Phosphorus	Manganese	Potash	Sulfur	Iron	Sodium	Chlorine
Pearl	42	269	137	307	147	2.9	10.9	39
Foxtail	31	290	81	250	171	2.8	4.6	37
Finger	350	283	137	408	160	3.9	11	44
Barnyard	22	280	8.2	-	-	18.6	-	-
Wheat	-	306	138	284	128	3.5	17.1	47
Rice	-	160	90	-	-	1.8	-	-
Sorghum	25	222	171	131	54	5.4	7.3	44

(Source: Anonymous,2015)

Jaybhaye *et al*. (2014) reviewed the processes, various traditional and convenience foods including RTE food products developed from millets and product characteristics. Although millets are nutritionally superior to cereals their utilization as a food is still mostly confined to the traditional consumers and population of lower economic strata. The climate change, water scarcity, increase in population, declining yields of major cereals and adequate access to enough food on one hand and the special features of the millets and health consciousness of the consumer have made food scientists and engineers to develop various food products and mechanize the processes.

Table 2.3 B: Micronutrient profile of trace elements (mg/100gm) of millets

Millets	Cupper	Manganese	Molibdomin	Zink	Cromium
Pearl	1.06	1.15	0.069	3.1	0.023
Foxtail	1.40	0.60	0.070	2.4	0.030
Finger	0.47	5.49	0.102	2.3	0.028
Barnyard	0.60	0.96	-	3	0.09
Wheat	0.68	2.29	0.051	2.7	0.012
Rice	0.14	0.59	0.058	1.4	0.004
Sorghum	0.46	0.78	0.039	1.6	0.008

(Source: Anonymous, 2015)

2.7.1 Health benefits of millets

Millets are a rich source of phosphorus, which is an important mineral for energy production and is an essential component of ATP – the energy store of the body. It also forms an essential part of nervous system and cell membranes. The energy of millet is greater than sorghum and nearly equal to that of brown rice because the lipid content is generally higher (3 to 6%).

Table 2.4: Essential amino acid profile of millets (mg/g of N)

Millets	Histidine	Lysine	Tryptophan	Phenyl	Tyrosine	Methionine	Threonine	Leucine	Isoleucin
Pearl	140	190	110	290	200	150	140	750	260
Foxtail	130	140	60	420	-	180	190	1040	480
Finger	130	220	100	310	220	210	240	690	400
Barnyard	012	015	0.5	043		18	200	650	360
Wheat	130	170	70	280	180	090	180	410	220
Rice	130	230	80	280	290	150	230	500	300
Sorghum	160	150	70	300	180	100	210	880	270

(Source: Anonymous, 2015)

Magnesium from millets also helps to relax blood vessels, enhances nutrient delivery by improving the blood flow and maintains the blood pressure and thus further protects the cardiovascular system. Magnesium increases insulin sensitivity and lowers triglycerides. It also acts as a co-factor for more than 300 enzymes (Anonymous, 2015).

Table 2.5: Fatty acid composition of millets

Millets	Palmitic	Stearic	Oleic	Linoleic	Linolenic
Pearl	20.85	-	25.40	46.00	4.10
Foxtail	6.40	6.30	13.00	66.50	-
Wheat	24.50	1.00	11.50	56.30	1.10
Rice	15.00	1.90	42.50	39.10	2.70
Sorghum	14.00	2.10	31.00	49.00	-

Use of minor millet lowers the risk of diabetes. Millets helps to lower blood glucose levels and improves insulin response. Besides, the magnesium present in millets is a co-factor in various enzymes involved in the secretion of insulin and metabolism of glucose in the body. Whole grains improve insulin sensitivity by lowering glycemic index of the diet by increasing content of fibre, magnesium and vitamin-E (Anonymous, 2015).

Suman *et al.* (1992) assessed the nutritional quality of Japanese barnyard millet (JBN) (*Echinochloafrumentacea*), its protein content, quality and digestibility and found that the proximate composition of the millet resembles that of other millets/cereals. The protein content had a mean value of 36.7 g/kg^{-1} and glutelins were the major storage proteins (60.8%) whereas phenolics and tannins were found to be low.

Phenolic compound especially flavanoids, have been found to inhibit tumor development (Huang and Ferraro 1992).Sharma and Kapoor (1996) have reported the phenols in pearl millet grains as 608.1mg/ 100g and that in pearl millet flour as 761mg/100g. Pearl millet can be recommended in the treatment of celiac diseases, constipation and several non-communicable diseases (Nambair *et al.,* 2011).

Mani *et al*. (1993) have reported that pearl millet (*Penniseteum typhoideum*), has the lowest GI (55) as compared to Varagu (*Plaspalum scorbiculatum)* alone and in combination with whole and dehuskedgreengram (*Phaseolusaureus Roxb*), Jowar (*Sorghum vulgare*) and Ragi (*Eleusine coracana*). Foods with a low glycemic index are useful to manage maturity onset diabetes, by improving metabolic control of blood pressure and plasma low density lipo protein cholesterol levels due to less pronounced insulin response (Asp, 1996).

Pearl millet is a gluten free grain and is the only grain that retains its alkaline properties after being cooked which is ideal for people with wheat allergies. Pearl millet grains are all very high in calories-precisely the reason they do wonders for growing children and pregnant women (www.icrisat.org).

Nutraceuticals are health enhancing physiologically active food components which are also called as phytochemicals. They play a key role as health protective and disease preventive agents and have tremendous impact on the health care system. There has been an upsurge of interest among scientific community to characterize the role of nutraceuticals in management of diseases and development of functional/designer foods for various purposes. Alongside, elevated interest among health conscious consumers in health foods is also evident in the community. Millets have a role to play here, owing to their nutrient and phytochemical composition (Ugare, 2008).

Shashi *et al*. (2007) reported that ragi is an important cereal because of its storage properties of the grains and the nutritive value, which is higher than that of rice and equal to that of wheat. It is also a good source of micronutrients like Calcium, Iron, Phosphorous. Due to presence of anti-nutrients in grains such as tannins and phytates, these micronutrients are less bio-accessable. These anti-nutritional factors modify the nutritional value of the individual grains. Among millets, finger millet was reported to contain high amounts of tannins (Ramachandra *et al*., 1977), ranging from 0.04 to 3.47%. Poor iron availability in brown varieties is due to their high tannin content which adversely affect the nutritional quality of the grains (Udayasekhara and Deosthale, 1988).

Kang *et al*.(2008)observed that the ragi provides higher level of calcium, antioxidants properties, phytochemicals, which makes it easily and slowly digestible. Hence it helps to control blood glucose levels in diabetic patients very efficiently.

Lakshmi and Sumathi (2002) reported that the bulkiness of fibres and the slower digestion rate makes us feel fuller on, fewer calories and therefore may help to prevent us from eating excess calories. Therefore, ragi is considered to be ideal food for diabetic individuals due to its low sugar content and slow release of glucose/sugar in the body.

Highest phenolic content is reported for kodo (368 mg/g) followed by finger (brown variety), little, foxtail and barnyard millet (Hegde and

Chandra, 2005). Phenolic acids in finger millet are present mostly in free form (71%). Ferulic and p-coumaricacid are the major bound phenolic acid (19 mg/100 g) identified, whereas protocatechuic acid is reported as the major free phenolic acid (45 mg/100 g) in finger millet. The antioxidant activity of a free phenolic acid mixture of finger millet is higher compared to that of a bound phenolic acid mixture (Rao and Muralikrishna, 2004).

Bajra or pearl millet *(Pennisetum americanum),* ragi or finger millet (*Eleusine coracana),*navane or foxtail millet (*Setaria italica*), samai or little millet (*Panicum miliare),* haraka or kodo millet (*Paspalum scrobiculatum*), panivaragu or proso millet (*Panicum miliaceum*), banti or barnyard millet (*Echinochloa frumentacea*) are the important millets cultivated largely in the Asian and African countries. These are cultivated in India in almost all the states and the major millet producing states are Karnataka, Rajasthan, Gujarat, Haryana and Maharashtra.

Growing traditional local landraces and under ecological conditions, most millets such as foxtail are totally pest free. They need very little water for their production. They do not demand chemical fertilizers. In fact, under dry land conditions, they grow better in the absence of chemical fertilizers. Hence, do not need any pesticides. Even in storage conditions, most millet such as foxtail not only not need any fumigants, but act as anti pest agents to store delicate pulses such as green gram. Each of the millets is a storehouse of dozens of nutrients in large quantities. They include major and micro nutrients needed by the human body. Hence they can help people withstand malnutrition (Anonymous, 2015). As food, they are nutritionally equivalent or superior to most cereals; containing high levels of methionine, cystine, and other vital amino acids for human health. They are also unique sources of pro-vitamin A (yellow pearl millets) and micronutrients (Zn, Fe and Cu) which are especially high in finger millet. (Obilana,2003).

Millet grains are now receiving specific attention from these developing countries in terms of utilization as food as well as from some developed countries in terms of its good potential in the manufacturing of bioethanol and biofilms (Li *et al*., 2008). Millets also offer several health benefits to consumers. These crops lack gluten and hence can be consumed by people suffering from celiac disease (Gabrovska *et al*., 2002). Millet consumption can also lower glycemic response, which can be helpful for the treatment of type II diabetes (Choi *et al.,* 2005). Inclusion of millet in the human diet can also lower the risk of duodenal ulcers, anemia and constipation (Jayaraj *et al*., 1980;Nambiar *et al*., 2011). For patients suffering from allergic diseases such as atopic dermatitis, Japanese barnyard millet grains have been recommended to replace rice and wheat grains (Watanabe, 1999). Dietary fibre content in pearl and finger millet was found to be higher than that in sorghum, wheat and rice (Kamath and Belavady, 1980). Millets are also rich in phenolic acid and has high anti-oxidant activity (Chandrashekhar and Shahidi, 2010). They are valuable sources of some essential minerals such as potassium, magnesium, calcium, iron and zinc (Ravindran, 1991). Despite their beneficial nutritional properties and tolerance for adverse growing conditions, millet consumption has been less compared to major cereals such as rice, wheat and corn. Millet products from 100% millet flour are rarely manufactured. Among millets, small millets have been most neglected. There is a need to increase awareness about the superior nutritional quality of millets and make them one of the important commodities in our food basket.

Millets are most recognized nutritionally for being a good source of minerals i.e., calcium, magnesium, manganese and phosphorus. Research has linked magnesium to a reduced risk for heart attack and phosphorus is important for the development of body tissue and energy metabolism. Millets are also rich in phytochemicals, including phytic acid (Shashi *et al*., 2007), which is believed to lower cholesterol, and phytate, which is associated with reduced cancer risk. Thus, millets are strategic in terms of their food, nutritional and livelihood security and their role in local agro-ecosystems (Joshi *et al*., 2008). The finger millet contains important amino acids viz., isoleucine (4.4 g), leucine (9.5 g), methionine (3.1 g) and phenyl alanine (5.2 g) which are deficient in other starchy meals. Millets also contains B vitamins, especially niacin, Pyridoxine and folic acid (Vachanth *et al*., 2010). Against the Indian Council of Medical Research recommended levels of 520g cereals, 50 g pulses and 45 g oil/fat along with other necessary components for balanced diet for adult (Singh, 2000). The present per capita cereal availability (530g/head per day) is sufficed whereas the pulses availability (35 g/head per day) is below the minimum recommendation thus making the diet of proteins.

The different technologies like baking, roasting, extrusion cooking, puffing as sand/ salt puffing, oil frying, hot air puffing, gun puffing, microwave puffing etc. are being utilized to prepare variety of ready-to-eat foods. The baking and roasting are high temperature long time processes whereas extrusion cooking is high temperature high pressure technique and involving use of expensive and sophisticated technology. The puffing technology imparts the complete processing at high temperature and in short time but utilizes only whole grains like rice, paddy, sorghum, maize, wheat, bajra etc. i.e., single source of nutrition for preparation of RTE foods. The sand/salt puffing processes are likely to contaminate the end product. The gun puffing and hot air puffing require huge heating arrangements. The microwave puffed product is fat free.

Extrusion cooking is one of the very popular contemporary food processing technologies and is largely followed for corn and rice but the millets could also be extruded to prepare ready-to-eat (RTE) products. A majority of world population suffers from qualitative and quantitative insufficiency of dietary protein and calories intake. In all such cases physiological maintenance and growth are impaired, and malnutrition results. In this context extrusion is a beneficial process. Extrusion cooking is a HTST cooking process, which could be used for processing of starchy as well as proteinaceous materials. The use of extrusion cooking has distinct advantages like versatility, high productivity, high product quality, increase in in-vitro protein digestibility (Dahlin and Lorenz, 1992) and production of new food without effluents. Extrusion Cooking is accomplished through the application of heat either directly by steam injection or indirectly through jacket or by dissipation of mechanical energy through shearing occurring within the blend. Since, the seed coat or the bran affects the expansion ratio and also the eating quality of the extrudates, it is desirable to use refined grits and flour, preferably of less than 40 mesh size. Equilibrating the flour to about 18% moisture content and extruding in a single- or twin-screw extruder at about 150 °C and 200 rpm, gives extrudates of highly desirably food qualities with an expansion of 1.5 - 2 times. The products will have crunchy texture and can be coated with traditional ingredients to prepare sweet or savoury snacks. Alternately, the grits could be mixed with spices and condiments prior to extrusion to obtain RTE snacks of desirable taste.

2.8 Sensory evaluation

Lazim and Suriani (2009) determined the best of quality attribute through sensory evaluation using fuzzy decision making model. Three products of coffee drinks were used for sensory evaluation. Data were collected from thirty judges at a hypermarket in Kuala Terengganu, Malaysia. The judges were asked to specify their sensory evaluation in linguistic terms of the quality attributes of colour, smell, taste and mouth feel for each product and also the weight of each quality attribute. Five fuzzy linguistic terms representing the quality attributes were introduced in prior analyzing. These implicate the importance of sensory evaluation in identifying consumers, preferences and also the competency of fuzzy approach in decision making.

Singh *et al.* (2012) studied the preparation of bread by using millet flours by replacing wheat flour. Barnyard-millet and wheat composite flour (BWCF) was formulated and prepared by mixing 61.8 g/100 g barnyard-millet, 31.4 g/100 g wheat and 6.8 g/100 g gluten. Bread samples were prepared using two composite flours and wheat flour, which was used to compare the quality of the breads prepared from the composite flours by using sensory data to identify the acceptability of these samples. This can be done by using fuzzy logic. The results of sensory data showed that the acceptability of bread samples prepared from composite flours was almost equal to the wheat bread.

Mukhopadhyay *et al.* (2013) studied the following objectives: (1) to find acceptable levels of ingredients on a dry mass basis to constitute the chhana podo feed-mix and (2) to conduct a sensory evaluation study of chhana podo samples. Chhana podo is a baked traditional dairy product of India. In addition to chhana and sugar, different additional ingredients were tried in various proportions, namely, corn flour, refined wheat flour, raw semolina and roasted semolina. Acceptable levels of roasted semolina and sugar in the feed-mix was found to be 0.1 kg (db) and 0.5 kg (db), respectively per kg of chhana (db). Five samples (two market samples, two samples produced at other conditions and one produced at optimum conditions, were evaluated and results were analyzed using fuzzy logic. Data of samples using fuzzy logic showed that product produced at optimum conditions as obtained from constrained optimization using genetic algorithm was indeed better than other samples. Importance of quality attributes for chhana podo in general was (in decreasing order): taste, color, aroma and mouthfeel. For the optimized product, the most important quality attribute was taste, followed by mouthfeel, color and aroma.

Shinde and Pardeshi (2014) studied the sensory evaluation by using fuzzy logic. The four different jam samples available in market were taken for their liking by the consumers. A sensory data was conducted for analysis of acceptability of these samples and it can be done by fuzzy logic. The preference ranking of the different samples was obtained using fuzzy logic. This methodology takes an account of the judges, behavior to articulate the preference ranking. The evaluation of the sample depends on the color, flavor, texture and overall appearance. The output given by fuzzy logic model, the samples are ranked very good, good, satisfactory and unsatisfactory. It was observed that the fuzzy logic technique could be satisfactorily utilized for evaluation of the samples. The results of sensory data showed that the sample X4 was ranked highest followed by X1, X3 and X2.

Mukherjee (1997) and Khodke (2002) used metalized polyester, high density polyethylene and low-density polyethylene, for HTST hot air puffed potato cubes and instant potato cubes, respectively and found metalized polyester to be highly suitable for packaging of a product followed by high density polyethylene.

2.9 Packaging and Storage Studies

Sullivan *et al.* (1974) conducted storage studies to evaluate the stability of explosion-puffed, dried potato dice with regard to the development of browning and off-flavors. The results of this storage test show that all samples stored at 23 °C or lower, regardless of the package atmosphere, remain stable with regard to browning and flavor throughout the 1-year period.

Another form of deterioration of breakfast cereals after processing and packaging is moisture uptake, which causes loss of the distinctive crisp texture. Moisture uptake is prevented by the use of the correct type and quality of moisture vapour-proof packaging materials (Fast, 1987).

The keeping quality of the prepared product depends to a large extent on the content and keeping quality of the oil present in it. Thus, products made from cereals having low oil content (wheat, barley, rice, maize grits: oil content 1.5-2.0 %) have an advantage in keeping quality. Severe heat treatment, as in toasting or puffing, may destroy antioxidants or induce formation of pro-oxidants, stability of the oil being progressively reduced as treatment temperature is raised, treatment time lengthened, or moisture content of the material at the time of treatment lowered (Cooper, 1988).

The literary information compiled as above regarding importance of puffing, different processes of puffing, puffed products, technology for hot air puffing, evaluation of qualities of puffed foods, recording observation, data analysis, etc. is useful for formulation of methodology and discussing the results thereto.

CHAPTER III

MATERIAL AND METHODS

This chapter deals with the materials, equipments and methods used during the development of Semi automated multigrain continuous hot air puffing system and its evaluation for puffing of different grains. The optimization of process parameters for puffing different millets, using semi automated continuous hot air puffing system developed during the course of investigation, determination of properties of different puffed grain, analysis of data, shelf life study, etc. is discussed in this chapter.

3.1 Raw Materials

Sorghum (Plate 3.1 a), Bajra (Plate 3.1 b) were obtained from the local market Akola, Finger Millet (Plate 3.1 c) was procured from Jay Industries, Nasik and Kodo millet (Plate 3.1 d) and Kutki (Plate 3.1 e) were procured from Indira Gandhi Krishi Vishwavidyalaya, Raipur, India for hot air puffing experimental purpose. The grains were cleaned and graded using appropriate set of sieve to remove foreign matter, small and immature grains. Variation in size of seeds may cause low puffing efficiency and expansion ratio of final puffed grain.

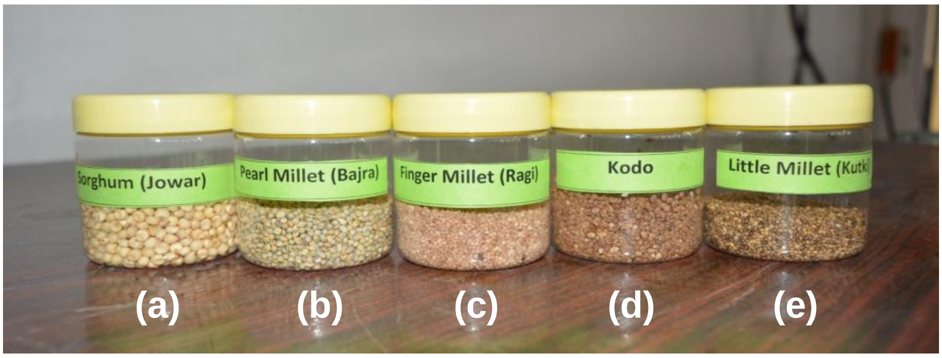


Plate 3.1: Raw millets (multigrain)

3.2 Continuous hot air puffing system

The puffing experiments were conducted using the experimental continuous hot air puffing system (Fig. 3.1) developed by Babar(2011) and Pardeshi (2008) and later on Jadhav (2013) in the Department of

Agricultural process Engineering, College of Agricultural Engineering and Technology, Dr. P. D. K.V., Akola (India). This system could be regulated to any desired puffing air temperature and velocity with high accuracy. It consists of air blower electrical heater based heating system with manual control, puffing chamber and exit for the puffed grains at any time during puffing from cyclone separator and a provision for continuous hot air flow for reutilization of hot air as to reduce heat load. The air heated up to desired temperature in the heating chamber was passed to the puffing chamber. The puffing air temperature (controlled within ± 2 % uncertainty) was measured directly in the puffing chamber and air velocity was measured at the exit of the system. The sample of grain was poured in the puffing column, where the grain sample was kept whirling at high temperatures in vertically upward flowing air till the puffing effect was imparted.

The already existing whirling bed technique for hot air puffing is continuous one and is an advancement of batch type whirling bed hot air puffing system developed by Mukharjee (1997), Afterword some modification ware made by Nath (2006), especially in the feeding mechanism. The continuous hot air puffing system especially for reutilization of hot air, with use of electrical heater and heat sensor for controlling desired puffing temperature as per sample in puffing chamber of system, increased working capacity and ease in operation was developed by Babar (2011) as shown in detailed schematic diagram of the experimental setup (Fig.3.1) and subsequently the energy efficient continuous hot air puffing system modified by Jadhav (2013).

The system developed by Babar (2011) consists of,

1. Electric Heating Assembly (10 Plate heaters of size 1 kW each)
2. Continuous feeding system for raw material (with positive feeding mechanism)
3. Continuous outlet system
4. Continuous collection of puffed material using cyclone separator
5. Re-circulation of used but till high temperature air

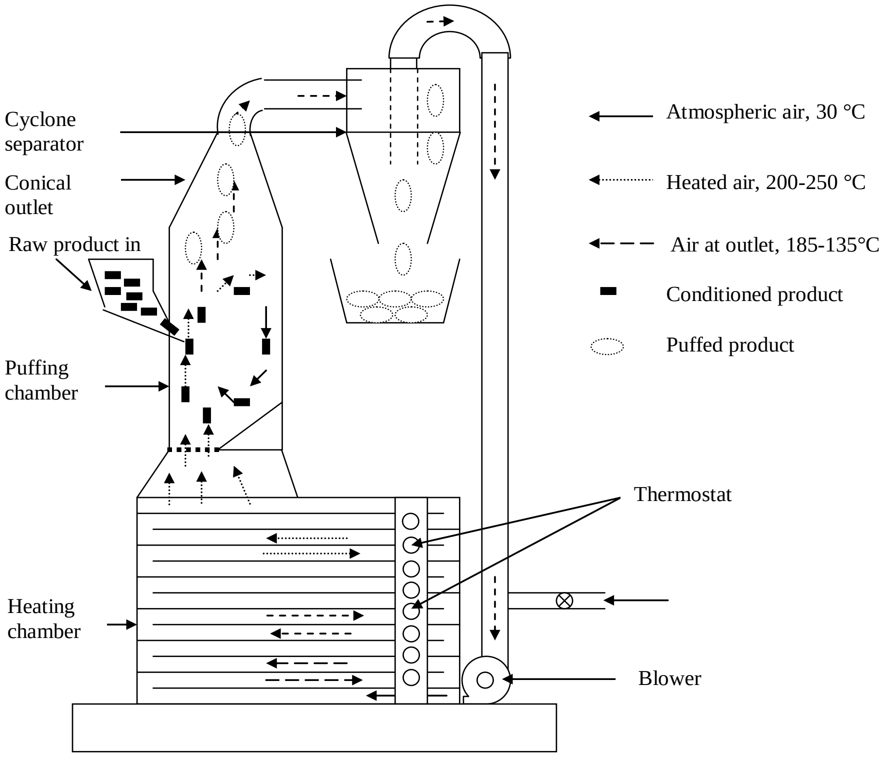


Fig. 3.1 Sketch of the developed continuous hot air puffing system

3.3 Development of semi-automated multigrain continuous hot air puffing system

The semi-automated multigrain continuous hot air puffing system was developed as shown in Fig 3.2 and Plate 3.2. System operated with 1 hp electric power source for blower, 11 heater with capacity of 0.75 kW for each, used in heating unit to attain desired puffing temperature. The puffing capacity of newly developed semi-automated multigrain continuous hot air puffing system was 6 to 8 kg/h. The system consists of electric heating assembly, continuous feeding system, continuous outlet system, cyclone separator and re-circulation of air unit. The details of components have been given in following sub section.

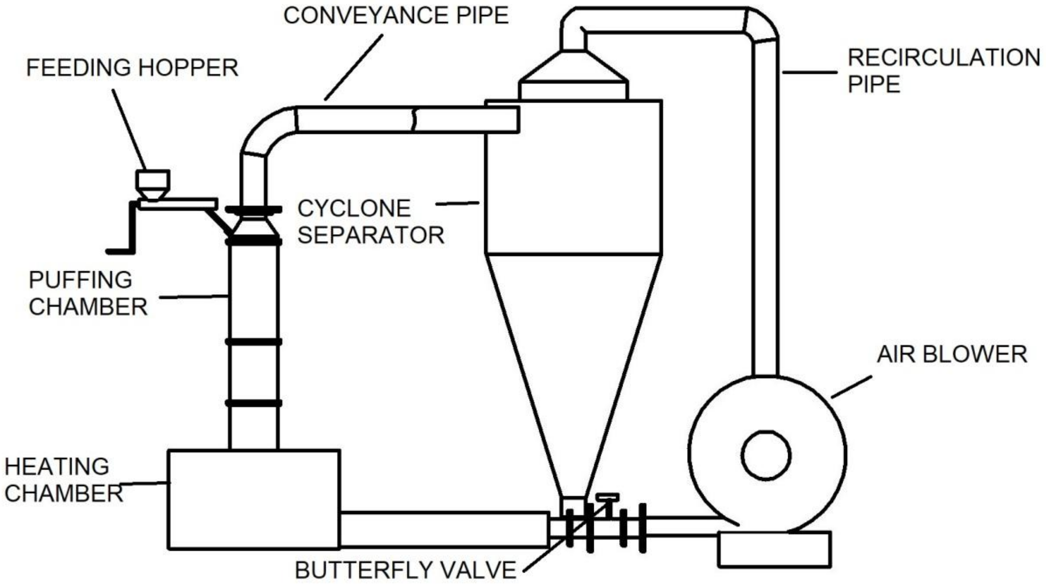


Fig. 3.2 Line diagram of semi-automated multigrain continuous hot air puffing system

The set up details of the proposed continuous hot air puffing system are discussed through 3.3.1 to 3.3.7.

3.3.1 Centrifugal air blower

The centrifugal air blower is used to supply and circulate air. The blower can supply air at atmospheric temperature (30 °C) at the velocity of 10-24 m/s with outlet diameter of 75 mm. The air supply can be controlled at desired velocity by means of a butterfly valve provided at air outlet of the blower. As per the filler trial, the required air velocity for puffing of the millet grain was kept 1.5 to 6 m/s (in puffing chamber of 125 mm diameter) with the help of this valve. Thus blower of 1 hp is suitably used for supply and circulation of the air.

3.3.2 Heating chamber

The heating chamber is cubical box, which is divided into four layers accommodating of eleven number electrical heaters (Each heater is of 0.75 kW capacity) arranged in typical manner. Each heater is of size 450 x 40 x 20 mm. Rectangular fins of dimension 60 x 30 mm are provided on heater, spaced at 10 mm, that helps for efficient transfer of heat from heaters surface to the flowing air. The chamber is well insulated by glass wool sheet of 3 mm thickness arranged in 3 layers alternately with air gap left in between two successive layers of glass wool sheet.

Plate 3.2: Semi-automated multigrain continuous hot air puffing system

3.3.3 Puffing chamber

Puffing chamber is the circular pipe (22 gauge MS sheet) of 125 mm diameter, arranged vertically right above the stabilization chamber. The height of puffing chamber is kept adjustable, so that it can be changed as per requirement with respect to the product to be puffed. The dural wedge (Mukharjee, 1997; Pardeshi, 2008; Babar, 2011 and Jadhav, 2013) is arranged typically at bottom of the puffing chamber, so as to impart whirling effect to hot air. The whirling effect facilitates sufficient retention time to the puffing product in puffing chamber. Height of chamber is kept 265 mm for present study, i.e., for the grains used for evaluation. The material to be puffed is directly poured into puffing chamber through feeding hopper.

3.3.4 Feeding mechanism

The grains to be puffed were supplied from the vertical circular feeding hopper, in which feed gravitationally enters into continuously rotating screw conveyor, located in horizontal circular pipe (25 mm), attached at bottom side of hopper. Afterward, grains pass to inclined circular pipe of outlet, which opened above dural wedge in puffing chamber. The raw product is fed by means of positive feeding mechanism (Chandrashekhar, 1989).The complete feeding assembly was made by SS 304.

3.3.5 Conveyance pipe

Conveyance pipe (63.5 mm diameter) is fabricated from SS 304 sheet of 22 gauge. After puffing, the puffed material being lighter in weight gets picked up and oozes out of puffing chamber. From puffing chamber, the puffed product enters in the conveyance pipe opening in cyclone separator.

3.3.6 Cyclone separator

The cyclone separation principle is used for continues removal of the puffed product. The cyclone separator is fabricated from stainless steel (SS 304) sheet of 20 gauges. The special provision and modifications in basic structure of cyclone separator is introduced, so as to ease collection of puffed product. This makes the product to get out of airflow quickly. As soon as puffed product enters cyclone separator, immediately air releases the product to outlet of cyclone separator.

3.3.7 Recirculation pipe

When air releases the final product, it is still at high temperature (at about 190-200 °C). The conduit at air outlet of cyclone separator is provided to recirculation hot air through air blower. The GI sheet of 22 gauge is used to fabricate this recirculation pipe keeping diameter 63.5 mm.

The recirculation pipe can be insulated by glass wool sheet encased in GI sheet.

3.4 Operation and working

The air blower was switched ON to allow the air circulation in system. Initially the set up was allowed to run idle for 15 min, so that the desired air temperature level was reached and attained equilibrium. The temperature was adjusted by regulating electrical heater, 2 electrical heater switch ON or OFF by heat sensor temperature controller for control desire puffing temperature as per grain and 9 electrical heaters were continuously ON for maintain puffing temperature in puffing chamber of the system. The air velocity was preset to the desired level by adjusting the butterfly valve. The set up was also found to work smoothly for several hours. After switching OFF the electrical heaters, the blower fan was in continuously kept ON till the system got cooled down up to normal temperature, which required about one hour.

The air blower was switched ON to allow the air circulation in system. Then heaters were gradually switched ON. Initial 9 heaters were switched ON to heat the flowing air to 200-230 °C temperature and found stabilized at. Then remaining 2 heaters were put to ON, to increase the temperature to required levels for testing. It took 15 minutes for reaching temperature of first 200 °C. The temperatures of air in puffing chamber were varied by switching ON the extra heaters, one by one.

The setting of temperature of air at inlet of puffing chamber as per grain was done by switching ON increasing numbers of heaters gradually, as a temperature increases beyond setting temperature, the temperature controller was measured and cut the power to maintain desire temperature. The temperature was read once the temperature reading was nearly stabilized. The multi channel digital temperature indicator was used for measuring the temperature of whole puffing assembly.

The nine numbers of switched heaters could achieve and stabilize air to temperature of 200-230 °C temperature after 15 minutes. Sequentially next two heaters were switched, i.e. total eleven numbers of heaters ON switching could achieve temperature of 300–380 °C in 35 minutes from start. Hence, eleven numbers of heaters were used.

The air velocity at air inlet of puffing chamber was measured using Anemometer without heating of air. The air velocity of air could be varied from 1.5 to 6 m/s using butterfly valve installed at exit end of blower. However the air velocity was set as whirling velocity obtained as per different grain sample.

The continuous hot air puffing system works on centrifugal air blower and electric heaters arranged typically in chamber. The air blower supplies air at atmospheric temperature (30 °C), at the rate of 0.045 to 0.1 m^3/s. This air is passed over series of electric heaters for heating from atmospheric temperature (30 °C) to required temperature (150 to 400 °C). It takes about 15 minutes for initial heating of air, to reach temperature of 230-380 °C. This hot air is used for puffing in the puffing chamber. Once air is used, it is then recycled through re-circulating pipe (which is still hot and at about 190-200 °C after being utilized) for further heating. The puffing chamber is vertical cylinder of diameter 125 mm, from the bottom of which hot air comes in typical manner. The grain to be puffed is fed through the feed hopper that works on positive feeding mechanism. The typical arrangement made to take, the final puffed grain, out off the puffing chamber, carries the puffed material towards cyclone separator. The final puffed grain is taken out of the process from this cyclone separator and waste air (still hot at temperature of about 190-200 °C) is again re-circulated for its reuse. The provision at blower inlet is provided to make up the pressure drop in the conduit. The temperatures at inlet and outlet of puffing chamber and at air exit end (upper end) of cyclone were measured by inserting the thermocouples and using multichannel digital temperature indicator.

3.5 Sample preparation

3.5.1 Sample preparation for sorghum and bajra grain

Preliminary trials were conducted with different grains viz., sorghum and bajra to determine the suitability for its puffing in semi-automated multigrain continuous hot air puffing system. As moisture content of whole grain was very low to impart puffing, the moisture content of wholegrain was increased to a predetermined level for maximum expansion effect and puffing yield. The sample of finger millet, kodo millet and kutki did not require additional moisture, because the whole grain moisture content was adequate for better puffing (as per the observation of filler trials).

The samples of the desired moisture contents were prepared by adding distilled water. The amount of water to be added was calculated using Eq. 3.1. (Vishwakarma *et al*., 2011)

$$Q = \frac{W_i \, (M_f - M_i)}{100 + M_i} \qquad \text{.... (3.1)}$$

Where Q = quantity of water to be added (kg);

W_i = initial weight of the sample (kg);

M_i = initial moisture content of the sample (%, d.b.);

M_f = desired moisture content of the sample (%, d.b.).

Samples were stored in HDPE pouches and conditioned by keeping in a refrigerator at 5±2 °C for a week to attain moisture equilibration throughout the grain. The conditioned grains were allowed to attain room temperature before performing various tests (Nimkar, 1997; Shirkole, 2010 and Kenge, 2011).

3.5.2 Sample preparation for finger millet

Preliminary trials were conducted with finger millet to determine the suitability for its puffing in semi-automated continuous hot air puffing system.

The finger millet is not amenable for puffing in the form of whole grains, because, the seed coat of the finger millet grains if not removed, it not only affects the puffing quality but also its expansion ratio. The endosperm of the millet is covered with the rigid seed coat. Since, the Seed coat is firmly attached to the endosperm, the decortications becomes inevitable for puffing purpose.

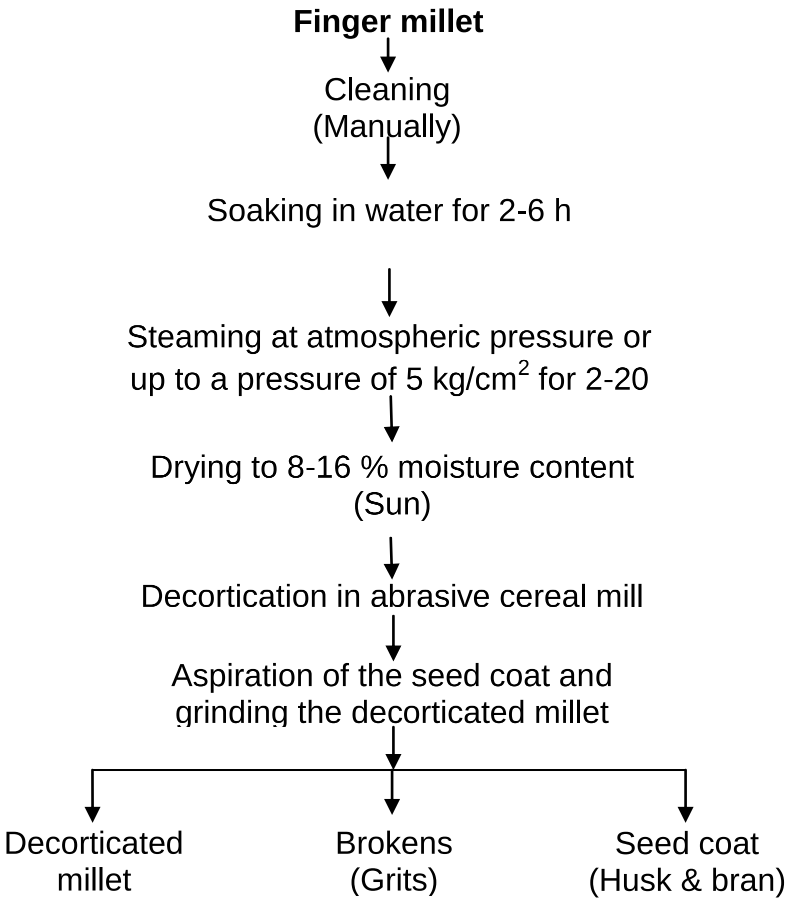


Fig. 3.3 Flow chart decortications of finger millet

This section describes the experimental design used for semi-automated multigrain continuous hot air puffing process for development of different grains viz., sorghum, bajra, finger millet, kodo millet and kutki. The process parameters like puffing temperature, air velocity, feed rate and moisture content for puffing grains on the basis of puffed grain qualities namely final moisture content, hardness, crispness(peak +ve), colour (L-value) and expansion ratio are described under experimental design along with the levels and combinations of treatments.

3.6.1 Experimental design for sorghum and bajra

In the present study, the ranges of experimental parameters were selected based on preliminary trials. The process variables considered were puffing temperature (250 to 350 °C), air velocity (4-6 m/s), feed rate (6000-9000 g/h), initial moisture content (0.18-0.28 kg/kg dm) for sorghum and temperature (280 to 380 °C), air velocity (2.5-4.5 m/s), feed rate (6000-9000 g/h), initial moisture content (0.20-0.30 kg/kg dm) for bajra grain, respectively these parameters were sufficient to impart whirling effect to the respective puffing grain.

Table 3.1 Levels, codes and intervals of variation for hot air puffing process of sorghum

Name of Process variable	Range	Code (X_i)	X_{i1}	LEVELS				Interval of variation
				X_{i2}	X_{i3}	X_{i4}	X_{i5}	
			-2	**-1**	**0**	**1**	**2**	
Puffing Temperature °C	250-350	X_1	225	250	300	325	350	25
Air Velocity m/s	4-6	X_2	4	4.5	5	5.5	6	0.5
Feed Rate g/h	6000-9000	X_3	6000	6750	7500	8250	9000	750
Moisture content kg/kg dm	0.18-0.28	X_4	0.18	0.205	0.23	0.255	0.28	0.025

Table 3.2 Levels, codes and intervals of variation for hot air puffing process of bajra

Name of Process variable	Range	Code (X_i)	X_{i1}	LEVELS				Interval of variation
				X_{i2}	X_{i3}	X_{i4}	X_{i5}	
			-2	**-1**	**0**	**1**	**2**	
Puffing Temperature °C	280-380	X_1	280	305	330	355	380	25
Air Velocity m/s	2.5-4.5	X_2	2.5	3	3.5	4	4.5	0.5
Feed Rate g/h	6000-9000	X_3	6000	6750	7500	8250	9000	750
Moisture content kg/kg dm	0.20-0.30	X_4	0.20	0.225	0.25	0.275	0.30	0.025

The experimental design was applied after selection of the ranges. Thirty experiments were performed according to a central composite rotatable design (CCRD) with four variables and five levels of each variable. Table 3.1 and Table 3.2 gives the levels of variables in coded and actual units, for sorghum and bajra, respectively and Table 3.3 and Table 3.4 indicates the treatment combinations of variable levels used in the CCRD, for respective grain. Experiments were randomized in order to minimize the effects of unexplained variability in the observed responses due to extraneous factors. The center point in the design was repeated six times to calculate the reproducibility of the method Montgomery (2001).

In Table 3.1 and 3.2, the coded levels of process variables are fixed as given below Myers (1971);

Coded level for central experiments = 0,
Coded level for factorial experiments =± 1,
Coded level for star point experiments $= \pm 2^{N/4}$
N= No. of variables $= \pm 2^{4/4} = \pm 2$

The actual values of process variables at given coded levels are calculated as below,

$$Ya_{ij} = X_{ij} \times V_i + Ya_3 \quad \ldots (3.2)$$

Where,

I = 1 to 4, Process variable number
J = 1 to 5, Level number
Ya_{ij} = Actual value of i^{th} process variable at given j^{th} coded level
X_{ij} = Coded value of i^{th} process variable at given j^{th} coded level
V_i = interval of variation for i^{th} process variable
Ya_3 = Actual value of i^{th} variable at its central coded level
(X_{i3}) = Average of extremities of range of actual values

Multigrain continuous hot air puffing experiments were conducted according to the CCRD design (Table 3.1 and Table 3.2) and RSM was applied to the experimental data using a commercial statistical package, *Design Expert* - *version 11.0* (Stat-Ease, 2018). The relative effect of the process variables (PT °C, AV m/s, FR g/h and IMC kg/kg dm) on the responses was studied and the multigrain continuous hot air puffing processes were optimized in order to get best quality HTST air puffed grain sorghum and bajra. The responses studied were final moisture content (FMC, kg/kg dm), hardness (HD), crispness (CSP peak +ve), colour (L-value) and expansion ratio (ER).

Table 3.3 Treatment combinations for multigrain continuous hot air puffing with 4 variable second order design of sorghum

Expt. No.	Coded values				Actual values			
	X_1	X_2	X_3	X_4	Puffing Temperature °C	Air Velocity m/s	Feed Rate g/h	Initial Moisture content kg/k dm
1	-1	-1	-1	-1	275	4.5	6750	0.21
2	1	-1	-1	-1	325	4.5	6750	0.21
3	-1	1	-1	-1	275	5.5	6750	0.21
4	1	1	-1	-1	325	5.5	6750	0.21
5	-1	-1	1	-1	275	4.5	8250	0.21
6	1	-1	1	-1	325	4.5	8250	0.21
7	-1	1	1	-1	275	5.5	8250	0.21
8	1	1	1	-1	325	5.5	8250	0.21
9	-1	-1	-1	1	275	4.5	6750	0.26
10	1	-1	-1	1	325	4.5	6750	0.26
11	-1	1	-1	1	275	5.5	6750	0.26
12	1	1	-1	1	325	5.5	6750	0.26
13	-1	-1	1	1	275	4.5	8250	0.26
14	1	-1	1	1	325	4.5	8250	0.26
15	-1	1	1	1	275	5.5	8250	0.26
16	1	1	1	1	325	5.5	8250	0.26
17	-2	0	0	0	250	5	7500	0.23
18	2	0	0	0	350	5	7500	0.23
19	0	-2	0	0	300	4	7500	0.23
20	0	2	0	0	300	6	7500	0.23
21	0	0	-2	0	300	5	6000	0.23
22	0	0	2	0	300	5	9000	0.23
23	0	0	0	-2	300	5	7500	0.18
24	0	0	0	2	300	5	7500	0.28
25	0	0	0	0	300	5	7500	0.23
26	0	0	0	0	300	5	7500	0.23
27	0	0	0	0	300	5	7500	0.23
28	0	0	0	0	300	5	7500	0.23
29	0	0	0	0	300	5	7500	0.23
30	0	0	0	0	300	5	7500	0.23

Table 3.4 Treatment combinations for multigrain continuous hot air puffing with 4 variable second order design of bajra

Expt. No.	Coded values				Actual values			
	X_1	X_2	X_3	X_4	Puffing Temperature °C	Air Velocity m/s	Feed Rate g/h	Initial Moisture content kg/k dm
1	-1	-1	-1	-1	305	3	6750	0.225
2	1	-1	-1	-1	355	3	6750	0.225
3	-1	1	-1	-1	305	4	6750	0.225
4	1	1	-1	-1	355	4	6750	0.225
5	-1	-1	1	-1	305	3	8250	0.225
6	1	-1	1	-1	355	3	8250	0.225
7	-1	1	1	-1	305	4	8250	0.225
8	1	1	1	-1	355	4	8250	0.225
9	-1	-1	-1	1	305	3	6750	0.275
10	1	-1	-1	1	355	3	6750	0.275
11	-1	1	-1	1	305	4	6750	0.275
12	1	1	-1	1	355	4	6750	0.275
13	-1	-1	1	1	305	3	8250	0.275
14	1	-1	1	1	355	3	8250	0.275
15	-1	1	1	1	305	4	8250	0.275
16	1	1	1	1	355	4	8250	0.275
17	-2	0	0	0	280	3.5	7500	0.25
18	2	0	0	0	380	3.5	7500	0.25
19	0	-2	0	0	330	2.5	7500	0.25
20	0	2	0	0	330	4.5	7500	0.25
21	0	0	-2	0	330	3.5	6000	0.25
22	0	0	2	0	330	3.5	9000	0.25
23	0	0	0	-2	330	3.5	7500	0.2
24	0	0	0	2	330	3.5	7500	0.3
25	0	0	0	0	330	3.5	7500	0.25
26	0	0	0	0	330	3.5	7500	0.25
27	0	0	0	0	330	3.5	7500	0.25
28	0	0	0	0	330	3.5	7500	0.25
29	0	0	0	0	330	3.5	7500	0.25
30	0	0	0	0	330	3.5	7500	0.25

The second order polynomial response surface model (Eq. 3.3) was fitted to each of the response variable (Y_k) with the independent variables (X_i)

$$Y_k = b_{k0} + \sum_{i=1}^{4} b_{ki} X_i + \sum_{i=1}^{4} b_{kii} X_i^2 + \sum_{i \neq j=1}^{4} b_{kij} X_i X_j \qquad \text{... (3.3)}$$

Where b_{k0} , b_{ki}, bk_{ii}, and bk_{ij} are the constant, linear, quadratic and cross-product regression coefficients, respectively and X_i is are the coded independent variables of X_1, X_2, X_3 and X_4. The experimental values were in fraction and did not maintain, so taken as round figure for ease of operation.

3.6.2 Experimental design for finger millet, kodo millet and kutki

In the present study, the ranges of experimental parameters were selected based on preliminary trials. The process variables considered were puffing temperature (250 to 350 °C), air velocity (2-4 m/s), feed rate (6000-9000 g/h) for finger millet and temperature (280 to 380 °C), air velocity (2-4 m/s), feed rate (6000-9000 g/h) for kodo millet grain and temperature (300 to 400 °C), air velocity (2-3 m/s), feed rate (6000-9000 g/h) for kutki, respectively these parameters were sufficient to impart whirling effect to the respective puffing grain.

The experimental design was applied after selection of the ranges. Twenty experiments were performed according to a second order central composite rotatable design (CCRD) with three variables and five levels of each variable. Table 3.5, Table 3.6 and Table 3.7 gives the levels of variables in coded and actual units and Table 3.8, Table 3.9 and Table 3.10 indicates the treatment combinations of variable levels used in the CCRD. Experiments were randomized in order to minimize the effects of unexplained variability in the observed responses due to extraneous factors. The center point in the design was repeated six times to calculate the reproducibility of the method Montgomery (2001).

In Table 3.5 to 3.7, the coded levels of process variables are fixed as given below;

Coded level for central experiments = 0,
Coded level for factorial experiments = ± 1,
Coded level for star point experiments = $\pm 2^{N/4}$
N = No. of variables = $\pm 2^{3/4}$ = ±1.68

Table 3.5 Levels, codes and intervals of variation for multigrain continuous hot air process of finger millet

Name of process variable	Range	Code (X_i)	X_{i1}	LEVELS				Interval of variation
				X_{i2}	X_{i3}	X_{i4}	X_{i5}	
			-1.68	**-1**	**0**	**1**	**1.68**	
Puffing Temperature °C	250-350	X_1	250	270	300	330	350	25
Air Velocity m/s	2-4	X_2	2	2.5	3	3.5	4	0.5
Feed Rate g/h	6000-9000	X_3	6000	6608	7500	8400	9000	750

Table 3.6 Levels, codes and intervals of variation for multigrain continuous hot air process of kodo millet

Name of process variable	Range	Code (X_i)	X_{i1}	LEVELS				Interval of variation
				X_{i2}	X_{i3}	X_{i4}	X_{i5}	
			-1.68	**-1**	**0**	**1**	**1.68**	
Puffing Temperature °C	250-350	X_1	250	270	300	330	350	25
Air Velocity m/s	2-4	X_2	2	2.5	3	3.5	4	0.5
Feed Rate g/h	6000-9000	X_3	6000	6608	7500	8400	9000	750

Table 3.7 Levels, codes and intervals of variation for multigrain continuous hot air process of kutki

Name of process variable	Range	Code (X_i)	X_{i1}	LEVELS				Interval of variation
				X_{i2}	X_{i3}	X_{i4}	X_{i5}	
			-1.68	**-1**	**0**	**1**	**1.68**	
Puffing Temperature °C	300-400	X_1	300	320	350	380	400	25
Air Velocity m/s	2-3	X_2	2	$2.2 \approx 2$	2.5	$2.79 \approx 2.5$	3	0.25
Feed Rate g/h	6000-9000	X_3	6000	6750	7500	8250	9000	750

The actual values of process variables at given coded levels are calculated as below,

$$Ya_{ij} = X_{ij} \times V_i + Ya_3 \qquad \text{... (3.4)}$$

Where,

I = 1 to 3, Process variable number

J = 1 to 5, Level number

Ya_{ij} = Actual value of i^{th} process variable at given j^{th} coded level

X_{ij} = Coded value of i^{th} process variable at given j^{th} coded level

V_i = interval of variation for i^{th} process variable

Table 3.8 Treatment combinations for hot air puffing with 3 variable second order design of finger millet

Expt. No.	Coded values			Actual values		
	X_1	X_2	X_3	Puffin Temperature °C	Air Velocity m/s	Feed Rate g/h
1	-1	-1	-1	270	2.5	6600
2	1	-1	-1	330	2.5	6600
3	-1	1	-1	270	3.5	6600
4	1	1	-1	330	3.5	6600
5	-1	-1	1	270	2.5	8400
6	1	-1	1	330	2.5	8400
7	-1	1	1	270	3.5	8400
8	1	1	1	330	3.5	8400
9	-1.68	0	0	250	3	7500
10	1.68	0	0	350	3	7500
11	0	-1.68	0	300	2	7500
12	0	1.68	0	300	4	7500
13	0	0	-1.68	300	3	6000
14	0	0	1.68	300	3	9000
15	0	0	0	300	3	7500
16	0	0	0	300	3	7500
17	0	0	0	300	3	7500
18	0	0	0	300	3	7500
19	0	0	0	300	3	7500
20	0	0	0	300	3	7500

Table 3.9 Treatment combinations for hot air puffing with 3 variable second order design of kodo millet

Expt. No.	Coded values			Actual values		
	X_1	X_2	X_3	Puffin Temperature °C	Air Velocity m/s	Feed Rate g/h
1	-1	-1	-1	270	2.5	6600
2	1	-1	-1	330	2.5	6600
3	-1	1	-1	270	3.5	6600
4	1	1	-1	330	3.5	6600
5	-1	-1	1	270	2.5	8400
6	1	-1	1	330	2.5	8400
7	-1	1	1	270	3.5	8400
8	1	1	1	330	3.5	8400
9	-1.68	0	0	250	3	7500
10	1.68	0	0	350	3	7500
11	0	-1.68	0	300	2	7500
12	0	1.68	0	300	4	7500
13	0	0	-1.68	300	3	6000
14	0	0	1.68	300	3	9000
15	0	0	0	300	3	7500
16	0	0	0	300	3	7500
17	0	0	0	300	3	7500
18	0	0	0	300	3	7500
19	0	0	0	300	3	7500
20	0	0	0	300	3	7500

Ya_3= Actual value of i^{th} variable at its central coded level

(X_{i3}) = Average of extremities of range of actual values

Similarly experiments were conducted according to the CCRD design (Table 3.8, Table 3.9 and Table 3.10) and RSM was applied to the experimental data using a commercial statistical package, *Design Expert - version 11.0* (Stat-Ease,2018). The relative effect of the process variables (PT °C, AV m/s, FR g/h and MC kg/kg dm) on the responses was studied and the hot air puffing processes were optimized in order to get best quality hot air puffed grain for finger millet, kodo millet and kutki. The responses studied were final moisture content (FMC, kg/kg dm), hardness (HD), crispness (CSP peak +ve), Colour (L-value) and expansion ratio (ER).

Table 3.10 Treatment combinations for hot air puffing with 3 variable second order design of kutki

Expt. No.	Coded values			Actual values		
	X_1	X_2	X_3	Puffin Temperature °C	Air Velocity m/s	Feed Rate g/h
1	-1	-1	-1	320	2	6600
2	1	-1	-1	380	2	6600
3	-1	1	-1	320	3	6600
4	1	1	-1	380	3	6600
5	-1	-1	1	320	2	8400
6	1	-1	1	380	2	8400
7	-1	1	1	320	3	8400
8	1	1	1	380	3	8400
9	-1.68	0	0	300	2.5	7500
10	1.68	0	0	400	2.5	7500
11	0	-1.68	0	350	2	7500
12	0	1.68	0	350	3	7500
13	0	0	-1.68	350	2.5	6000
14	0	0	1.68	350	2.5	9000
15	0	0	0	350	2.5	7500
16	0	0	0	350	2.5	7500
17	0	0	0	350	2.5	7500
18	0	0	0	350	2.5	7500
19	0	0	0	350	2.5	7500
20	0	0	0	350	2.5	7500

The second order polynomial response surface model (Eq. 3.5) was fitted to each of the response variable (Y_k) with the independent variables (X).

$$Y_k = b_{k0} + \sum_{i=1}^{2} b_{ki} X_i + \sum_{i=1}^{2} b_{kii} X_i^2 + \sum_{i \neq j=1}^{2} b_{kij} X_i X_j \qquad \text{... (3.5)}$$

Where b_{k0} , b_{ki}, bk_{ii}, and bk_{ij} are the constant, linear, quadratic and cross-product regression coefficients, respectively and X_i is are the coded independent variables of X_1, and X_2.

3.7 Evaluation of response parameters

After hot air puffing of grain samples, the various response parameters were considered for the purpose of optimization of process parameters. The response parameters considered were final moisture content (kg/kg dm), hardness (g), crispness (number of +ve peaks), colour (L- values) and expansion ratio (ER). The moisture content was determined as discussed in section 3.10.1.2. The parameters were determined as discussed below.

3.7.1 Expansion ratio (ER) measurement

The expansion ratio (ER) for all the puffed grain samples was determined in terms of ratio of average bulk volume *(v)* of puffed grain during puffing to the average initial bulk volume (v_o) (Chandrasekhar, 1989)of grain before introducing in puffing system.

3.7.2 Textural measurement (hardness and crispness)

Pomeranz and Meloan (1994) reported that texture can be regarded as a manifestation of the rheological properties of a food.

Matz (1962) found that it is an important attribute in that it affects processing and handling influences food habits, and affects shelf-life and consumer acceptance of foods.

The first peak from the force- time profile was recorded as hardness of the chunks. The average of ten samples were reported as hardness (Solanke, 2017).

Crispiness was measured in terms of major positive peaks (Cruzycelis *et al.,*1996) with the help of texture analyzer. For measurement of crispiness a macro was developed which counts number of major peaks represented in the force-time deformation curve (Fig.3.4) obtained during compression (Nath and Chattopadhayay, 2007).

The tests for texture analysis of puffed product are conducted on Texture Analyzer (Model- TA-Exponent Lites' Version-32) as shown in Plate (3.3).

Test Set-Up:

The details of probes and macros used for testing are as given in Table 3.11.

Table 3.11 Probes and macros used for testing textural measurement

Mode	Measure Force in Compression
Option	Return To Start
Pre-Test Speed	1 mm/s
Test Speed	5 mm/s
Post-Test Speed	10.0 mm/s
Distance	17 mm
Trigger type	Button

Plate 3.3: Texture analyser and fixture brobe

Position the chosen Extrusion Plate into the Ottawa Cell (48.5 x 48.5 x 90mm). With the arm of the instrument in its highest position, attach the plunger by screwing into the load cell. Slowly lower, the arm of the instrument until the plunger is just above the top of the Ottawa cell. Adjust the position of the Ottawa cell to ensure central accommodation of the plunger with clearance to avoid frictional contribution during a test. Once centrally located secure the Ottawa cell in this position and a 'blank' test be run as a check with calibration of the force as per given in manual. The test setup of for measurement of force applied and distance of application to be recorded was used as per given in Table 3.11.

The particular attributes were measured to define the textural properties of product as Hardness and crispness as shown in Fig. 3.4.

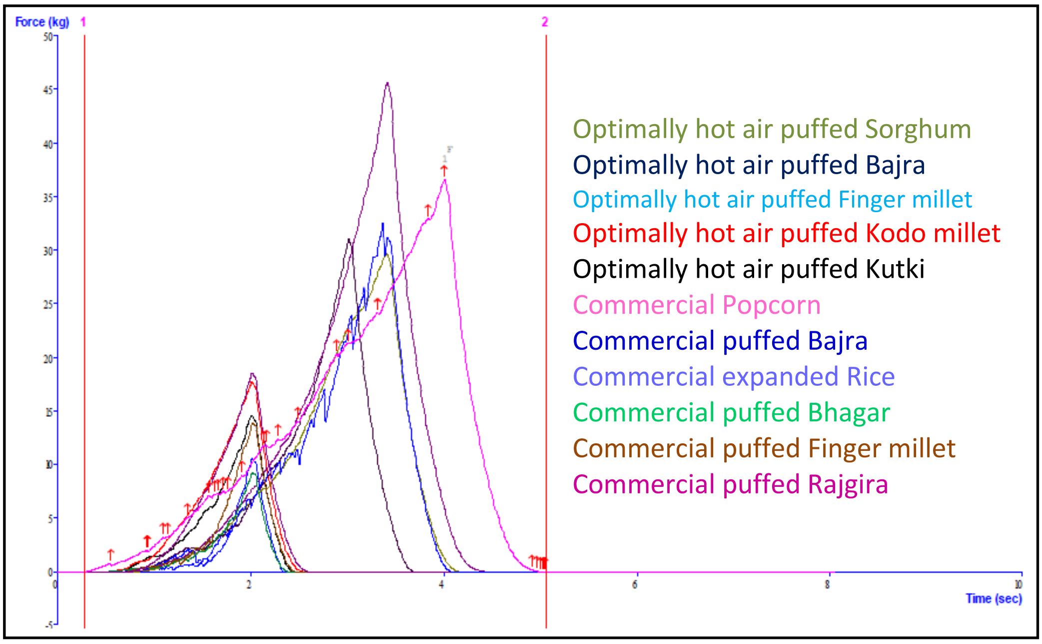


Fig. 3.4 Graphical representation of textural properties (hardness and crispness)

3.7.3 Colour measurement

The colour (L, a and b-value) was measured using hunter lab colorimeter (Plate3.4) as followed by Khodke (2002). The L-values, which denotes degree of whiteness (black=0 and white=100), was chosen to represent the colour of samples. The colour (L, a and b-value) and was measured using a simple digital imaging method Yam and Papadakis (2004). All measurements were replicated ten times and the mean readings were taken.

Plate 3.4: Colorimeter

3.8 Data analysis and optimization

Regression analysis and analysis of variance (ANOVA) were conducted for fitting the models represented by Eq. 3.4 and 3.5 and to examine the statistical significance of the model terms. The adequacy of the models were determined using model analysis, lack-of fit test and R^2 (coefficient of determination) analysis as outlined by Lee *et al*. (2000)

and Weng *et al*. (2001). The lack of fit is a measure of the failure of a model to represent data in the experimental domain at which points were not included in the regression or variations in the models cannot be accounted for by random error Montgomery (2001). If there is a significant lack of fit, as indicated by a low probability value, the response predictor is discarded. The R^2 is defined as the ratio of the explained variation to the total variation and is a measure of the degree of fit Haber and Runyon (1977). Coefficient of variation (CV) indicates the relative dispersion of the experimental points from the prediction of the model. Response surfaces and contour plots were generated with the help of commercial statistical package, *Design Expert* - *version 11.0* (Stat-Ease, 2018). The numerical and graphical optimization was also performed by the same software.

3.9 Numerical optimization

Numerical optimization technique of the Design-Expert software was used for simultaneous optimization of the multiple responses. The desired goals for each factor and response were chosen. The goals may apply to either factors or responses. The possible goals are: maximize, minimize, target, within range, none (for responses only). All the independents factors were kept within range while the responses were either maximized or minimized. In order to search a solution optimizing multiple responses, the goals are combined into an overall composite function, D(x), called the desirability function Myers and Montgomery, (2002), which is defined as:

$$D(x) = (d_1 \times d_2 \times .... \times d_n)^{1/n} \quad \text{… (3.7)}$$

Where, d_1, d_2…d_n are desirability of responses and n is the total number of responses in the measure.

Desirability is an objective function that ranges from zero outside of the limits to one at the goal. It reflects the desirable ranges for each response (d_i). The desirable ranges are from zero to one (least to most desirable, respectively). The numerical optimization finds a point that maximizes the desirability function. The characteristics of a goal may be altered by adjusting the weight or importance (Stat-Ease, 2018).

Graphical optimization was also carried out for the process parameters for hot air puffing obtaining the best product. For graphical optimization, super imposition of contour plots for all responses was done with respect to process variables using Design-Expert software. The superimposed contours of all responses for puffing temperature, air velocity, feed rate, initial moisture content and their intersection zone for minimum final moisture content, maximum expansion ratio, hardness (in the range) and maximum crispness indicated the ranges of variables which could be considered as the optimum range for best product quality in terms of responses. The optimum combination of product and process variables for hot air puffing conditions were derived by averaging those ranges of variables.

3.10 Biochemical composition analysis of raw and final puffed different grain

The biochemical composition of the different raw and optimally puffed grain samples were measured by standard analytical procedures given in AOAC (1984),analysis was done in terms of moisture content, protein, fat, ash and carbohydrates, etc. and each observation was recorded thrice. The techniques for measurement of biochemical composition of raw and puffed grain samples are mentioned below.

3.10.1 Moisture content

The moisture content of the sample was determined by using hot air oven (0 to 300°C). The weighed samples were subjected to remove moisture at 105 ± 2 °C for 24 h. After which it was kept inside a desiccators for cooling to ambient temperature and the change in weight (measured using electronic weighing balance) was noted (AOAC, 1984). The moisture content was expressed as kg moisture/ kg wet matter (wet basis, wb) or kg moisture/ kg dry mater (dry basis, db). Mean of three replications was reported throughout the course of study.

3.10.2 Protein content

Protein Content was determined by AOAC (1984) method NO. 2.049. Two gram of sample was taken in Kjeldahl flask Plate (3.5). Two gram of catalyst mixture (1.5 g K_2SO_4 with 0.0075 g Se) and 25 ml concentrated $H_2SO_4$was added to it. The flask was placed in an inclined position on the stand in the digestion chamber for digestion. The flask was heated gently over a low flame until the initial frothing ceases and the mixture was boiled briskly at moderate rate. The heating was continued until the color of digest was pale blue. The digest was cooled and 40 ml of water was added in 5 ml proportion with mixing. The digest was then transferred to 100 ml volumetric flask. The rest of volume was filled with water. A blank digestion without the sample was carried out and the digest was made to 100 ml. Then 5 ml of the digest was taken in a micro-Kjeldhal condenser and 10 ml 30 % NaOH was added to it. Five ml of 2 % boric acid with 4 drops of mixed indicator was taken in a clean conical flask and placed it under the outline pipe so that the outlet pipe tip should be dipped in the boric acid. After distillation, the ammonia which escaped with steam through the condenser was dissolved into the boric acid solution. The boric acid changes from bluish purple to bluish green as soon as it comes in contact with ammonia. Five minutes later the conical flask was lowered so that the condenser tip was 10 mm above the liquid. After removing from the burner, the excess boric acid was titrated with standard hydrochloric acid until the blue color disappeared. The blank distillation and titration were carried out as in the case of the sample.

$$\text{Nitrogen \%} = \frac{\text{(Sample titre-blank titre) x Normality of HCL x 14 x Volume made up x 100}}{\text{Aliquot of digestion taken x Weight of the dried sample x 100}} \quad \text{... (3.8)}$$

$$\text{Protein \%} = \text{Nitrogen \% x F}$$

Where *'f'* is multiplying factor as 5.70 for wheat flour, 5.95 for rice flour and 5.71 for soybean flour Thimmaiah (2006).

Plate 3.5: Protein estimation instrument

3.10.3 Fat content

Fat soluble material in a food is extracted from an oven-dried sample using a Soxhlet extraction apparatus palte (3.6).The hexane was evaporated and the residue weighed (Nath, 2006).

Plate 3.6: Soxhlet apparatus

$$\text{Fat Content \%} = \frac{\text{(Weight of hexane soluble material x 100)}}{\text{Weight of sample}} \quad \text{... (3.9)}$$

3.10.4 Carbohydrates (including fibers) (by difference)

The carbohydrate content (including fibers) was estimated by subtracting the values of protein, ash, and crude fat on dry basis from 100 % dry matter (FAO, 1998).

3.10.5 Ash content

It was determined according to AOAC (1984) (14.059) using muffle furnace method Plate (3.7).

Two gram of sample was weighed into a porcelain dish that had been ignited, cooled in desiccator then transferred to muffle furnace at 550 °C until light grey ash resulted or to constant weight. It was then cooled in desiccator and weighed soon after reaching room temperature.

Plate 3.7: Muffle furnace

3.10.6 Tannin Estimation

Tannin contents in composite flours (CF1 and CF2) were estimated by the Folin–Denis assay and tannic acid was used as a standard Schanderi (1970). Sample 500 mg was weighed into extraction tubes and extracted with 75 ml water after boiling for 30 minutes. The sample with the extraction solvent was centrifuged for 15 minutes at 4000 rpm. One ml extract was mixed with 5 ml Folin–Denis reagent and 10 ml of sodium carbonate (saturated) and diluted to 100 ml. The absorption was measured at 765 nm using spectrophotometer (Model U 2001, Hitachi UV/Vis spectrophotometer) and the tannin content was expressed as tannic acid equivalents in mg per 100g dry material**.**

3.10.7 Extraction of polyphenols

Polyphenols content was estimated by following the method of Malik and Singh (1980). Weighed exactly 1 g dry flour and ground it with a mortar and pestle in 10 ml of 80% (v/v) ethanol and centrifuged the homogenate at 10,000 rpm for 10 minutes. The supernatant was collected and reextracted the residue twice with five ml 80% (v/v) ethanol. Pooled the supernatants and made final volume to 15 ml. Took one ml of the supernatant and made up the final volume to 4.0 ml with distilled water. Then added 0.5 ml of 1N Folin-Ciocalteau reagent and then after three minutes, 2 ml of saturated Na_2CO_3 solution was added to each tube. The contents were mixed thoroughly and placed the tube in boiling water bath for exactly one minute. Tubes were cooled and absorbance was recorded on UV–Vis spectrophotometer (Thermo Scientific EVOLUTION 201) at 650 nm against a reagent blank. A standard curve prepared using different concentrations of catechol (0-100 mg/ml) was used to calculate polyphenol content. Results are expressed as mg catechol equi./100 g dry flour.

3.11 Sensory evaluation

Sensory evaluation is an important tool in food industry. Sensory characteristics of hot air puffed millet grains and commercially available puffed millets were evaluated for the different sensory attributes by panel of judges. The data so obtained from the panel were analyzed by using the fuzzy logic to find out the sensory and quality attributes of developed snack (Das, 2005). The sensory evaluation of hot air puffed millet grains were carried out by a panel of available twenty members of untrained judges consisting of students and staff of the Dept. of Agricultural Process Engineering, PDKV, Akola. Score card used for the evaluation is given in Appendix-VII. The sensory scale factors and their numerical values assigned to each of the quality attributes were poor, fair, good, very good and excellent. Judges were asked to give a tick mark and also numerical score against the category corresponding to each attribute of all samples and also to give their rank of preferences for quality attributes of snack food samples in general. The scale factors used for quality attributes of snack food in general were "not at all important‟, "somewhat important‟, "important‟, "highly important‟ and "extremely important‟.

The sum of the number of tick marks for hot air puffed millet grains and commercially available puffed millets and quality attributes in general were obtained. The data available from subjective evaluation of hot air puffed millet grains and commercially available puffed millets were analyzed by Fuzzy Logic method to find out ranking of the prepared samples, ranking of individual quality attributes of each of sample tested and the relative importance of quality attributes in general.

3.11.1 Modeling of sensory scores using fuzzy theory

The sensory preference and scores given by judges are uncertain phenomenon and can be treated mathematically by Fuzzy sets theory (Zadeh, 1965). The ranking of the snack food and new products can be done by fuzzy comprehensive modeling (Zhang and Litchfield 1991). PM snack food samples and quality attributes were assigned fuzzy membership on a five point sensory scale (Das, 2005). In the triangular fuzzy membership distribution, sensory scales are represented by a set of three numbers called "triplets‟. Sensory scores of snack food samples and their quality attributes are converted into triplets, which were used for the estimation of similarity values needed for the ranking of samples. In the fuzzy modeling of sensory evaluation the following major steps are involved: (1) calculation of overall sensory scores of snack food samples in the form of triplets (2) calculation of membership function on standard fuzzy scale (3) calculation of overall membership function on standard fuzzy scale for snack food samples (4) estimation of similarity values and ranking of samples (5) quality attribute ranking of snack food samples in general and (6) ranking of quality attributes of individual snack food samples (Jaya and Das, 2003; Sinija and Mishra, 2011).

3.11.1.1 Triplets associated with five point sensory scale

The sensory scores are converted into a set of three numbers, called "triplet‟ on five point scale. The distribution pattern of five point sensory scale is poor/not at all important, fair/somewhat important, medium/important, good/highly important and excellent/ extremely important as shown in Fig. 3.5

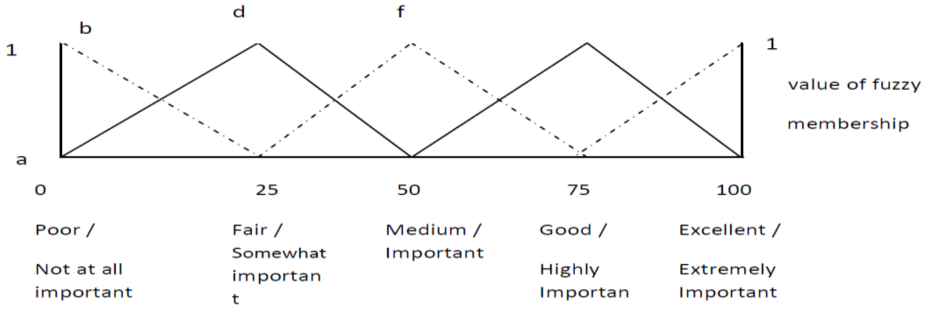


Fig. 3.5 Triplets associated with five point sensory scale

As for example triangle “abc‟ represents membership function for poor/not at all important category, triangle “ade‟ represents distribution function for fair/somewhat important category, etc.

Table 3.12 represents the triplets associated with five point sensory scales. First number of the triplet denotes the coordinate of the abscissa at which the value of the membership function is one. Second and third number of the triplet designates the distance to the left and right respectively of the first number where the membership function is zero.

Table 3.12 Triplets associated with five point sensory scale

Poor/Not at all important	Fair/Some what important	Good/Important	Very good/ Highly important	Excellent/ extremely important
0 0 25	25 25 25	50 25 25	75 25 25	100 25 0

3.11.1.2 Triplets for sensory scores of hot air puffed grain samples and overall quality

The triplet for a particular quality attribute of given sample can be obtained from the sum of sensory scores, triplets associated with five point sensory scale and the number of judges. For example, the colour attribute of a sample, when total number of judges were 20 and out of the total 20 judges, three judges gave “Fair‟ score, six judges gave the score as “Medium‟, fourteen gave “Good‟ and seven gave “Excellent‟; the triplets for the sensory scores of colour can be calculated by Eq. 3.9.

$Cs1$ = 0 0 0 25 +5 25 25 25 +8 50 25 25 +5 75 25 25 +2(100 25 0) 20 … (3.9)

Triplets for each quality attribute of all the samples and quality attributes of snack food samples in general were obtained as per Eq. 3.9. Similarly, from the general weightage given by judges to the quality attributes of snack food samples in general, the triplets for relative weightage of quality attributes (QRel) were also calculated.

The triplets for overall sensory scores of hot air puffed grain samples were calculated using Eq. 3.10, in which triplet for sensory score for each quality attribute was multiplied with the triplet for relative weightage of that particular attribute and the sum of resultant triplet values for all attributes was taken.

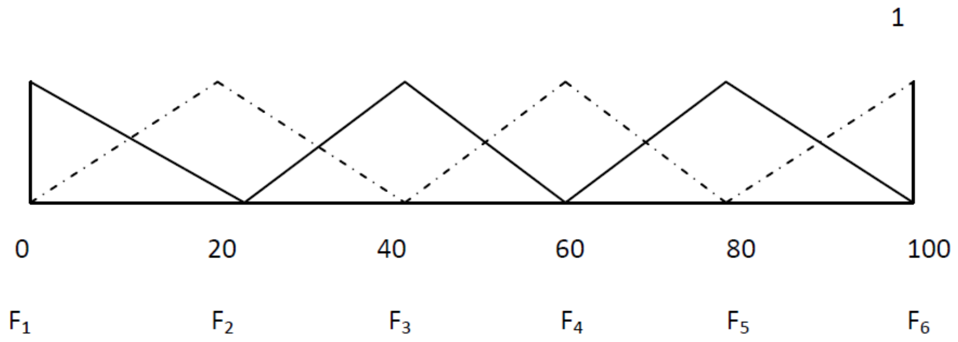
$$SO1 = CS1\times QCrel+FS1 \times QFr + TS1 \times +QTrel+ OS1\times QOrel \qquad \ldots (3.10)$$

Where, CS1, FS1, TS1 and OS1 represents the triplets corresponding to the colour, flavor, texture and overall acceptability of sample one and QCrel, QFrel, QTrel and QOrel denotes the triplets corresponding to the relative weightage of quality attributes like color, flavor, texture and OAA of snack food in general. Using similar Equations, the overall scores for all samples were calculated. The multiplication of triplet (a b c) with triplet (d e f) was done by applying a rule as given in Eq. 3.11.

$$(a\ \ b\ \ c) \times (d\ \ e\ \ f) = (a \times d \quad a \times e + d \times b \quad a \times f + d \times c) \qquad \ldots(3.11)$$

3.11.1.3 Membership function for standard fuzzy scale

The triplets obtained by Five Point scale are converted into Six Point sensory scale referred to as Standard Fuzzy scale. The triangular distribution pattern of sensory scales using symbols F1, F2, F3, F4, F5 and F6 is given in Fig. 3.6. Membership function of each of the sensory scales follows triangular distribution pattern where maximum value of membership function is one.



Not satisfactory/ Not all at important	Fair / Somewhat important	Satisfactory / Necessary	Good / Important	Very good / Highly important	Excellent / Extremely important

Fig. 3.6 Standard fuzzy scale

The values of fuzzy membership function lie between 0 to 10. Therefore, values of F1 through F6 are defined by a set of 10 numbers as given in Eq. 3.12.

F1 = (1, 0.5, 0, 0, 0, 0, 0, 0, 0, 0)
F2 = (0.5, 1, 1, 0.5, 0, 0, 0, 0, 0, 0)

F2 = (0.5, 1, 1, 0.5, 0, 0, 0, 0, 0, 0)

F3 = (0, 0, 0.5, 1, 1, 0.5, 0, 0, 0, 0)

F4 = (0, 0, 0, 0, 0.5, 1, 1, 0.5, 0, 0)

F5 = (0, 0, 0, 0, 0, 0, 0.5, 1, 1, 0.5)

F6 = (0, 0, 0, 0, 0, 0, 0, 0, 0.5, 1) …(3.12)

3.11.1.4 Overall membership function of sensory scores on standard fuzzy scale

The graphical representation of membership function of a triplet (a, b, c) is given in Fig. 3.6 represents). The figure showed that for a triplet (a, b, c), when the value of abscissa is a, value of membership function is 1 and when it is less than a-b or greater than a+c, the value is 0. For a given value of x on abscissa, value of membership function Bx can be expressed as Eq. 3.13.

$Bx = x{-}(a{-}b)\ b$

$fora - b<x<a$

$Bx = a{+}c - xc$

$fo<x< (a + c)$ … (3.13)

Bx = 0 $<a - bandx> (a + c)$

For each of the samples and its triplets, value of membership function Bx at x=0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100. This membership function value of samples on standard fuzzy scale will be given a set of 10 numbers which are “(maximum value of Bx at 0 < x < 10), (maximum value of Bx at 10 < x < 20), (maximum value of Bx at 20 < x < 30), (maximum value of Bx at 30 < x < 40), (maximum value of Bx at 40 < x < 50), (maximum value of Bx at 50 < x < 60), (maximum value of Bx at 60 < x < 70), (maximum value of Bx at 70 < x < 80), (maximum value of Bx at 80 < x < 90), (maximum value of Bx at 90 < x < 100)‟.

3.11.1.5 Similarity values and ranking of snack food samples

After getting the B values for each sample on standard fuzzy scale as a set of 10 values, the similarity values for each sample were obtained by the Eq. 3.14 (Sinija and Mishra 2011).

$$S, = F \times B' \ Max \ (F \times F' \ and B \times B') \qquad \ldots (3.14)$$

Where, Sm is the similarity value for the sample, F × B′ is the product of matrix F with the transpose of matrix B, F × F′ is the product of matrix F with the transpose of F and B × B′ is the product of matrix B with its transpose. For sample one similarity values will be Sm (F1, B1), Sm (F2, B1), Sm (F3, B1), Sm (F4, B1), Sm (F5, B1) and Sm (F6, B1). The values were calculated using the rules of matrix multiplication. Similarity values under the six categories of sensory scales were compared to find out the highest similarity value. The category corresponding to the highest similarity value was considered responsible for its quality. The overall quality of each of the samples was defined using above procedure. By combining the defined overall qualities of the samples as calculated by the above procedure, ranking of three samples was done.

The quality attributes ranking of puffed grain in general was done by using above described method. Using the overall sensory scores as triplets of the four quality attributes and the standard fuzzy scales, similarity values for each of the quality attributes was calculated. By comparing the similarity values for each of the four quality criteria, the highest similarity value was found out and regarded as the best quality criteria for puffed grain in general.

In order to compare the rankings of samples and quality attributes of snack foods obtained by fuzzy analysis, sensory scores were obtained from judges based on ten point scale. The mean scores for quality attributes and overall acceptability of samples were calculated and analysis of variance for quality attributes in general was done to find statistical significance.

3.12 Storage of hot air puffed grain samples

Storage studies were conducted at 40 °C and 95% relative humidity temperature and packaging materials on the final puffed grain products prepared by optimized process conditions. Multilayer flexible film (MF) and HDPE were used for storage studies, as these materials are known to be fairly good moisture and oxygen resistant and being used commercially for packaging of crispy snack foods (Pawar, 2017).

3.12.1 Sorption isotherm of hot air puffed grain samples

Sorption isotherm behaviour of the puffed grains sample at ambient condition was studied to show the variation in moisture content with water activity (a_W). Crispness, the main criteria for acceptability of the product corresponding to variation in moisture content was measured in the Texture Analyzer. Critical moisture content and critical water activity where the product lost its crispness was determined through these studies (Pardeshi, 2008).

3.12.2 Determination of water vapor transmission rate (WVTR) of packaging material

The values of permeability for given thickness of the packaging materials was determined by using Eq. 3.15 (Khodke, 2002 and Pardeshi, 2008).

The permeability of packaging material was calculated using following equation:

$$K_A = \frac{\Delta W / \Delta \theta}{P_{out} A'} \qquad \ldots (3.15)$$

Where, W = weight gain by desiccant (g)

θ = time (days)

K_A = permeability (kg m^{-2} day^{-1} Pa^{-1}) for given thickness (x) of the packaging material

A’ = area of the package (m^2)

x = thickness of packaging material (mm)

P_{out} = water vapor pressure at 40 °C (Pa)

3.12.3 Shelf life calculation

Shelf life of the puffed product ‘θ’ (days) i.e. period required for the moisture content of the puffed grains sample to increases from an initial value of Mi (kg water per kg dm) to its critical value Mc where it lost its crispness was estimated numerically (Das, 2005).

$$\theta = \frac{W_s}{P^* K_A A'} \int_{M_i}^{M_c} \frac{M}{RH - a_W} \qquad \text{… (3.16)}$$

Where, θ = shelf life (days)

Ws = dry matter of the puffed product (kg)

W_{gain} = weight gain due to moisture uptake = Ws (M_c – M_i)

P* = saturation vapor pressure of water at T °C (Pa)

$$= \exp\left(23.0603 - \frac{3723.67}{222.857 + T}\right) \text{ (Geankoplis, 1983)}$$

K_A = permeability of the packaging material (kg m^{-2} day^{-1} Pa^{-1})

A’ = area of the package (m^2)

RH = relative humidity in which package is placed (fraction)

a_W = water activity (fraction) of the product at T °C = f (M)

a_{Wc} = critical water activity and is less than or equal to RH

M = Moisture content of the puffed product (kg water per kg dm)

i and c = are the suffix for initial and critical moisture contents respectively.

CHAPTERV

RESULTS AND DISCUSSION

This section deals with results of various investigations on development of semi-automated multigrain continuous hot air puffing system for grain and also hot air puffing process, optimization of process for hot air puffing of multi grain and changes in chemical composition of grains before and after hot air puffing, sensory evaluation and storage studies of optimally puffed grains.

4.1 Sample preparation for sorghum and bajra grain

The sorghum and bajra samples were prepared as discussed in section 3.5.1. The moisture content of pre treated sorghum and bajra grains were in between 0.18 to 0.28 kg/kg dm and 0.20 to 0.30 kg/kg dm, respectively. Details of decortications of finger millet were described earlier in section 3.5.2 with the moisture content of 0.101 kg/kg dm.

Plate 4.1: Hot air puffed millets (multigrain)

4.2 Hot air puffing of different grain

4.2.1 Hot air puffing of sorghum grain

The experiment on hot air puffing of sorghum was conducted in CCRD with four variables viz., puffing temperature (PT, °C), air velocity (AV, m/s), feed rate (FR, g/h) and initial moisture content, (IMC, kg/kg dm). The response variables measured for studying the effect and optimization of process parameters were taken as final moisture content (FMC, kg/kg dm), hardness (HD, g), crispness (CSP, No. of +ve peaks), colour (L-value) and expansion ratio (ER). The observations recorded are given in Appendix- II.

4.2.1.1 Effect of various process parameters on final moisture content (FMC, kg/kg dm) during hot air puffing of sorghum grain

The observations for each experiment were as recorded in Appendix-II. The data were analyzed for its stepwise regression analysis as shown in Table 4.1. It could be observed that the values of FMC ranged between 0.033 to 0.0572 kg/kg dm. The quadratic model was fitted to the experimental data and statistical significance for quadratic terms was calculated for FMC as shown in Table 4.1. The R^2 value was calculated by a least square technique and found to be 0.7065, showing good fit of model to the data. The model F-value of 15.04 implies that the model is significant ($P<0.01$). The quadratic terms PT^2, AV^2 ($P<0.01$) and FR^2 and IMC^2 ($P<0.1$) are significant. The F-value of lack of fit was non significant, which indicates that the developed model was adequate for predicting the response. Moreover, the model adequacy evaluated with predicted R^2 of 0.4881 showed it to be in reasonable agreement with the adjusted R^2 of 0.6595. This indicated that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on FMC in terms of actual levels of variables is given as,

$$FMC=0.039-4.14576\text{-}09 \times PT^2+7.51565\text{-}06 \times AV^2+1.82535\text{-}11 \times FR^2-0.01602 \times IMC^2 \quad \text{.... (4.1)}$$

The comparative effect of each factor on the FMC could be observed by the F-values in the ANOVA and also by the magnitudes of coefficients of the coded variables (Table. 4.1). The F-values indicated that PT^2 was the most influencing followed by AV^2 over FMC. The IMC^2 was least influencing while FR^2 had moderate effect on FMC. To visualize the combined effect of two variables on the FMC, the response surface and contour plots were generated for the fitted model as a function of two variables while keeping other two variables at their central values.

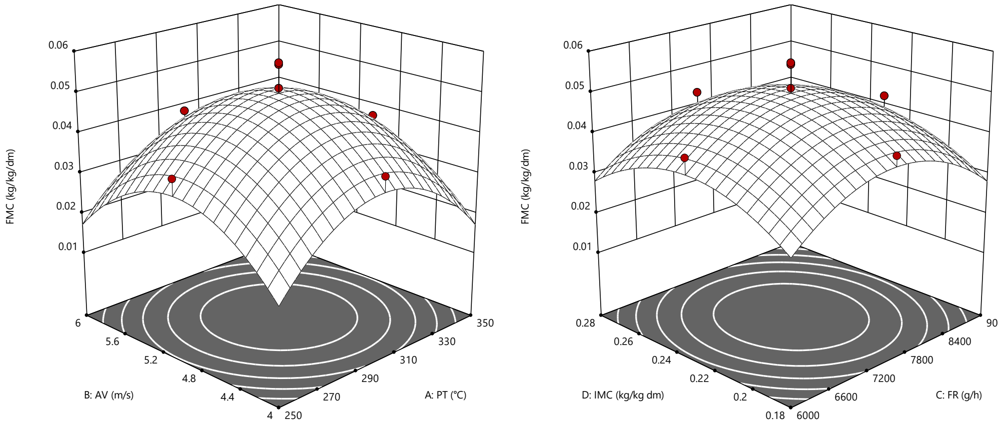
Table 4.1 ANOVA table showing the effects of variables of FMC (kg/kg dm) and the coefficients of predictive models for puffing of sorghum grain

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	0.001	4	0.0002	15.04	< 0.0001
PT^2	0.0005	1	0.0005	29.91	< 0.0001
AV^2	0.0004	1	0.0004	26.79	< 0.0001
FR^2	0.0002	1	0.0002	14.76	0.0007
IMC^2	0.0002	1	0.0002	11.41	0.0024
Residual	0.0004	25	0		
Lack of Fit	0.0002	20	0	0.347	0.9594^{NS}
Pure Error	0.0002	5	0		
Cor Total	0.0014	29			
R^2	0.7065				
Adj R^2	0.6595				
Pred R^2	0.4881				
C.V. %	10.33				
SD	0.004				

NS- Non significant

It could be observed from Fig. 4.1 (A) and (B) that FMC increase initially with increase in PT, AV, FR and IMC upto certain maxima i.e., upto 300 °C of PT, 5 m/s of AV, 7500 g/h of FR and 0.23 kg/kg dm of IMC and decreasing subsequently as depicted by quadratic term in Eq. 4.1.

FMC increased initially with increase in PT, AV, FR and IMC upto certain maxima, may be due to the fact that feed was with more moisture (maximum initial moisture content present in grain) and afterward PTincreased lead to reduced moisture of puffing material. During exposer of grain in puffing coloum, PT is most responsible for decreasing moisture content.The rate of PT and AV for moisture removal was higher than FR. PT was decreased moisture up to grain finish resident time in puffing coloum, the resident time of grain in the puffing coloum finished on the kernal expantion and therby puffed grain flew out of the coloum.



(A) (B)

Fig. 4.1 The contour and response surface plots showing the effect of (A) PT and AV and (B) FR and IMC on FMC (kg/kg dm) for puffing of sorghum grain

The decrease in moisture content of puffed product with increase in puffing temperature and puffing time had been recorded by Mukherjee (1997) for HTST air puffing of potato cubes and Nath *et al.* (2007) for HTST air puffing of potato-soy snack foods and Pawar (2017) for HTST microwave puffing of sprouted soy fortified millet flour based RTE snack. The reduced FMC after puffing of grain may be due to the fact that increased PT for longer time and AV to some extend causing reduction in moisture content due to exposer of grain to hot air, leading to conversion of more moisture mass into vapours, causing removal of comparatively more moisture, once puffing was advanced.

4.2.1.2 Effect of various process parameters on expansion ratio (ER) during hot air puffing of sorghum grain

The data recorded for ER after each set of experiment (Appendix-II)were analyzed for stepwise regression analysis, as shown in Table 4.2. It could be observed that the values of ER were ranged between 6.4 and 13.8. The quadratic model was fitted to the experimental data and statistical significance for linear and quadratic terms was calculated for ER as shown in Table 4.2. The R^2 value was calculated by a least square technique and found to be 0.7076, showing good fit of model to the data. The model F-value of 11.61 implies that the model is significant

($P<0.01$). The linear terms PT ($P<0.01$) is significant, quadratic terms like PT^2, FR^2 and IMC^2 ($P<0.05$) are significant and interaction term of PT and IMC ($P<0.1$) is significant. The F-value of lack of fit was non-significant for the model obtained as shown in Eq. 4.2, which indicates that the developed model was adequate for predicting the response. Moreover, the predicted R^2 of 0.4772 was in reasonable agreement with the adjusted R^2 of 0.6466. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation (Eq. 4.2) describing the effects of the process variables on ER in terms of actual levels of variables is given as,

$$ER = -154.924 + 1.098531 \times PT - 0.19583 \times PT \times IMC - 0.00171 \times PT^2 - 2.1E\text{-}08 \times FR^2 + 92.43174 \times IMC^2 \quad \text{... (4.2)}$$

The comparative effect of each factor on the ER could be observed by the F-values in the ANOVA and also by the magnitudes of coefficients of the coded variables (Table. 4.2). The F-values indicated that PT^2 was the most influencing factor followed by FR^2, IMC^2 and PT over ER . The interaction term of PT and IMC was least effective over ER. To visualize the combined effect of two variables on the ER, the response surface and contour plots [Fig. 4.2 (A) and (B)] were generated for the fitted model as a function of two variables while keeping other two variables at their central values.

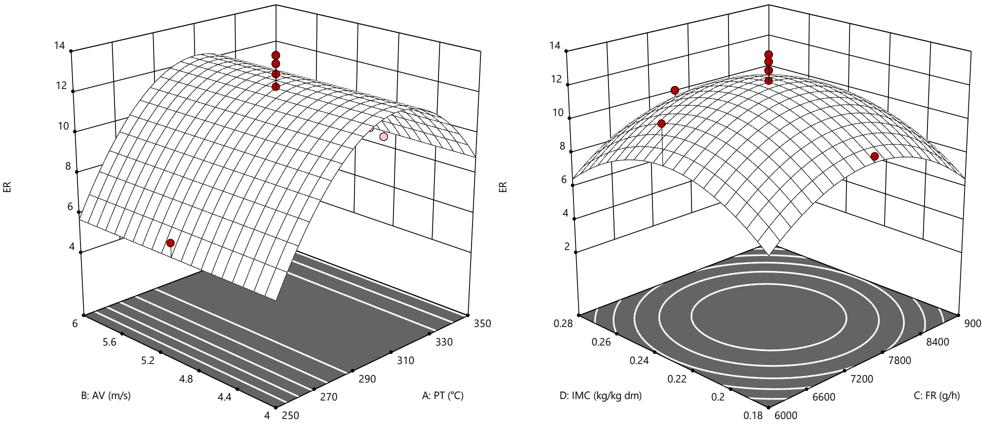
The positive linear terms and negative quadratic terms of PT indicated that ER initially increased with increase in PT up to its maxima (at PT=300 °C) and decreased thereafter prominently (as numerical value of quadratic term is higher than that of linear term), while it increased with increase in FR and IMC upto its maxima (at FR=7500 g/h and IMC=0.23 kg/kg dm), respectively and indicated little decrease, thereafter (as numerical value of linear term is higher than that of quadratic term).

The expansion ratio increased as the moisture content and time increased then these parameters decreased with further increase of moisture. These results agreed with the previous studies of Pajic (1990) and Metzger *et al.* (1989).

Table 4.2 ANOVA table showing the effects of variables of ER and the coefficients of predictive models for puffing of sorghum grain

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	83.32	5	16.66	11.61	< 0.0001
PT	14.38	1	14.38	10.02	0.0042
PT x IMC	11.72	1	11.72	8.17	0.0087
PT^2	43.07	1	43.07	30.01	< 0.0001
FR^2	15.31	1	15.31	10.67	0.0033
IMC^2	14.82	1	14.82	10.33	0.0037
Residual	34.44	24	1.43		
Lack of Fit	28.01	19	1.47	1.15	0.482^{NS}
Pure Error	6.43	5	1.29		
Cor Total	117.75	29			
R^2	0.7076				
Adj R^2	0.6466				
Pred R^2	0.4772				
C.V. %	11.88				
SD	1.2				

NS- Non significant



(A) (B)

Fig. 4.2 The contour and response surface plots showing the effect of (A) PT and AV and (B) FR and IMC on ER for puffing of sorghum grain

As moisture content of kernel increases, the melting temperature of the pericarp decreases, thus when the water content is high, the pressure in the kernel at popping moment is lower, causing less expansion and lower final popped volume as suggested by Shimoni *et al.* (2002). The pericarp acts as a vessel cap, hence the high mechanical resistance of the pop sorghum pericarp allows it to sustain high pressure, favouring high popping ratio in sorghum.

The increase in ER with increased PT and IMC coincides with simultaneously reduced moisture content. This may be due to more case hardening, leading to conversion of comparatively more moisture mass into vapours, causing higher expansion effect.

4.2.1.3 Effect of various process parameters on colour (L-value) during hot air puffing of sorghum grain

The data recorded for C (L-value) after each set of experiment shown in Appendix-II was analyzed for stepwise regression analysis, and the results are shown in Table 4.3. It could be observed that the values of C (L-value) were ranged between 61.693 and 72.317. The quadratic model was fitted to the experimental data and statistical significance for linear and quadratic terms was calculated for C (L-value) as shown in Table 4.3. The R^2 value was calculated by a least square technique and found to be 0.8952, showing good fit of model to the data. The model F-value of 32.75 implies that the model is significant ($P<0.01$). The linear term of FR ($P<0.1$) is significant and IMC and quadratic terms of PT^2 ($P<0.01$) are significant and AV^2, FR^2 and IMC^2 ($P<0.1$) are significant. The F-value of lack of fit was non-significant for the model obtained shown in Eq. 4.3. Moreover, the predicted R^2 of 0.7488 was in reasonable agreement with the adjusted R^2 of 0.8679. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on C (L-value) in terms of actual levels of variables is given as,

$$C\ (L\text{-value}) = 30.62798+0.00343 \times FR+132.74704 \times IMC+1.18148E\text{-}05 \times PT^2+0.04378 \times AV^2 -1.93E\text{-}07 \times FR^2-195.14220 \times IMC^2 \quad \ldots (4.3)$$

The C (L-value) followed non linear behaviour with FR and IMC due to quadratic terms of FR and IMC in Eq. 4.3. The C (L-value) improved with increase PT, AV, FR and IMC upto certain maxima and therafter decresasing (305 °C PT, 4.8 m/s AV, 7800g/h FRand 0.23 kg/kg dmIMC).

The C (L-value) decreased with increasee in PT. At lower PT, the C (L-value) observed to be unchanged or improved with AV. This indicates that the puffing of grain was getting more browned at higher PT with lower AV. The improvement in C (L-value) can be accredated to higer expansion effect and decreased C (L-value) may be due to prolonged exposure of product to higher puffing temperature (PT), leading to the browning of puffed grain sample.

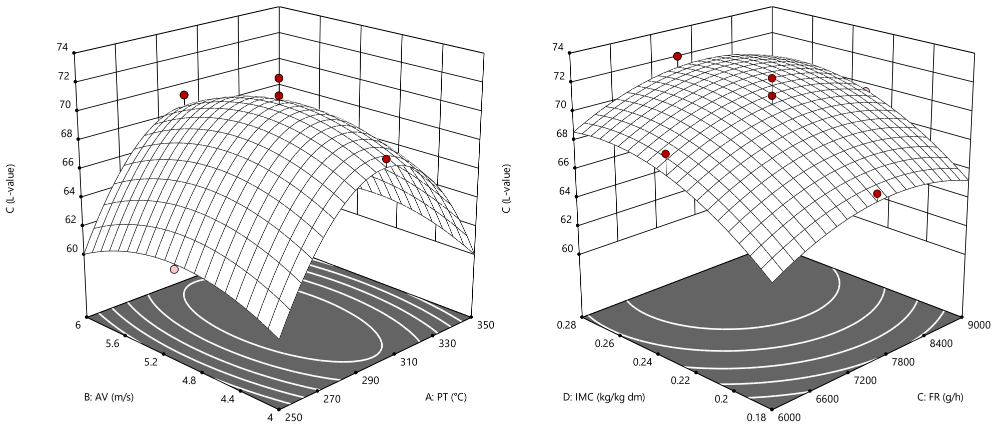
Table 4.3 ANOVA table showing the effects of variables of C (L-value) and the coefficients of predictive models for puffing of sorghum grain

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	155.31	6	25.88	32.75	< 0.0001
FR	3.99	1	3.99	5.04	0.0346
IMC	35.07	1	35.07	44.37	< 0.0001
PT^2	123.26	1	123.26	155.94	< 0.0001
AV^2	7.29	1	7.29	9.22	0.0059
FR^2	5.37	1	5.37	6.79	0.0158
IMC^2	5.74	1	5.74	7.26	0.013
Residual	18.18	23	0.7904		
Lack of Fit	11.99	18	0.666	0.5377	0.8482^{NS}
Pure Error	6.19	5	1.24		
Cor Total	173.49	29			
R^2	0.8952				
Adj R^2	0.8679				
Pred R^2	0.7488				
C.V. %	1.31				
SD	0.8891				

NS- Non significant

The same could be revealed from Fig. 4.3 (A) and (B) by visualizing the combined effect of two variables on the C (L-value), the response surface and contour plots generated for the fitted model as a function of two variables while keeping other two variables at their central values.

Effect of puffing temperature and feed rate on colour difference during HTST air puffing of fryum was also reported by Babar (2010), observed that browning occurred only after a certain feed rate in puffing coloum, which was more than 100 g/min with the puffing air temperature of 250 °C. These observations supported the present findings regarding the effects of the PT and FR on the colour (L-value) of sorghum grain during its hot air puffing.



(A) (B)

Fig. 4.3 The contour and response surface plots showing the effect of (A) PT and AV and (B) FR and IMC on C (L-value) for puffing of sorghum grain

4.2.1.4 Effect of various process parameters on hardness (HD, g) during hot air puffing of sorghum grain

The data recorded for HD after each set of experiment shown in Appendix-II were analyzed for stepwise regression analysis, as shown in Table 4.4. It could be observed that the values of HD were ranged between 37862 and 80220. The quadratic model was fitted to the experimental data and statistical significance for linear and quadratic terms was calculated for HD as shown in Table 4.4. The R^2 value was calculated by a least square technique and found to be 0.8007, showing that model was fitting well to the data. The model F-value of 25.12 implies that the model is significant ($P<0.01$). The linear terms PT and quadratic terms of IMC^2 ($P<0.01$) are significant. The linear terms AV and IMC ($P<0.5$) are significant. The F-value of lack of fit was non-significant for the model obtained shown in Eq. 4.4. Moreover, the predicted R^2 of 0.7219 was in reasonable agreement with the adjusted

R^2 of 0.7689. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on HD in terms of actual levels of variables is given as,

$$HD = 4.68114E{+}05 + 278.68562 \times PT - 6640.46392 \times AV - 3.91332E{+}06 \times IMC + 8.16907E{+}06 \times IMC^2 \quad \text{... (4.4)}$$

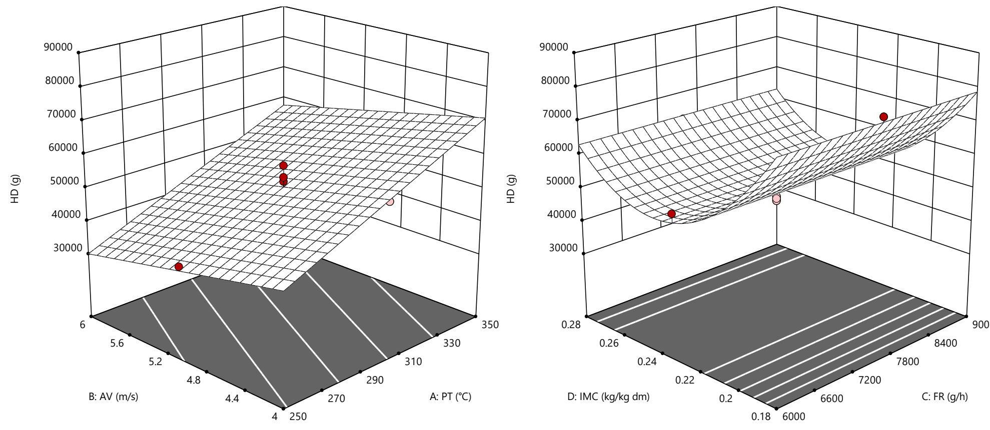
The F-values of linear and quadratic terms indicated that PT was most influencing followed by IMC^2. Other factors like IMC and AV were moderate influencing the variation in HD during puffing.

Table 4.4 ANOVA table showing the effects of variables of HD and the coefficients of predictive models for puffing of sorghum grain

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	2.34E+09	4	5.85E+08	25.12	< 0.0001
PT	1.17E+09	1	1.17E+09	50.03	< 0.0001
AV	2.65E+08	1	2.65E+08	11.36	0.0024
IMC	3.43E+08	1	3.43E+08	14.74	0.0007
IMC^2	7.70E+08	1	7.70E+08	33.08	< 0.0001
Residual	5.82E+08	25	2.33E+07		
Lack of Fit	4.91E+08	20	2.45E+07	1.34	0.4001^{NS}
Pure Error	9.13E+07	5	1.83E+07		
Cor Total	2.92E+09	29			
R^2	0.8007				
Adj R^2	0.7689				
Pred R^2	0.7219				
C.V. %	8.87				
SD	4825.61				

NS- Non significant

The HD increased with increase in PT and HD decreased initially with increase in IMC up to its minima about 0.24 kg/kg dm and increased thereafter. The same could be revealed from Fig. 4.4 (A) and (B), by visualizing the combined effect of two variables on the HD, the response surface and contour plots generated for the fitted model as a function of two variables while keeping other two variables at their central values.



(A) (B)

Fig. 4.4 The contour and response surface plots showing the effect of (A) PT and AV and (B) FR and IMC on HD (g) for puffing of sorghum grain

The hardness increased linearly with increase in puffing temperature from 225 to 350 °C, this may be caused due to the fact that at higher temperature, water evaporated from the surface of the grain which form the condition of case hardening and created the very hard surface and the further removal of water from the grain and thus increases the hardness (Srivastav *et al.,*1994).

4.2.1.5 Effect of various process parameters on crispness (CSP +ve peaks) during hot air puffing of sorghum grain

The observations for CSP with different combinations of the process parameters are presented in Appendix-II. It varied between 37.2 to 111.2 within the combination of variables studied. The quadratic model was fitted to the experimental data and statistical significance was calculated for CSP as shown in Table 4.5. The R^2 value was calculated by a least square technique and found to be 0.6564, showing good fit of model to the data. The model F-value of 9.17 implies that the model is significant ($P<0.01$). The linear terms of PT ($P<0.05$) is significant while AV, IMC, interaction term PT and IMC and quadratic term IMC^2 ($P<0.1$) are significant. The F-value of lack of fit was non-significant for the model obtained shown in Eq. 4.5. Moreover, the predicted R^2 of 0.4893 was in reasonable agreement with the adjusted R^2 of 0.5849. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on C (L-value) in terms of actual levels of variables is given as,

$$\text{CSP}= -1145.97234+1.54734 \times \text{PT}+8.46392 \times \text{AV}+8532.42023 \times \text{IMC}-8.57409 \times \text{PT} \times \text{IMC}-12343.14484 \times \text{IMC}^2 \quad \text{... (4.5)}$$

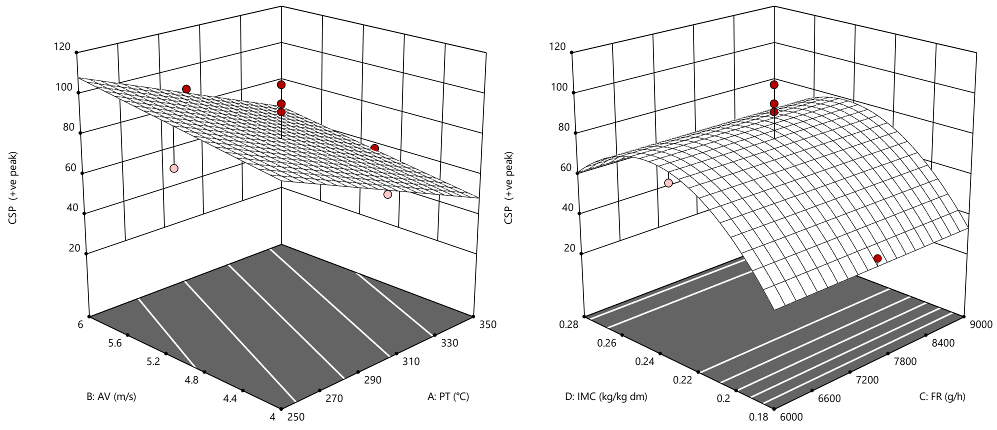
The comparative effect of each factor on the CSP could be observed by the F-values in the ANOVA and also by the magnitudes of coefficients of the coded variables (Table. 4.5).

Table 4.5 ANOVA table showing the effects of variables of CSP and the coefficients of predictive models for puffing of sorghum grain

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**
Model	6297.07	5	1259.41	9.17	< 0.0001
PT	2636.15	1	2636.15	19.2	0.0002
AV	429.83	1	429.83	3.13	0.0896
IMC	1131.26	1	1131.26	8.24	0.0084
PT x IMC	465.60	1	465.6	3.39	0.078
IMC^2	1758.82	1	1758.82	12.81	0.0015
Residual	3295.67	24	137.32		
Lack of Fit	2201.08	19	115.85	0.5292	0.8564^{NS}
Pure Error	1094.59	5	218.92		
Cor Total	9592.74	29			
R^2	0.6564				
Adj R^2	0.5849				
Pred R^2	0.4893				
C.V. %	16.08				
SD	11.72				

NS- Non significant

The effect of PT was most prominent while FR^2, IMC was moderate and AV and PT x IMC were least effective on CSP. Lack of Fit was non-significantly affecting CSP of the puffing sorghum grain.



(A) (B)

Fig. 4.5 The contour and response surface plots showing the effect of (A) PT and AV and (B) FR and IMC on CSP for puffing of sorghum grain

The CSP decreased with increase in PT while it increased with increase in AV and positive linear terms and negative quadratic terms of IMC indicated that CPS initially increased with increase in IMC up to its maxima (at IMC=0.24 kg/kg dm) and decreased thereafter prominently (Eq. 4.5).

The same trend was observed in graphical representation shown in the surface and contour plot [Fig.4.5 (A) and (B)] of two variables while other two were kept constant at their central levels. The lower values of CSP in present case are similar to the value of CSP of 105, HTST air puffed potato snack foods with the operating conditions of temperature, time, initial moisture content, and air velocity as 225 °C, 45s, 0.5384 kg/kg dm and 3.6 m/s respectively (Nath, 2006).

4.2.1.6 Optimization of hot air puffing process for puffed sorghum grain

Numerical and graphical optimization was carried out for the process parameters for hot air puffing for obtaining the best puffed grain sample. To perform this operation, Design-Expert program (*Version 11.0*) of the (Stat-Ease, 2018) software, as discussed in section 3.5.1, was used for simultaneous optimization of the multiple responses. The desired goals for each factor and response were chosen as shown in Table 4.6.

Table 4.6 Optimization criteria for different process variables and responses for hot air puffing of sorghum grain

Name	Goal	Lower Limit	Upper Limit
PT(°C)	is in range	275	325
AV (m/s)	is in range	4.5	5.5
FR (g/h)	is in range	6750	8250
IMC (kg/kg dm)	is in range	0.205	0.255
FMC (kg/kg dm)	Minimize	0.033	0.0572
HD (g)	is in range	37862	80220
CSP(+ve peaks)	Maximize	37.2	111.2
C (L- value)	Maximize	61.693	72.317
ER	Maximize	6.4	13.8

Table 4.7 shows that the software generated two optimum conditions of independent variables with the predicted values of responses. Solution No.1, having the maximum desirability value (0.699) was selected as the optimum conditions of hot air puffing for developing sorghum grains.

The optimum values of process variables obtained by numerical optimization:

Puffing temperature (PT) : 285.54 ≈ 286 °C

Air velocity (AV) : 5.5 m/s

Feed rate (FR) : 7987 g/h

Initial moisture content (IMC): 0.025 kg/kg dm

The superimposed contours of all responses for PT and AV and FR and IMC (Fig.4.6 A and B) and their intersection zone for minimum FMC, in range HD, maximum CSP (+ve peak), maximum C (L-value) and maximum ER indicated the ranges of variables which could be considered as the optimum range for best puffed sorghum grain quality.

Table 4.7 Solutions generated by the software for hot air puffing of sorghum grain

No.	PT (°C)	AV (m/s)	FR (g/h)	IMC (kg/kg dm)	FMC (kg/kg dm)	HD	CSP (+ve peak)	C (L value)	ER	Desirability
1	**285.53**	**5.5**	**7982**	**0.255**	**0.041**	**44459.88**	**91.268**	**70.21**	**10.86**	**0.699 ***
2	285.74	5.5	7991	0.255	0.041	44520.92	91.13	70.23	10.86	0.699

***Selected**

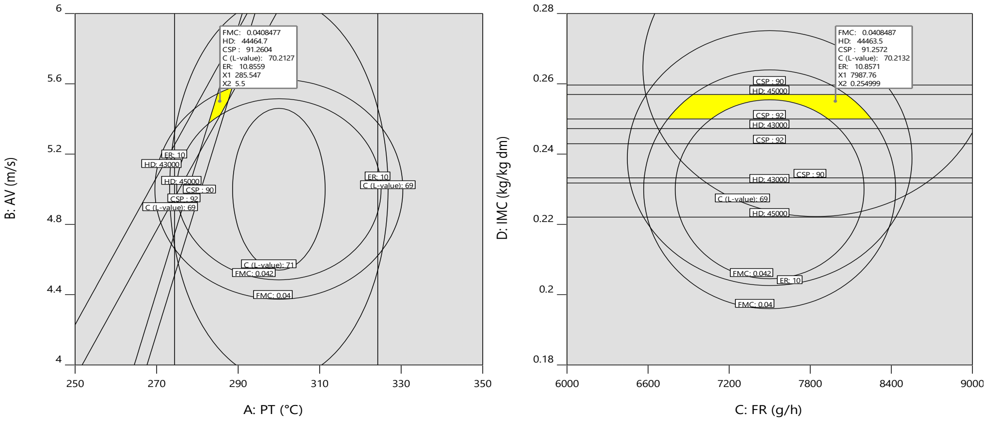
The range of optimum values of process variables obtained from the superimposed contours are as follows,

Puffing temperature (PT) : 280-290 °C

Air velocity (AV) : 5.3-5.6 m/s

Feed rate (FR) : 6700-8300 g/h

Initial moisture content (IMC): 0.25- 0.255 kg/kg dm



(A) (B)

Fig. 4.6 Superimposed contours for FMC (kg/kg dm), HD(g), CSP (+ve peaks), C (L-value) and ER, for puffing of sorghum at varying (A) puffing temperature (PT) and air velocity (AV) and (B) feed rate (FR) and initial moisture content (IMC)

4.2.1.7 Verification of the model for hot air puffed sorghum grain

Hot air puffing experiments were conducted at the optimum process condition and the quality attributes of the resulting sorghum grain was determined. The observed experimental values (mean of 5 measurements) and values predicted by the equations of the model are presented in Table 4.8. The values of C.V. (<10%) and closeness between the experimental and predicted values of the quality parameters indicated the suitability of the corresponding models.

Table 4.8 Comparison between predicted and actual response variables at optimum process conditions for preparation of hot air puffed sorghum grain

Response	Predicted value	Actual value (± SD)	Variation, %	C.V., %
FMC (kg/kg dm)	0.041	0.0372(±0.0014)	8.695	3.83
HD, g	44459.88	44518.48(±308.062)	0.185	0.69
CSP (+ve peaks)	91.268	86(±2.2226)	5.855	2.58
C (L-value)	70.213	68.641(±0.6969)	2.446	1.02
ER	10.863	9.224(±0.3626)	9.958	3.93

4.2.2 Hot air puffing of bajra grain

The experiment on hot air puffing of bajra grain was conducted in CCRD with four variables viz., puffing temperature (PT, °C), air velocity (AV, m/s), feed rate (FR, g/h) and initial moisture content, (IMC, kg/kg dm). The response variables measured for studying the effect and optimization of process parameters were taken as final moisture content (FMC, kg/kg dm), expansion ratio (ER), colour (L-value), hardness (HD, g) and crispness (CSP, No. of +ve peaks). The observations recorded are given in Appendix-III.

4.2.2.1 Effect of various process parameters on final moisture content (FMC, kg/kg dm) during hot air puffing of bajra grain

The observations for each experiment were as recorded in Appendix-III. The data were analyzed for its stepwise regression analysis as shown in Table 4.9. It could be observed that the values of FMC ranged between 0.0276 to 0.0603 kg/kg dm. The quadratic model was fitted to the experimental data and statistical significance for linear, interaction and quadratic terms were calculated for FMC as shown in Table 4.9. The R^2 value was calculated by a least square technique and found to be 0.6451, showing good fit of model to the data. The model F-value of 6.97 implies that the model is significant ($P<0.05$). The linear terms FR, interaction term PT x AV, PT x FR and quadratic term PT^2 ($P<0.05$) were significant, while linear term IMC and interaction term PT x IMC were significant at ($P<0.01$). The F-value of lack of fit was not significant, which indicates that the developed model was adequate for predicting the response. Moreover, the model adequacy evaluated with predicted R^2 of 0.3896 showed it to be in reasonable agreement with the adjusted R^2 of 0.5525. This indicated that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on FMC in terms of actual levels of variables is given as,

$$FMC=0.187112+ 4.09E\text{-}05 \times FR-2.20757 \times IMC+8.67E\text{-}06 \times PT \times AV - 1.3E\text{-}07 \times PT \times FR + 0.006436 \times PT \times IMC-9.5E\text{-}07 \times PT^2 \quad .... (4.6)$$

The F-values indicated that PT x AV was the most influencing followed by PT x FR, PT^2 and FR over and later followed by PT x IMC and over FMC. To visualize the combined effect of two variables on the FMC, the response surface and contour plots were generated for the fitted model as a function of two variables while keeping other two variables at their central values. It could be observed from Fig. 4.7 (A) and (B) that FMC increased with increase in PT at lower AV and it increased initially with increase in AV up to its maxima about 0.055 kg/kg dm and decreased thereafter and FMC was decreased linearly with FR and IMC increasing as depicted by quadratic term in Eq. 4.6.

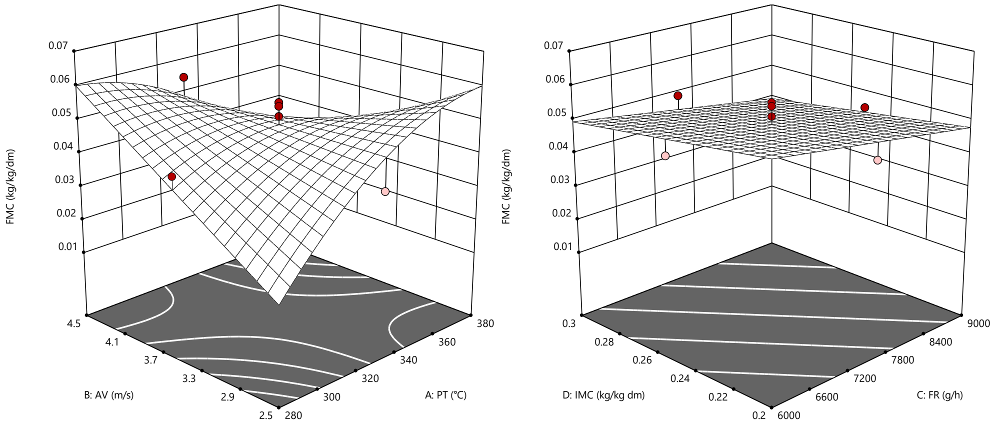
The variation in moisture content of puffed bajra grains with PT and AV is following similar trend as discussed in section 4.2.1.1.

The decrease in moisture content of puffed product with increase in puffing temperature and puffing time had been recorded by Mukherjee (1997) for HTST air puffing of potato cubes and Nath *et al.* (2007) for HTST air puffing of potato-soy snack foods and Pawar (2017) for HTST microwave puffing of sprouted soy fortified millet flour based RTE snack.

Table 4.9 ANOVA table showing the effects of variables of FMC (kg/kg dm) and the coefficients of predictive models for puffing of bajra

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	0.0012	6	0.0002	6.97	0.0003
FR	0.0002	1	0.0002	5.37	0.0297
IMC	0.0001	1	0.0001	3.74	0.0655
PT x AV	0.0004	1	0.0004	14.94	0.0008
PT x FR	0.0002	1	0.0002	7.69	0.0108
PT x IMC	0.0001	1	0.0001	4.63	0.0422
PT^2	0.0002	1	0.0002	5.43	0.029
Residual	0.0006	23	0		
Lack of Fit	0.0005	18	0	1.5	0.3463^{NS}
Pure Error	0.0001	5	0		
Cor Total	0.0018	29			
R^2	0.6451				
Adj R^2	0.5525				
Pred R^2	0.3896				
C.V. %	11.31				
SD	0.0053				

NS- Non significant



(A) (B)

Fig. 4.7 The contour and response surface plots showing the effect of (A) PT and AV and (B) FR and IMC on FMC for puffing of bajra grain

The reduced FMC after puffing of grain may be due to the fact that increased PT for longer time and AV to some extend causing reduction in moisture content due to exposer of grain to hot air, leading to conversion of more moisture mass into vapours, causing removal of comparatively more moisture, once puffing was advanced.

4.2.2.2 Effect of various process parameters on expansion ratio (ER) during hot air puffing of bajra grain

The data recorded for ER after each set of experiment is shown in Appendix-III were analyzed for stepwise regression analysis, as shown in Table 4.10. It could be observed that the values of ER were ranged between 1.81034 and 4.26087. The quadratic model was fitted to the experimental data and statistical significance for linear, interaction and quadratic terms was calculated for ER as shown in Table 4.10. The R^2 value was calculated by a least square technique and found to be 0.641. The model F-value of 6.84 implies that the model is significant ($P<0.05$). The linear terms AV, FR, interaction terms PT x AV, PT x FR, PT x IMC and quadratic term PT^2 ($P<0.1$) were significant. The F-value of lack of fit was non-significant for the model obtained shown in Eq. 4.7, which indicates that the developed model was adequate for predicting the response. Moreover, the predicted R^2 of 0.3562 was in reasonable agreement with the adjusted R^2 of 0.5473. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on ER in terms of actual levels of variables is given as,

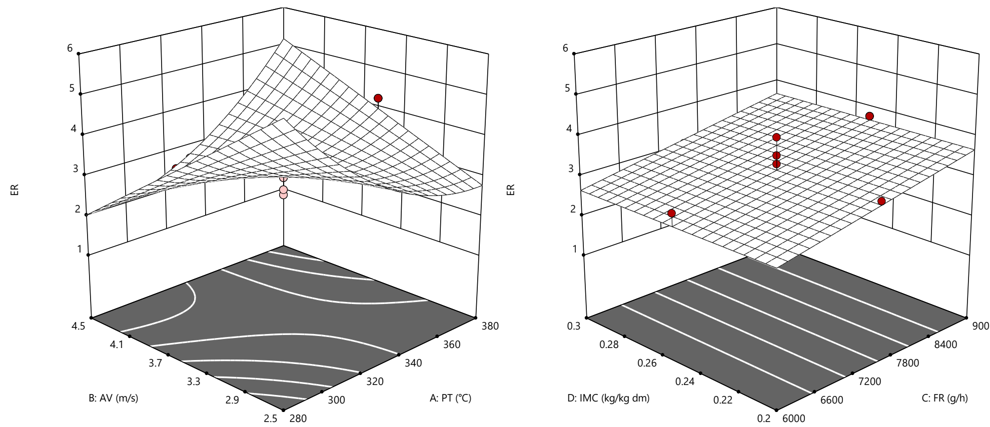
$$ER=0.771333+0.126262 \times AV+0.000453 \times FR+0.001384 \times PT \times AV-6.7E\text{-}05 \times PT \times FR-0.01531 \times PT \times IMC-1.5E\text{-}08 \times PT^2 \quad .... (4.7)$$

The F-values indicated that PT x AV was most influencing followed by PT x FR, PT x IMC and FR over ER during puffing, while PT^2 and AV were least affecting the ER. To visualize the combined effect of two variables on the ER, the response surface and contour plots Fig. 4.8 (A) and (B) were generated for the fitted model as a function of two variables while keeping other two variables at their central values. The ER decreased with increase in AV, it decreased initially with increase in PT up to its minima about 2.5 and increased thereafter, and ER was increased linearly with FR and IMC increasing as depicted by quadratic term in Eq. 4.7.

Table 4.10 ANOVA table showing the effects of variables of ER and the coefficients of predictive models for puffing of bajra grain

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	10.37	6	1.73	6.84	0.0003
AV	0.8511	1	0.8511	3.37	0.0794
FR	1.55	1	1.55	6.15	0.0209
PT x AV	2.45	1	2.45	9.69	0.0049
PT x FR	2.31	1	2.31	9.13	0.0061
PT x IMC	2.04	1	2.04	8.06	0.0093
PT^2	1.18	1	1.18	4.66	0.0415
Residual	5.81	23	0.2526		
Lack of Fit	4.32	18	0.2398	0.8036	0.6703^{NS}
Pure Error	1.49	5	0.2985		
Cor Total	16.18	29			
R^2	0.641				
Adj R^2	0.5473				
Pred R^2	0.3562				
C.V. %	15.08				
SD	0.5026				

NS- Non significant



(A) (B)

Fig. 4.8 The contour and response surface plots showing the effect of (A) PT and AV and (B) FR and IMC on ER for puffing of bajra grain

The increase in ER with PT and IMC is in agreement with results for hot air puffed sorghum grain discussed in section 4.2.1.2.

4.2.2.3 Effect of various process parameters on colour (L-value) during hot air puffing of bajra grain

The data recorded for C (L-value) after each set of experiment shown in Appendix-III were analyzed for stepwise regression analysis, as shown in Table 4.11. It could be observed that the values of C (L-value) were ranged between 58.605 and 68.896. The quadratic model was fitted to the experimental data and statistical significance for linear, quadratic and interaction terms was calculated for C (L-value) as shown in Table 4.11. The R^2 value was calculated by a least square technique and found to be 0.6832, showing good fit of model to the data. The model F-value of 6.78 implies that the model is significant ($P<0.05$). The linear terms of PT, IMC and interaction terms AV x IMC and interaction term IMC^2 are significant at ($P<0.1$), while linear terms AV and quadratic term AV^2 are significant at ($P<0.05$), respectively. The lack of fit F-value was non-significant for the model obtained shown in Eq. 4.8. Moreover, the predicted R^2 of 0.3964 was in reasonable agreement with the adjusted R^2 of 0.5823. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on C (L-value) in terms of actual levels of variables is given as,

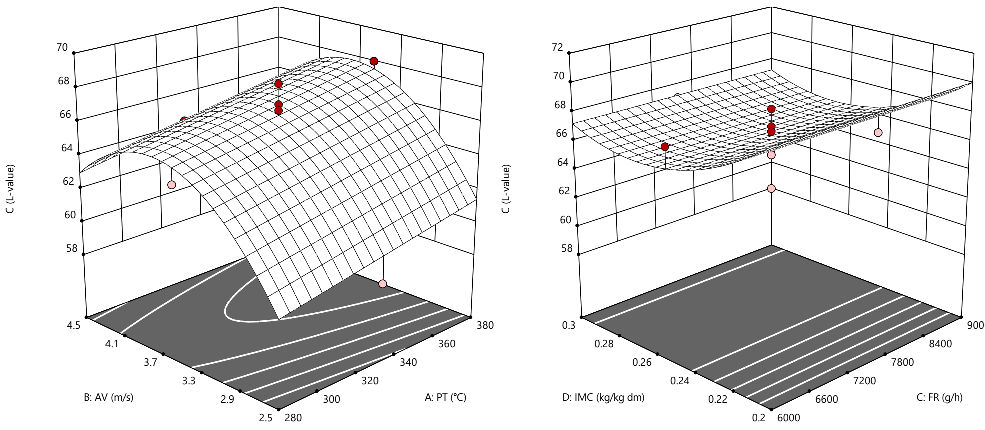
$$C\ (L\text{-Value}) = 113.0115 + 0.030231 \times PT + 17.23565 \times AV - 673.249 \times IMC - 1E\text{-}06 \times PT \times FR + 56.76 \times AV \times IMC - 4.21169 \times AV^2 + 893.125 \times IMC^2 \qquad \text{.... (4.8)}$$

The F-values indicated that AV^2 was more influencing followed by AV. Other factors like PT IMC, IMC^2 and interaction were also moderate influencing the variation in C (L-value) during puffing. The C (L-value) increased with increase in PT while initially increased upto maxima (occurred at about 3.7 m/s AV) and decreased thereafter. C (L-value) increased with increase in FR and it decreased initially with increase in IMC up to its minima about 63 and increased thereafter. The same could be revealed from Fig. 4.9 (A) and (B), by visualizing the combined effect of two variables on the C (L-value), the response surface and contour plots generated for the fitted model as a function of two variables while keeping other two variables at their central values.

Table 4.11 ANOVA table showing the effects of variables of C (L-value) and the coefficients of predictive models for puffing of bajra grain

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	102.82	7	14.69	6.78	0.0002
PT	7.76	1	7.76	3.58	0.0717
AV	22.67	1	22.67	10.46	0.0038
IMC	11.78	1	11.78	5.44	0.0293
PT x FR	7.88	1	7.88	3.64	0.0696
AV x IMC	8.05	1	8.05	3.72	0.0669
AV^2	31.53	1	31.53	14.55	0.0009
IMC^2	8.86	1	8.86	4.09	0.0555
Residual	47.69	22	2.17		
Lack of Fit	29.37	17	1.73	0.4715	0.8875^{NS}
Pure Error	18.32	5	3.66		
Cor Total	150.5	29			
R^2	0.6832				
Adj R^2	0.5823				
Pred R^2	0.3964				
C.V. %	2.23				
SD	1.47				

NS- Non significant



(A) (B)

Fig. 4.9 The contour and response surface plots showing the effect of (A) PT and AV and (B) FR and IMC on C (L-value) for puffing of bajra grain

The initial increase in C (L-value) i.e., brightness of puffing product with increase in PT and AV was observed may be due to improved puffing effect, the expanded product may be attaining brightness. But at higher PT and for prolonged AV, the reduced moisture level of product may be subjecting the product to caramalization leading to browning Fennema (1976), thus decreased C (L-values). These observations are consistent with previous studies by Mukherjee (1997), Khodke (2002), Nath (2006), Pardeshi (2008) and Pawar (2017).

4.2.2.4 Effect of various process parameters on hardness (HD, g) during hot air puffing of bajra grain

The data recorded for HD after each set of experiment, shown in Appendix-III, were analyzed for stepwise regression analysis, as shown in Table 4.12. It could be observed that the values of HD were ranged between 56317.1 and 83973.3. The quadratic model was tried to fit to the experimental data and statistical significance for linear, quadratic and interaction terms were calculated for HD as shown in Table 4.12. The R^2 value was calculated by a least square technique and found to be 0.7268, showing that model was fitting well to the data. The model F-value of 8.36 implies that the model is significant ($P<0.01$). The linear terms of FR, IMC and interaction terms like PT×AV, PT ×FR and quadratic term PT^2 ($P<0.05$) are significant, the linear terms of AV and interaction terms like PT x IMC ($P<0.1$) is significant. The F-value of lack of fit was non-significant for the model obtained shown in Eq. 4.9. Moreover, the predicted R^2 of 0.444 was in reasonable agreement with the adjusted R^2 of 0.6398. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on HD in terms of actual levels of variables is given as,

$$HD=179295.1+14834.17 \times AV -19.759 \times FR-397541 \times IMC+29.75367 \times PT \times AV-1.40852 \times PT \times FR+169.285 \times PT \times IMC+0.000891 \times PT^2 \quad .... (4.9)$$

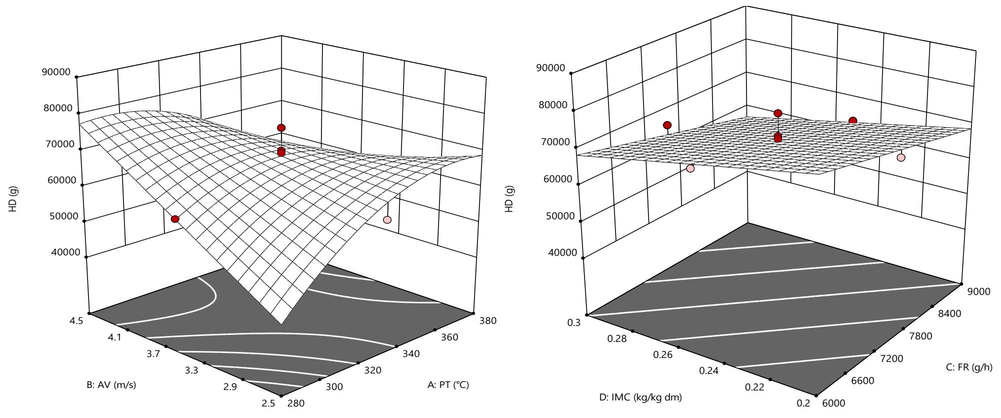
The F-values of interaction term indicated that PT x FR was most influencing followed by linear term IMC and FR. Other factors like AV and PT^2 and the interaction were also much influencing the variation in HD during puffing. The HD increased with increase in AV and it increased initially with increase in PT upto its maxima about 65000 g and remain contact at lower AV and decreased at higher AV thereafter. However, HD decreased linearly both with FR and IMC increasing as depicted by quadratic term in Eq. 4.9. The same could be revealed from Fig. 4.10 (A) and (B) by visualizing the combined effect of two variables on the HD, the response surface and contour plots generated for the fitted model as a function of two variables while keeping other two variables at their central values.

The hardness increased linearly with increase in puffing temperature from 225 to 350 °C, this may be caused due to the fact that at higher temperature water evaporated from the surface of the grain forms the condition of case hardening which create the very hard surface for further removal of water from the grain and thus increases the hardness (Srivastav *et al*.,1994).

Table 4.12 ANOVA table showing the effects of variables of HD and the coefficients of predictive models for puffing of bajra grain.

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	1.22E+09	7	1.74E+08	8.36	< 0.0001
AV	1.09E+08	1	1.09E+08	5.26	0.0317
FR	2.03E+08	1	2.03E+08	9.77	0.0049
IMC	2.11E+08	1	2.11E+08	10.14	0.0043
PT x AV	1.77E+08	1	1.77E+08	8.52	0.0079
PT x FR	2.93E+08	1	2.93E+08	14.07	0.0011
PT x IMC	8.09E+07	1	8.09E+07	3.89	0.0612
PT^2	1.43E+08	1	1.43E+08	6.87	0.0156
Residual	4.57E+08	22	2.08E+07		
Lack of Fit	3.72E+08	17	2.19E+07	1.28	0.4215^{NS}
Pure Error	8.52E+07	5	1.71E+07		
Cor Total	1.67E+09	29			
R^2	0.7268				
Adj R^2	0.6398				
Pred R^2	0.444				
C.V. %	6.81				
SD	4559.52				

NS- Non significant



(A) (B)

Fig. 4.10 The contour and response surface plots showing the effect of (A) PT and AV and (B) FR and IMC on HD for puffing of bajra grain

4.2.2.5 Effect of various process parameters on crispness (CSP +ve peaks) during hot air puffing of bajra grain

The observations for CSP with different combinations of the process parameters are presented in Appendix-III. It varied between 16.667 and 38.5 within the combination of variables studied. The ANOVA for CSP were obtained and is presented in Table 4.13. The ANOVA for CSP indicates that the model is highly significant as the F value 9.99 is very high as at $P<0.01$. Reasonably good fit was obtained with coefficient of determination (R^2) = 0.7607 and coefficient of variation 11.4, which showed that model developed was adequate for the experimental data. The lack-of-fit test was also found non significant, which indicates that the model was adequate to predict the experimental data. Moreover, the predicted R^2 of 0.5084 was in reasonable agreement with the adjusted R^2 of 0.6846. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. A quadratic model was fitted to the experimental data. The relationships were obtained with actual values of PT, AV, FR and IMC using stepwise regression method as follows,

$$CSP=59.65278-7.41667 \times AV-0.0057 \times FR-108.257 \times IMC+0.03 \times PT \times AV+0.000667 \times PT \times FR-0.08609 \times PT \times IMC-8.6E-08 \times PT^2 \quad \text{.... (4.10)}$$

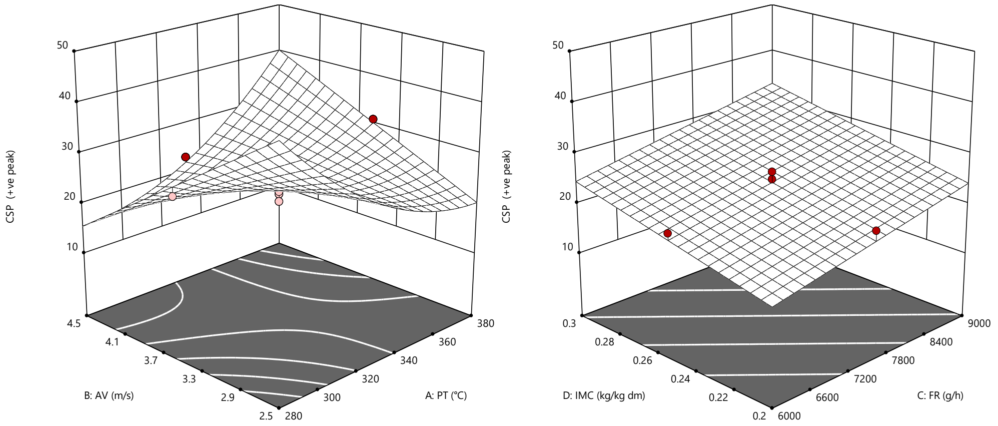
The comparative effect of each factor on the CSP could be observed by the F-values in the ANOVA and also by the magnitudes of coefficients of the coded variables (Table. 4.13). The effect of interaction terms of PT x AV (P<0.01) was most prominent followed by IMC and FR (P<0.01) where interaction term PT x FR on had moderate effect on CSP. The other factor like AV and PT^2 (P<0.05) were also influencing over CSP and term PT x IMC (P<0.10) also had effect on CSP.

With initial increase in PT and AV, CSP decreased upto its minima (>20) and increased subsequently and CPS was increased linearly with FR and IMC as depicted by quadratic term in Eq. 4.10. The same trend could be indicated in graphical representation shown in the surface and contour plot [Fig. 4.11 (A) and (B)] of two variables while other two constant at their central levels.

Table 4.13 ANOVA table showing the effects of variables of CSP and the coefficients of predictive models for puffing of bajra grain

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	595.69	7	85.1	9.99	< 0.0001
AV	35.04	1	35.04	4.11	0.0548
FR	108.37	1	108.37	12.72	0.0017
IMC	117.04	1	117.04	13.74	0.0012
PT x AV	154.17	1	154.17	18.1	0.0003
PT x FR	84.02	1	84.02	9.86	0.0047
PT x IMC	34.03	1	34.03	4	0.0581
PT^2	63.01	1	63.01	7.4	0.0125
Residual	187.39	22	8.52		
Lack of Fit	164.01	17	9.65	2.06	0.2169^{NS}
Pure Error	23.37	5	4.67		
Cor Total	783.08	29			
R^2	0.7607				
Adj R^2	0.6846				
Pred R^2	0.5084				
C.V. %	11.4				
SD	2.92				

NS- Non significant



(A) (B)

Fig. 4.11 The contour and response surface plots showing the effect of (A) PT and AV and (B) FR and IMC on CSP for puffing of bajra grain

4.2.2.6 Optimization of hot air puffing process for bajra grain

Numerical and graphical optimization was carried out for the process parameters for hot air puffing for obtaining the best puffed grain. To perform this operation, Design-Expert program *(Version 11.0)* of the software (Stat-Ease, 2018), as discussed in section 3.5.1 was used for simultaneous optimization of the multiple responses. The desired goals for each factor and response were chosen as shown in Table 4.14.

Table 4.14 Optimization criteria for different process variables and responses for hot air puffing of bajra grain

Name	Goal	Lower Limit	Upper Limit
PT(°C)	is in range	305	355
AV (m/s)	is in range	3	4
FR (g/h)	is in range	6750	8250
IMC (kg/kg dm)	is in range	0.225	0.275
FMC (kg/kg dm)	minimize	0.0276	0.0603
HD (g)	is in range	56317.1	83973.3
CSP(+ve peaks)	maximize	16.667	38.5
C (L- value)	maximize	58.605	68.896
ER	maximize	1.81034	4.26087

Table 4.15 shows that the software generated optimum conditions of independent variables with the predicted values of responses. Solution No.1, having the maximum desirability value (0.84) was selected as the optimum conditions of hot air puffing bajra grain.

The optimum values of process variables obtained by numerical optimization:

Puffing temperature (PT) : 355 °C

Air velocity (AV) : 4 m/s

Feed rate (FR) : 8250 g/h

Initial moisture content (IMC): 0.225≈ 0.23 kg/kg dm

Table 4.15 Solutions generated by the software for hot air puffing of bajra grain

No.	PT	AV	FR	IMC	FMC	HD	CSP	C (L-Value)	ER	Desirability
1	**355**	**4**	**8250**	**0.225**	**0.034**	**58856**	**31.458**	**68.16**	**4.566**	**0.84***
2	355	4	8249	0.225	0.034	58851	31.467	68.139	4.558	0.84

*** Selected**

The superimposed contours of all responses for PT and AV and FR and IMC [Fig.4.12 (A) and (B)] and their intersection zone for minimum FMC, in range HD, maximum CSP (+ve peak), maximum C (L-value) and maximum ER indicated the ranges of variables which could be considered as the optimum range for best puffed sorghum grain quality. The ranges of optimum values of process variables obtained from the superimposed contours are as follows,

Puffing temperature (PT) : 350-355 °C

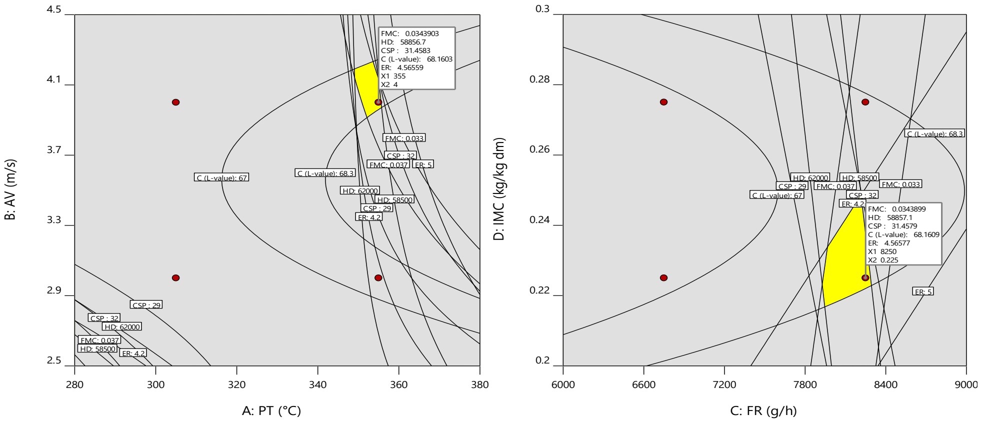
Air velocity (AV) : 3.8-4.2 m/s

Feed rate (FR) : 8000-8350 g/h

Initial moisture content (IMC): 0.2-0.24 kg/kg dm

4.2.2.7 Verification of the model for hot air puffed bajra grain

Hot air puffing experiments were conducted at the optimum process condition and the quality attributes of the resulting product were determined. The observed experimental values (mean of 5 measurements) and values predicted by the equations of the model are presented in Table 4.16. The values of C.V. <10% and closeness between the experimental and predicted values of the quality parameters indicated the suitability of the corresponding models.



(A) (B)

Fig. 4.12 Superimposed contours for FMC (kg/kg dm), HD(g), CSP (+ve peaks), C (L-value) and ER, for puffing of bajra at varying (A) puffing temperature (PT), air velocity (AV) and (B) feed rate (FR) and initial moisture content (IMC)

Table 4.16 Comparison between predicted and actual response variables at optimum process conditions for preparation of hot air puffed bajra grain

Response	Predicted value	Actual value (± SD)	Variation, %	C.V., %
FMC (kg/kg dm)	0.034	0.038(±0.00017)	10.44386	4.91
HD, g	58856.7	58752.4(±474.15)	1.926233	0.84
CSP (+ve peaks)	31.46	31.642(±1.3311)	9.006392	4.06
C (L-value)	68.16	68.59±2.6929)	8.497515	4.13
ER	4.566	4.569(±0.1755)	8.813043	4.14

4.2.3 Hot air hot air puffing of finger millet

The experiment on hot air puffing of finger millet was conducted in CCRD with three variables viz., puffing temperature (PT, °C), air velocity (AV, m/s) and feed rate (FR, g/h). The response variables measured for studying the effect and optimization of process parameters were taken as Final moisture content (FMC, kg/kg dm), Expansion ratio (ER), Colour (L-value), Hardness (HD, g) and Crispness (CSP, No. of +ve peaks). The observations recorded where as given in Appendix-IV.

4.2.3.1 Effect of various process parameters on final moisture content (FMC, kg/kg dm) during hot air puffing of finger millet grain

The observations for each experiment were as recorded in Appendix-IV. The data were analyzed for its stepwise regression analysis as shown in Table 4.17. It could be observed that the values of FMC ranged between 0.002 to 0.04 kg/kg dm. The quadratic model was fitted to the experimental data and statistical significance for linear, interaction and quadratic terms were calculated for FMC as shown in Table 4.17. The R^2 value was calculated by a least square technique and found to be 0.8733, showing good fit of model to the data. The model F-value of 14.94 implies that the model is significant ($P<0.01$). The linear terms PT^2 ($P<0.05$) is significant, while interaction terms PT x AV, PT x FR and quadratic terms $AV^2$and FR^2 ($P<0.1$) are significant. The F-value of lack of fit was non significant, which indicates that the developed model was adequate for predicting the response. Moreover, the model adequacy evaluated with predicted R^2 of 0.7186 showed it to be in reasonable agreement with the adjusted R^2 of 0.8149. This indicated that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on MC in terms of actual levels of variables is given as,

$$FMC = -0.15499 + 0.132097 + AV - 0.00021 \times PT \times AV + 2.05E\text{-}07 \times PT \times FR - 1.4E\text{-}06 \times PT^2 - 0.0142 \times AV^2 - 4.1E\text{-}09 \times FR^2 \quad \text{.... (4.11)}$$

The comparative effect of each factor on the FMC could be observed by the F-values in the ANOVA and also by the magnitudes of coefficients of the coded variables (Table. 4.17). The F-values indicated that AV was the most influencing followed by AV^2 and PT^2 over FMC.

The PT x FR was least influencing while PT x AV had moderate effect on FMC.To visualize the combined effect of two variables on the FMC, the response surface and contour plots were generated for the fitted model as a function of two variables while keeping other two variables at their central values.

Table 4.17 ANOVA table showing the effects of variables of FMC (kg/kg dm) and the coefficients of predictive models for hot air puffing of finger millet grain

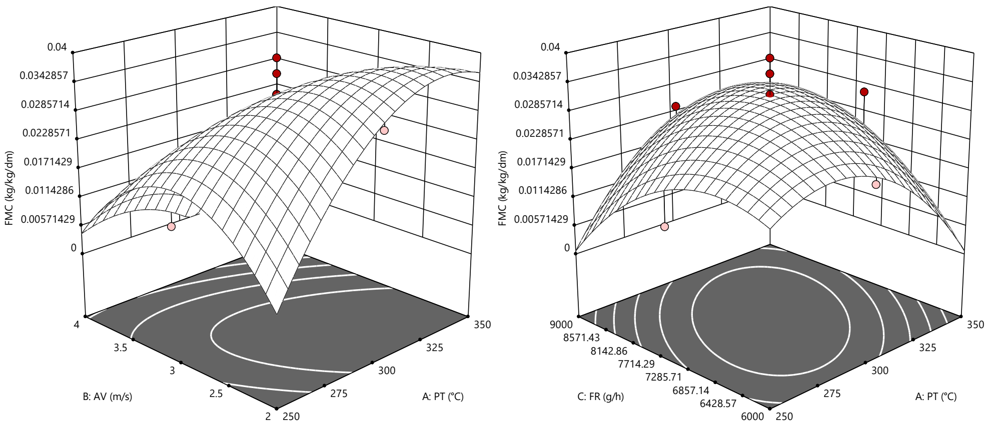
Source	Sum of Squares	Df	Mean Square	F-value	p-value
Model	0.0019	6	0.0003	14.94	< 0.0001
AV	0.001	1	0.001	47.2	< 0.0001
PT x AV	0.0002	1	0.0002	8.32	0.0128
PT x FR	0.0001	1	0.0001	4.52	0.0533
PT^2	0.0003	1	0.0003	12.02	0.0042
AV^2	0.0004	1	0.0004	18.1	0.0009
FR^2	0.0002	1	0.0002	7.56	0.0165
Residual	0.0003	13	0		
Lack of Fit	0.0002	8	0	0.7311	0.6702^{NS}
Pure Error	0.0001	5	0		
Cor Total	0.0022	19			
R^2	0.8733				
Adj. R^2	0.8149				
Pred. R^2	0.7186				
C.V. %	19.74				
S.D.	0.0047				

NS- Non significant

It could be observed from Fig. 4.13 (A) and (B) that FMC increase initially with increase in PT, AV and FR upto certain maxima i.e., upto 310 °C of PT, 3.0 m/s of AV and 7000 g/h of FR and decreasing subsequently as depicted by quadratic term in Eq. 4.11.

The decrease in moisture content of puffed product with increase in hot air puffing temperature and hot air puffing time had been recorded by Mukherjee (1997) for HTST air hot air puffing of potato cubes and Nath *et al.* (2007) for HTST air hot air puffing of potato-soy snack foods and Pawar (2017) for HTST microwave puffing of sprouted soy fortified millet flour based RTE snack.

The reduced FMC after puffing of grain may be due to the fact that increased PT for longer time and AV to some extend causing reduction in moisture content due to exposer of grain to hot air, leading to conversion of more moisture mass into vapours, causing removal of comparatively more moisture, once puffing was advanced.



(A) (B)

Fig. 4.13 The contour and response surface plots showing the effect of (A) AV and PT and (B) PT and FR on FMC (kg/kg dm) for puffing of finger millet grain

4.2.3.2 Effect of various process parameters on Expansion ratio (ER) during hot air puffing of finger millet grain

The data recorded for ER after each set of experiment (Appendix-IV) were analyzed for stepwise regression analysis, as shown in Table 4.18. It could be observed that the values of ER were ranged between 0.133 and 3.857. The quadratic model was fitted to the experimental data and statistical significance for linear, interaction and quadratic terms was calculated for ER as shown in Table 4.18. The R^2 value was calculated by a least square technique and found to be 0.9205, showing good fit of model to the data. The model F-value of 32.43 implies that the model is significant ($P<0.01$). The linear terms like AV and quadratic terms AV^2 ($P<0.01$) are significant, while interaction term PT x AV, quadratic terms like PT^2 and FR^2 ($P<0.05$) are significant. The F-value of lack of fit was non-significant for the model obtained shown in Eq. 4.12, which indicates that the developed model was adequate for predicting the response. Moreover, the predicted R^2 of 0.8233 was in reasonable agreement with the adjusted R^2 of 0.8921. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on ER in terms of actual levels of variables is given as,

$$ER = -13.319 + 11.98826 \times AV - 0.02242 \times PT \times AV + 0.000115 \times PT^2 - 1.16139 \times AV^2 + 4.75E\text{-}09 \times FR^2 \quad .... (4.12)$$

The comparative effect of each factor on the ER could be observed by the F-values in the ANOVA and also by the magnitudes of coefficients of the coded variables (Table. 4.18). The F-values indicated that AV was the most influencing factor followed by AV^2, PT x AV and FR^2 over the ER. The PT^2 was least effective over ER.

Table 4.18 ANOVA table showing the effects of variables of ER and the coefficients of predictive models for hot air puffing of finger millet grain

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**
Model	19.21	5	3.84	32.43	< 0.0001
AV	11.66	1	11.66	98.4	< 0.0001
PT x AV	2.32	1	2.32	19.55	0.0006
PT^2	1.41	1	1.41	11.9	0.0039
AV^2	3.58	1	3.58	30.18	< 0.0001
FR^2	1.65	1	1.65	13.89	0.0023
Residual	1.66	14	0.1185		
Lack of Fit	1.15	9	0.1274	1.24	0.4257^{NS}
Pure Error	0.5121	5	0.1024		
Cor Total	20.87	19			
R^2	0.9205				
Adj. R^2	0.8921				
Pred. R^2	0.8233				
C.V. %	14.12				
S.D.	0.3442				

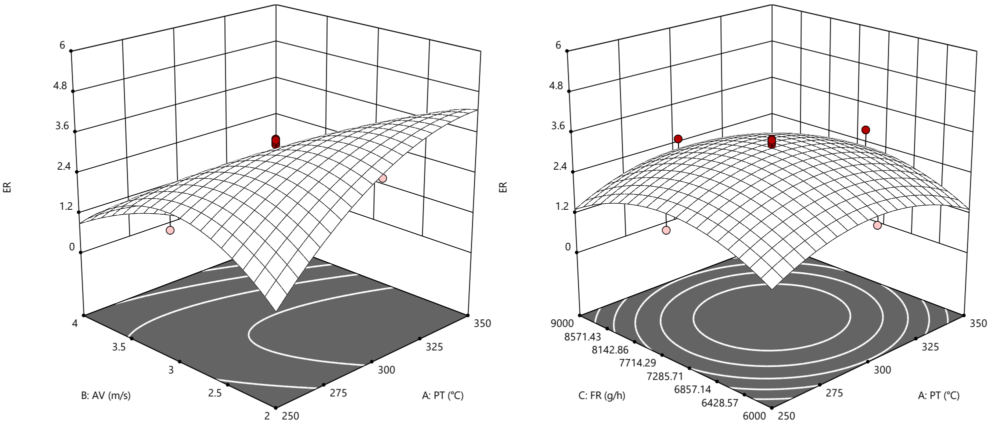
NS- Non significant

To visualize the combined effect of two variables on the ER, the response surface and contour plots [Fig. 4.14 (A) and (B)] were generated for the fitted model as a function of two variables while keeping other two variables at their central values.

It could be observed that ER increase initially with increase in PT, AV and FR up to certain maxima i.e., upto 300 °C of PT, 3.0 m/s of AV and 7000 g/h of FR and decreasing subsequently as depicted by quadratic term in Eq. 4.12

Mukherjee (1997) and Nath (2006) obtained higher volume expansion at higher hot air puffing temperature and at longer hot air puffing time for HTST air hot air puffing of potato cubes and potato-soy snack foods, respectively. Similar effects of temperature and time on expansion of rice grains during high temperature fluidized bed hot air puffing was also reported by Chandrasekhar and Chattopadhyay (1989), while Roshdy *et al.* (1984) observed the same for hot air puffing of corn. These findings were also in accordance with the present study.

The increase in ER with increase PT and FR coincides with simultaneously reduced moisture content. This may be due to more case hardening, leading to conversion of comparatively more moisture mass into vapours, causing higher expansion effect.



(A) (B)

Fig. 4.14 The contour and response surface plots showing the effect of (A) AV and PT and (B) PT and FR on ER for puffing of finger millet grain

4.2.3.3 Effect of various process parameters on colour (CL-value) during hot air puffing of finger millet grain

The data recorded for C (L-value) after each set of experiment shown in Appendix-IV were analyzed for stepwise regression analysis, and the results are shown in Table 4.19. It could be observed that the values of C (L-value) were ranged between 35.206 and 67.746. The quadratic model was fitted to the experimental data and statistical significance for linear, interaction and quadratic terms was calculated for C (L-value) as shown in Table 4.19. The R^2 value was calculated by a least square technique and found to be 0.9375, showing good fit of model to the data. The model F-value of 32.53 implies that the model is significant ($P<0.01$). The linear terms of AV and quadratic termAV^2 are significant at ($P<0.01$). Interaction term PT x AV, PT x FR and quadratic terms like PT^2 and FR^2 ($P<0.1$) are significant. The F-value of lack of fit was non-significant for the model obtained shown in Eq. 4.13. Moreover, the predicted R^2 of 0.8487 was in reasonable agreement with the adjusted R^2 of 0.9087. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on C (L-value) in terms of actual levels of variables is given as,

$$C\ (L\text{-Value}) = -113.609 + 130.9037 \times AV - 0.20436 \times PT \times AV + 0.000127 \times PT \times FR - 0.00056 \times PT^2 - 13.9529 \times AV^2 - 2.5E\text{-}06 \times FR^2 \qquad \ldots (4.13)$$

The comparative effect of each factor on the C (L-value) could be observed by the F-values in the ANOVA and by the magnitudes of coefficients of the coded variables (Table. 4.19). The F-values indicated that AV was the most influencing factor followed by AV^2, PTxAV, FR and PT^2 over the C (L-value) and the PT x FR was least effective over C (L-value).

To visualize the combined effect of two variables on the ER, the response surface and contour plots [Fig. 4.15 (A) and (B)] were generated for the fitted model as a function of two variables while keeping other two variables at their central values.

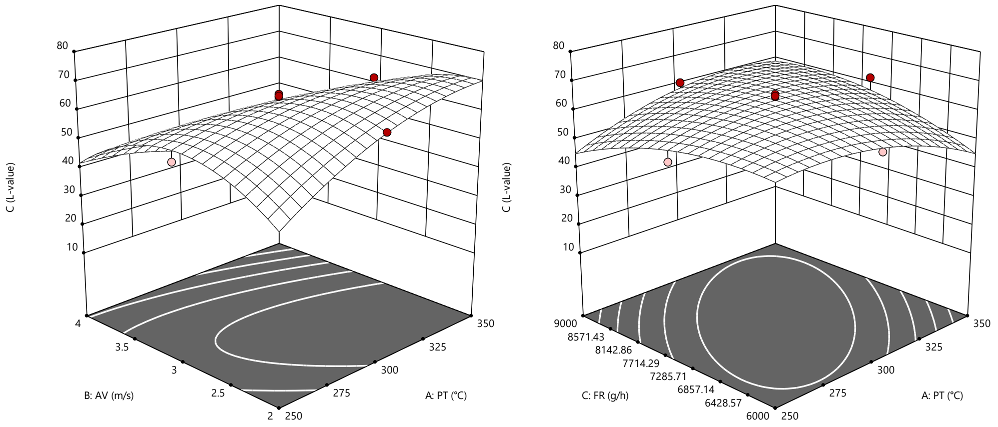
It could be observed that C(L-value) increase initially with increase in PT, AV and FR upto certain maxima i.e., upto 275 °C of PT, 3.0 m/s of AV and 6500 g/h of FR and decreasing subsequently as depicted by quadratic term in Eq. 4.13.

These observations are consistent with previous studies Mukherjee (1997) and Khodke (2002).

Table 4.19 ANOVA table showing the effects of variables of C (L-value) and the coefficients of predictive models for hot air puffing of finger millet grain

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	1361.88	6	226.98	32.53	< 0.0001
AV	797.75	1	797.75	114.31	< 0.0001
PT x AV	125.47	1	125.47	17.98	0.001
PT x FR	48.4	1	48.4	6.94	0.0206
PT^2	67.23	1	67.23	9.63	0.0084
AV^2	347.09	1	347.09	49.74	< 0.0001
FR^2	51.89	1	51.89	7.44	0.0173
Residual	90.72	13	6.98		
Lack of Fit	73.8	8	9.23	2.73	0.1421^{NS}
Pure Error	16.92	5	3.38		
Cor Total	1452.6	19			
R^2	0.9375				
Adj. R^2	0.9087				
Pred. R^2	0.8487				
C.V. %	22.0271				
S.D.	4.55				
Std. Dev.	2.64				

NS- Non significant



(A) (B)

Fig. 4.15 The contour and response surface plots showing the effect of (A) AV and PT and (B) PT and FR on C (L-value) for hot air puffing of finger millet grain

Effect of time on colour difference during dehydration of potato was also reported by Mishkin *et al.* (1983), who observed that browning occurred only after a certain time exposure which was more than 40 min with the drying air temperature of 80 °C. These observations supported the present findings regarding the effects of the PT and FR on the colour

(L-value) of hot air puffed finger millet grain.

4.2.3.4 Effect of various process parameters on hardness (HD, g) during hot air puffing of finger millet grain

The data recorded for HD after each set of experiment shown in Appendix-IV were analyzed for stepwise regression analysis, as shown in Table 4.20. It could be observed that the values of HD were ranged between 12984 and 30965. The quadratic model was fitted to the experimental data and statistical significance for interaction and quadratic terms was calculated for HD as shown in Table 4.20. The R^2 value was calculated by a least square technique and found to be 0.7736, showing that model was fitting well to the data. The model F-value of 18.22 implies that the model is significant ($P<0.01$). The quadratic of PT^2 and interaction terms of AV x FR ($P<0.01$) and PT x FR ($P<0.1$) are significant, respectively. The F-value of lack of fit was non-significant for the model obtained shown in Eq. 4.14. Moreover, the predicted R^2 of 0.7736 was in reasonable agreement with the adjusted R^2 of 0.7312. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on HD in terms of actual levels of variables is given as,

$$HD = 21905.84 - 0.00031 \times PT \times FR + 2.551729 \times AV \times FR - 0.05339 \times PT^2 \quad \text{... (4.14)}$$

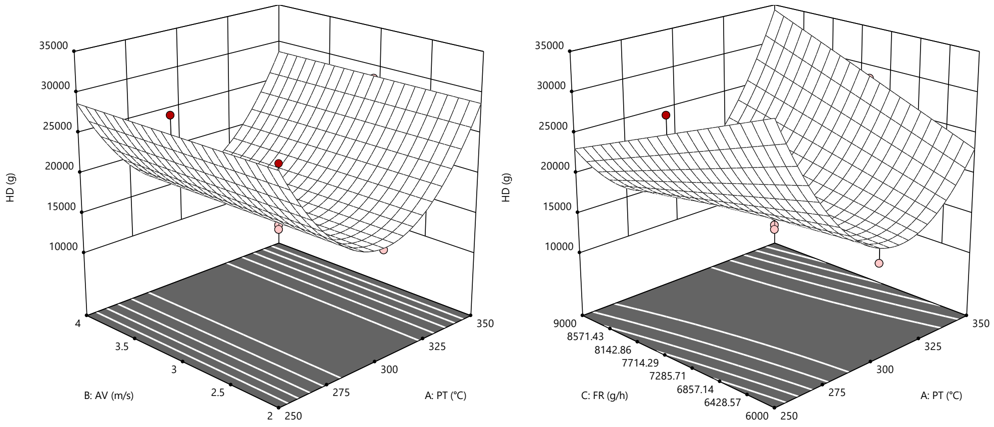
The F-values of quadratic terms indicated that PT^2 was most effect and interaction termsindicated that PT x FR and AV x FR were lest effect on HD during puffing.

The HD decreased initially with increase in PT, AV and FR up to its minima about 15000 g and increased thereafter. The same could be revealed from Fig. 4.16 (A) and (B), by visualizing the combined effect of two variables on the HD, the response surface and contour plots generated for the fitted model as a function of two variables while keeping other two variables at their central values.

Table 4.20 ANOVA table showing the effects of variables of HD and the coefficients of predictive models for hot air puffing of finger millet grain

Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**
Model	4.08E+08	3	1.36E+08	18.22	< 0.0001
PT x FR	3.22E+07	1	3.22E+07	4.32	0.0542
AV x FR	4.65E+07	1	4.65E+07	6.24	0.0238
PT^2	3.29E+08	1	3.29E+08	44.12	< 0.0001
Residual	1.19E+08	16	7.46E+06		
Lack of Fit	6.67E+07	11	6.07E+06	0.5767	0.7926^{NS}
Pure Error	5.26E+07	5	1.05E+07		
Cor Total	5.27E+08	19			
R^2	0.7736				
Adj. R^2	0.7312				
Pred. R^2	0.6305				
C.V. %	14.63				
S.D.	2730.84				

NS- Non significant



(A) (B)

Fig. 4.16 The contour and response surface plots showing the effect of (A) AV and PT and (B) PT and FR on HD for hot air puffing of finger millet grain

The hardness decreased initially with increase in puffing temperature up to 300 °C then increased thereafter, this may be caused due to the fact that at higher temperature water evaporated from the surface of the grain, which form the condition of case hardening and create the very hard surface for further removal of water from the grain and thus increases the hardness (Srivastav *et al*., 1994).

4.2.3.5 Effect of various process parameters on crispness (CSP +ve peaks) during hot air puffing of finger millet grain

The observations for CSP with different combinations of the process parameters are presented in Appendix-IV. It varied between 9.00 to 33.00 within the combination of variables studied. The quadratic model was fitted to the experimental data and statistical significance was calculated for CSP as shown in Table 4.21. The R^2 value was calculated by a least square technique and found to be 0.8962 showing good fit of model to the data. The model F-value of 18.71 implies that the model is significant ($P<0.01$). The linear of AV ($P<0.01$) is significant, interaction term of PT x AV and quadratic term of AV^2 and FR^2 ($P<0.05$) are significant and interaction terms of PT x FR and PT^2 ($P<0.1$) are significant. The F-value of lack of fit was non-significant for the model obtained shown in Eq. 4.15. Moreover, the predicted R^2 of 0.7773 was in reasonable agreement with the adjusted R^2 of 0.8483. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on CSP in terms of actual levels of variables is given as,

$$\text{CSP (+ve Peak)} = -105.582 + 93.89267 \times AV - 0.16159 \times PT \times AV + 0.000109 \times PT \times FR - 0.00053 \times PT^2 - 9.08675 \times AV^2 - 2.1E\text{-}06 \times FR^2 \quad \ldots (4.15)$$

The comparative effect of each factor on the CSP could be observed by the F-values in the ANOVA and also by the magnitudes of coefficients of the coded variables (Table 4.21). The effect of AV was most prominent ($P<0.01$) while PT x FR ($P<0.05$) were least effective on CSP of the hot air puffed finger millet grain.

It could be observed that CSP increased initially with increase in PT, AV and FR upto certain maxima i.e., upto 275 °C of PT, 3.0 m/s of AV and 6600 g/h of FR and decreasing subsequently as depicted by quadratic term in Eq. 4.15.

Table 4.21 ANOVA table showing the effects of variables of CSP and the coefficients of predictive models for hot air puffing of finger millet grain

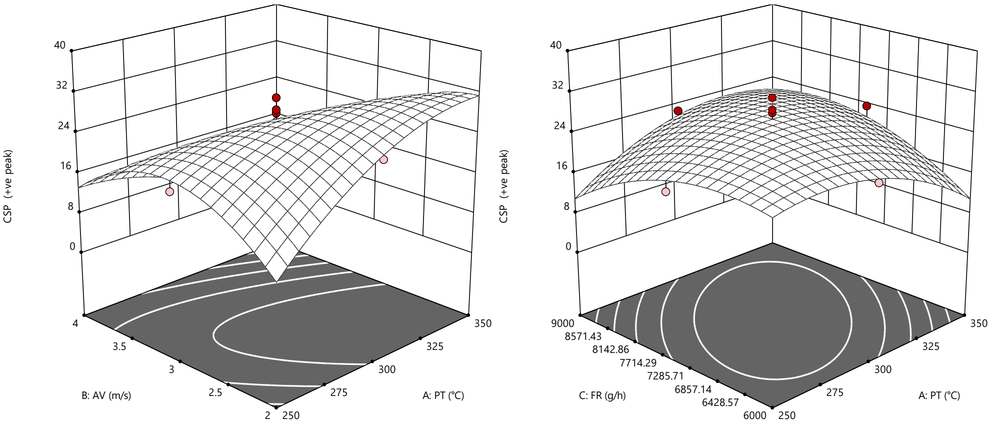
Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	645.38	6	107.56	18.71	< 0.0001
AV	331.53	1	331.53	57.68	< 0.0001
PT x AV	81.28	1	81.28	14.14	0.0024
PT x FR	30.03	1	30.03	5.22	0.0397
PT^2	52.52	1	52.52	9.14	0.0098
AV^2	154.07	1	154.07	26.8	0.0002
FR^2	46.25	1	46.25	8.05	0.014
Residual	74.72	13	5.75		
Lack of Fit	32.13	8	4.02	0.4714	0.8355^{NS}
Pure Error	42.6	5	8.52		
Cor Total	720.1	19			
R^2	0.8962				
Adj. R^2	0.8483				
Pred. R^2	0.7773				
C.V. %	15.7265				
S.D.	10.72				
Std. Dev.	2.4				

NS- Non significant

The same trend was observed in graphical representation shown in the surface and contour plot [Fig.4.17 (A) and (B)] of two variables while other two were kept constant at their central levels. The lower values of CSP in present case are similar to the value of CSP of 14, HTST air puffed potato snack foods with the operating conditions of temperature, time, initial moisture content, and air velocity as 225°C, 45s, 0.5384 kg/kg dm and 3.6 m/s, respectively Nath (2006).

4.2.3.6 Optimization of hot air puffing process for finger millets garin

Numerical and graphical optimization was carried out for the process parameters for hot air puffing for obtaining the best finger millets puffed grain sample. To perform this operation, Design-Expert program *(Version 11.0)* of the software (State-Ease, 2018), as discussed in section 3.5.1, was used for simultaneous optimization of the multiple responses. The desired goals for each factor and response were chosen as shown in Table 4.22.



(A) (B)

Fig. 4.17 The contour and response surface plots showing the effect of (A) AV and PT and (B) PT and FR on CPS for hot air puffing of finger millet grain

Table 4.22 Optimization criteria for different process variables and responses for hot air puffing of finger millet grain

Name	**Goal**	**Lower Limit**	**Upper Limit**
PT(°C)	is in range	270.27	329.73
AV (m/s)	is in range	2.4054	3.5946
FR (g/h)	is in range	6608.09	8391.91
FMC (kg/kg dm)	is in range	12984	30965
HD (g)	maximize	9	33
CSP(+ve peaks)	maximize	35.206	67.746
C (L- value)	maximize	0.133333	3.85714

Table 4.23 shows that the software generated optimum conditions of independent variables with the predicted values of responses. Solution No.1, having the maximum desirability value (0.636) was selected as the optimum conditions of hot air puffing for developing finger millets grain.

The optimum values of process variables obtained by numerical optimization:

Puffing temperature (PT):329.73 ≈ 330 °C

Air velocity (AV) : 2.5 m/s

Feed rate (FR) : 6608 g/h

Table 4.23 Solutions generated by the software for hot air puffing of finger millet grain

No.	PT	AV	FR	FMC	HD	CSP	C (L-Value)	ER	Desirability
1	**329.730**	**2.507**	**6608**	**0.030**	**20515**	**26.504**	**64.536**	**3.539**	**0.636***
2	329.730	2.508	6608	0.030	20511	26.499	64.530	3.537	0.636

*** Selected**

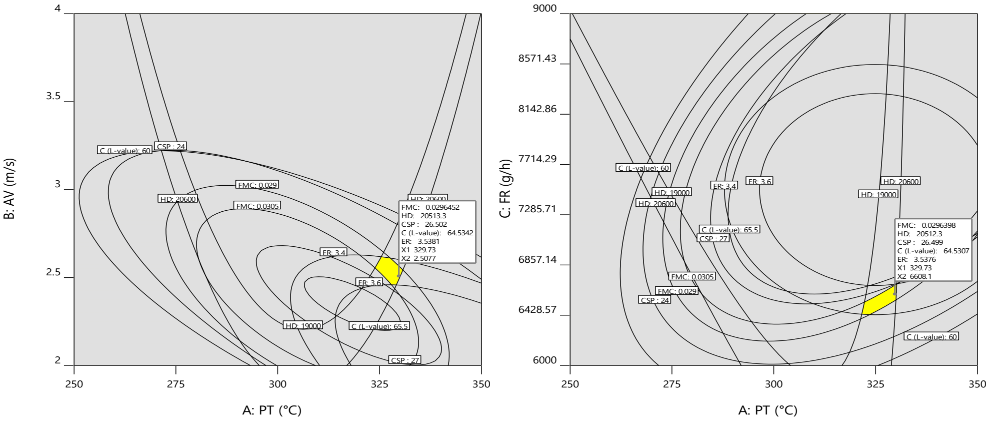
The superimposed contours of all responses for PT and AV and PT and FR [Fig. 4.18 (A) and (B)]and their intersection zone for minimum FMC, in range HD, maximum CSP (+ve peak), maximum C (L-value) and maximum ER indicated the ranges of variables which could be considered as the optimum range for best puffed finger millet grain quality.

The ranges of optimum values of process variables obtained from the superimposed contours are as follows,

Puffing temperature (PT): 310-335 °C

Air velocity (AV) : 2.00-2.60 m/s

Feed rate (FR) : 6500-6700 g/h



(A) (B)

Fig. 4.18 Superimposed contours for FMC (kg/kg dm), HD(g), CSP (+ve peaks), C (L-value) and ER, for puffing of finger millet at varying (A) puffing temperature (PT) air velocity (AV) and (B) feed rate (FR) and initial moisture content (IMC)

Table 4.24 Comparison between predicted and actual response variables at optimum process conditions for preparation of hot air puffed finger millet grain

Response	Predicted value	Actual value (± SD)	Variation, %	C.V., %
FMC (kg/kg dm)	0.03	0.03(±0.0011)	10.204	4.10
HD, g	20516	20622(±99.47)	1.346	0.51
CSP (+ve peaks)	26.504	25.421(±0.598)	3.786	2.58
C (L-value)	64.536	66.519(±1.995)	8.15	3.16
ER	3.539	3.087(±0.0946)	8.396	3.88

4.2.4 Hot air puffing of kodo millet grain

The experiment hot air puffing of kodo millet grain was conducted in CCRD with three variables viz., puffing temperature (PT, °C), air velocity (AV, m/s) and feed rate (FR, g/h). The response variables measured for studying the effect and optimization of process parameters were taken as final moisture content (FMC, kg/kg dm), expansion ratio (ER), colour (L-value), hardness (HD, g) and crispness (CSP, No. of +ve peaks). The observations recorded are given in Appendix-V.

4.2.4.1 Effect of various process parameters on final moisture content (FMC, kg/kg dm) during hot air puffing of kodo millet grain

The observations for each experiment were as recorded in Appendix-V. The data were analyzed for its stepwise regression analysis as shown in Table 4.25. It could be observed that the values of FMC ranged between 0.0211 to 0.0681 kg/kg dm. The quadratic model was fitted to the experimental data and statistical significance for quadratic terms was calculated for FMC as shown in Table 4.25. The R^2 value was calculated by a least square technique and found to be 0.6473, showing good fit of model to the data. The model F-value of 6.88 implies that the model is significant ($P<0.05$). The interaction terms PT x AV, AV x FR and quadratic term AV^2 ($P<0.1$) are significant. The F-value of lack of fit was non significant, which indicates that the developed model was adequate for predicting the response. Moreover, the model adequacy evaluated with predicted R^2 of 0.398 showed it to be in reasonable agreement with the adjusted R^2 of 0.5532. This indicated that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on FMC in terms of actual levels of variables is given as,

$$FMC = 0.369269 - 7E\text{-}05 \times FR - 4.2E\text{-}05 \times PT \times AV + 2.02E\text{-}05 \times AV \times FR - 0.02338 \times AV^2 \quad .... (4.16)$$

The comparative effect of each factor on the FMC could be observed by the F-values in the ANOVA and also by the magnitudes of coefficients of the coded variables (Table. 4.25). The F-values indicated that AV^2 was the most influencing followed by FR and the PT x AV and AV x FR were least influencing on FMC. To visualize the combined effect of two variables on the FMC, the response surface and contour plots were generated for the fitted model as a function of two variables while keeping other two variables at their central values.

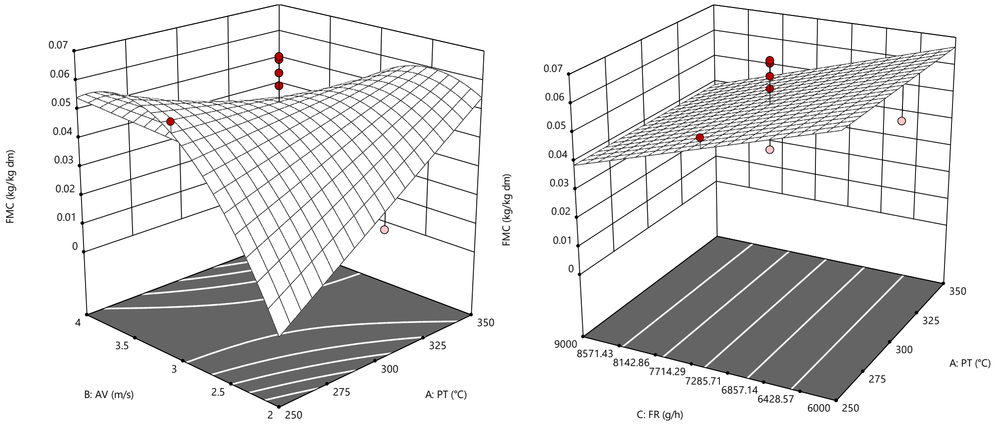
Table 4.25 ANOVA table showing the effects of variables of FMC (kg/kg dm) and the coefficients of predictive models for hot air puffing of kodo millet grain

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	0.003	4	0.0008	6.88	0.0024
FR	0.0009	1	0.0009	8.29	0.0115
PT x AV	0.0005	1	0.0005	4.79	0.0449
AV x FR	0.0005	1	0.0005	4.3	0.0557
AV^2	0.0011	1	0.0011	10.15	0.0061
Residual	0.0017	15	0.0001		
Lack of Fit	0.001	10	0.0001	0.678	0.7194^{NS}
Pure Error	0.0007	5	0.0001		
Cor Total	0.0047	19			
R^2	0.6473				
Adj. R^2	0.5532				
Pred. R^2	0.398				
C.V. %	22.03				
S.D.	0.0105				

NS- Non significant

It could be observed from Fig. 4.19 (A) and (B) that FMC decreased with increase in PT and it increased initially with increase in AV up to its maxima about 0.042 kg/kg dm and decreased thereafter and FMC was decreased linearly with FR and PT increasing as depicted by quadratic term in Eq. 4.16.The decrease in moisture content of puffed product with increase in hot air puffing temperature and hot air puffing time had been recorded by Mukherjee (1997) for hot air puffing of potato cubes and Nath *et al.* (2007) for hot air puffing of potato-soy snack foods and Pardeshi (2008) for HTST for puffing of snack food.Similar results were also reported by Pawar *et al.* (2014) for sprouted soy fortified RTE snack foods.

The reduced FMC after puffing of grain may be due to the fact that increased PT for longer time and AV to some extend causing reduction initial moisture content due to exposer of grain to hot air, leading to conversion of more moisture mass into vapours, causing removal of comparatively more moisture, once puffing was advanced.



(A) (B)

Fig. 4.19 The contour and response surface plots showing the effect of (A) PT and AV and (B) PT and FR on FMC (kg/kg dm) for hot air puffing of kodo millet grain

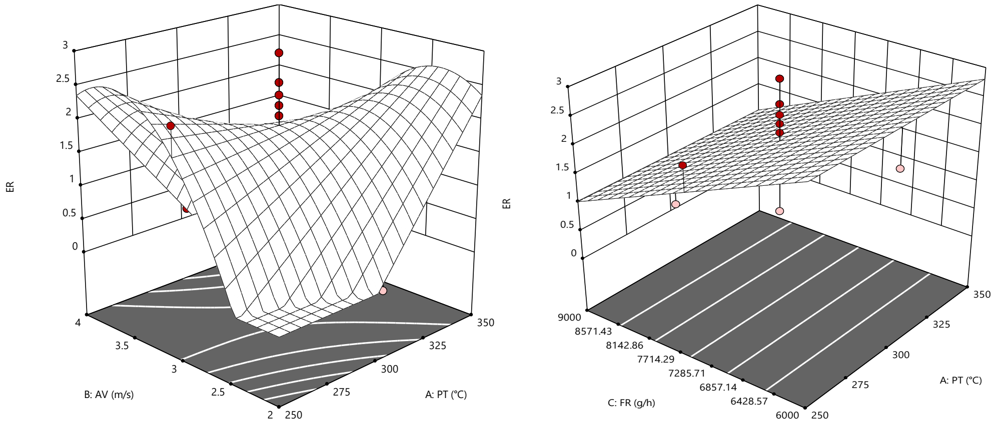
4.2.4.2 Effect of various process parameters on expansion ratio (ER) during hot air puffing of kodo millets grain

The data recorded for ER after each set of experiment Appendix-V were analyzed for stepwise regression analysis, as shown in Table 4.26. It could be observed that the values of ER were ranged between 0.012 and 2.9697. The quadratic model was fitted to the experimental data and statistical significance for linear, interaction and quadratic terms was calculated for ER as shown in Table 4.26. The R^2 value was calculated by a least square technique and found to be 0.613, showing good fit of model to the data. The model F-value of 8.45 implies that the model is significant ($P<0.05$). The quadratic terms AV^2 ($P<0.05$) is significant, linear term FR and interaction term PT x AV ($P<0.1$) are significant. The F-value of lack of fit was non-significant for the model obtained shown in Eq. 4.20, which indicates that the developed model was adequate for predicting the response.

Table 4.26 ANOVA table showing the effects of variables of ER and the coefficients of predictive models for hot air puffing of kodo millet grain

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	12.97	3	4.32	8.45	0.0014
FR	3.8	1	3.8	7.43	0.0149
PT x AV	3.62	1	3.62	7.08	0.0171
AV^2	5.55	1	5.55	10.84	0.0046
Residual	8.19	16	0.5117		
Lack of Fit	5.1	11	0.4639	0.7518	0.6789^{NS}
Pure Error	3.08	5	0.617		
Cor Total	21.16	19			
R^2	0.613				
Adjusted R^2	0.5405				
Predicted R^2	0.4073				
C.V. %	45.78				
Std. Dev.	0.7153				

NS- Non significant



(A) (B)

Fig. 4.20 The contour and response surface plots showing the effect of (A) PT and AV and (B) PT and FR on ER for hot air puffing of kodo milet grain

Moreover, the predicted R^2 of 0.4073 was in reasonable agreement with the adjusted R^2 of 0.5405. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on ER in terms of actual levels of variables is given as,

$$ER = 7.174093 - 0.00059 \times FR - 0.00158 \times PT \times AV + 0.024256 \times AV^2 \quad \text{..... (4.17)}$$

The comparative effect of each factor on the ER could be observed by the F-values in the ANOVA and also by the magnitudes of coefficients of the coded variables (Table. 4.26). The F-values indicated that AV^2 was the most influencing factor and FR and PT x AV were moderate effective over ER.

To visualize the combined effect of two variables on the ER, the response surface and contour plots [Fig. 4.20 (A) and (B)]were generated for the fitted model as a function of two variables while keeping other two variables at their central values.

It could be seen that as the puffing temperature and feed rate increased the expansion ratio was decreased, similar result was observed by Dahiwale (2013). The decreased in expansion ratio with increased puffing temperature may be caused due to the fact that increased puffing temperature caused over heating of the grain.

In the range of PT 250 to 300 °C the required puffing temperature of the kodo millet grain was not sufficient to expand or puffed the kodo millet grain, but as the temperature increases above the 300°C the grain was start too puffed. The increase in ER with increase PT and FR coincides with simultaneously reduced moisture content. This may be due to more case hardening, leading to conversion of comparatively more moisture mass into vapours, causing higher expansion effect.

Mukherjee (1997) and Nath (2006) obtained higher volume expansion at higher hot air puffing temperature and at longer hot air puffing time for hot air puffing of potato cubes and potato-soy snack foods, respectively. Similar effects of temperature and time on expansion of rice grains during high temperature fluidized bed hot air puffing was also reported by Chandrasekhar and Chattopadhyay (1989), while Roshdy *et al.*(1984) observed the same for hot air puffing of corn.

4.2.4.3 Effect of various process parameters on colour (CL-value) during hot air puffing of kodo millets grain

The data recorded for C (L-value) after each set of experiment shown in Appendix-V were analyzed for stepwise regression analysis, and the results are shown in Table 4.27. It could be observed that the values of C (L-value) were ranged between 60.021 and 71.451. The quadratic model was fitted to the experimental data and statistical significance for linear and quadratic terms was calculated for C (L-value) as shown in Table 4.27. The R^2 value was calculated by a least square technique and found to be 0.6746, showing good fit of model to the data. The model F-value of 5.8 implies that the model is significant ($P<0.05$). The linear terms of PT and FR, interaction terms PT, FR, PT x AV and AV x FR and AV^2 ($P<0.1$) are significant. The F-value of lack of fit was non-significant for the model obtained shown in Eq. 4.18. Moreover, the predicted R^2 of 0.4086 was in reasonable agreement with the adjusted R^2 of 0.5583. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on C (L-value) in terms of actual levels of variables is given as,

$$C\ (L\text{-Value}) = 144.3094 + 0.206858 \times PT - 0.02469 \times FR - 0.08527 \times PT \times AV + 0.007564 \times AV \times FR - 5.28557 \times AV^2 \qquad ..... (4.18)$$

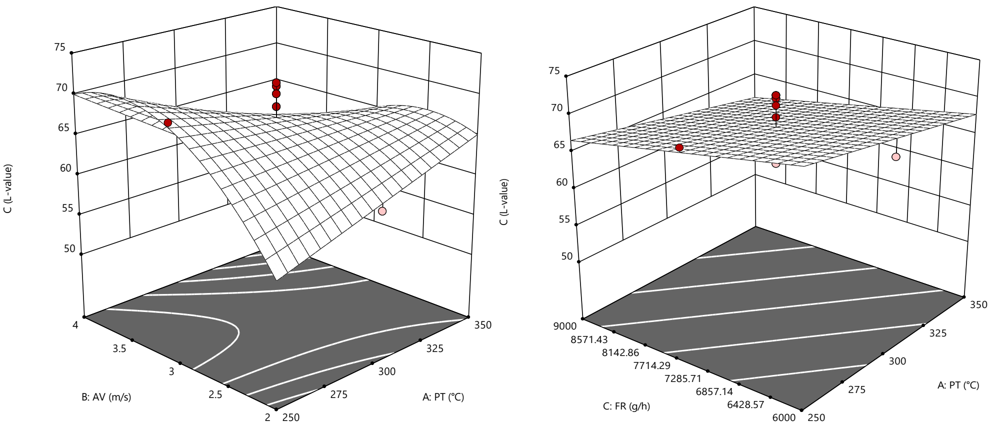
The F-values indicated that AV^2 was more influencing followed by AV x FR. Other factors like FR, PT x AV and PT were also moderate influencing the variation in C (L-value) during puffing. The C (L-value) increased with increase in FR while initially increased up to maxima (occurred at about 3.7 m/s, AV) and decreased thereafter.

Table 4.27 ANOVA table showing the effects of variables of C (L-value) and the coefficients of predictive models for hot air puffing of kodo millet grain

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	235.43	5	47.09	5.8	0.0042
PT	29.23	1	29.23	3.6	0.0785
FR	43.9	1	43.9	5.41	0.0355
PT x AV	31.87	1	31.87	3.93	0.0675
AV x FR	63.01	1	63.01	7.77	0.0145
AV^2	67.43	1	67.43	8.31	0.012
Residual	113.58	14	8.11		
Lack of Fit	55.02	9	6.11	0.5219	0.813^{NS}
Pure Error	58.56	5	11.71		
Cor Total	349.01	19			
R^2	0.6746				
Adj. R^2	0.5583				
Pred. R^2	0.4086				
C.V. %	4.32				
S.D.	2.85				

NS- Non significant

The same could be revealed from Fig. 4.21 (A) and (B), by visualizing the combined effect of two variables on the C (L-value), the response surface and contour plots generated for the fitted model as a function of two variables while keeping other two variables at their central values.



(A) (B)

Fig. 4.21 The contour and response surface plots showing the effect of (A) PT and AV and (B) PT and FR on C (L-value) for hot air puffing of kodo millet grain

As the air velocity increase the exposure of the grain with the hot air was very short period, so less effect of formation of caramelisation and browning occurs, so it increase the color value of the puffed kodo millet grain. These observations are consistent with previous studies Mukherjee (1997) and Khodke (2002). Effect of time on colour difference during dehydration of potato was also reported by Mishkin*et al.* (1983), who observed that browning occurred only after a certain time exposure which was more than 40 min with the drying air temperature of 80 °C. These observations supported the present findings regarding the effects of the PT and Pt on the colour (L-value) of wheat based cold extrudate during its hot air puffing.

4.2.4.4 Effect of various process parameters on hardness (HD, g) during hot air puffing of kodo millets grain

The data recorded for HD after each set of experiment shown in Appendix-V were analyzed for stepwise regression analysis, as shown in Table 4.28. It could be observed that the values of HD were ranged between 3832.93 and 8491.06. The quadratic model was fitted to the experimental data and statistical significance for linear and quadratic terms was calculated for HD as shown in Table 4.28. The R^2 value was calculated by a least square technique and found to be 0.6527, showing that model was fitting well to the data. The model F-value of 5.26 implies that the model is significant ($P<0.1$). The linear terms of PT and FR, quadratic terms of AV^2 and interaction term of PT x AV and AV x FR ($P<0.1$) are significant. The F-value of lack of fit was non-significant for the model obtained shown in Eq. 4.19. Moreover, the predicted R^2 of 0.3744 was in reasonable agreement with the adjusted R^2 of 0.5287. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on HD in terms of actual levels of variables is given as,

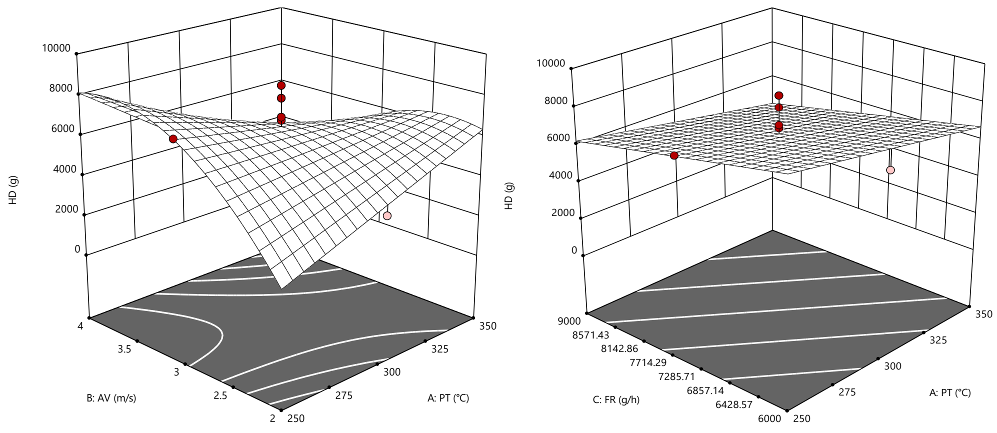
$$HD = 31688.56 + 78.01305 \times PT - 8.34688 \times FR - 31.9387 \times PT \times AV + 2.533134 \times AV \times FR - 1594.13 \times AV^2 \qquad .... (4.19)$$

Table 4.28 ANOVA table showing the effects of variables of HD and the coefficients of predictive models for hot air puffing of kodo millet grain

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	2.92E+07	5	5.83E+06	5.26	0.0063
PT	3.87E+06	1	3.87E+06	3.49	0.0828
FR	6.14E+06	1	6.14E+06	5.54	0.0338
PT x AV	6.02E+06	1	6.02E+06	5.43	0.0352
AV x FR	5.33E+06	1	5.33E+06	4.81	0.0457
AV^2	7.80E+06	1	7.80E+06	7.04	0.0189
Residual	1.55E+07	14	1.11E+06		
Lack of Fit	7.52E+06	9	8.36E+05	0.5231	0.8123^{NS}
Pure Error	7.99E+06	5	1.60E+06		
Cor Total	4.47E+07	19			
R^2	0.6527				
Adj. R^2	0.5287				
Pred. R^2	0.3744				
C.V. %	17.33				
S.D.	1052.65				

NS- Non significant

The F-values of linear and quadratic terms indicated thatAV^2 was most influencing followed by FR. Other factors like PT x AV and PT were moderate influencing the variation in HD during puffing. The HD increased with increase in PT up to its maxima about 300 °C and decrease thereafter.



(A) (B)

Fig. 4.22 The contour and response surface plots showing the effect of (A) PT and AV and (B) PT and FR on HD for hot air puffing of kodo millet grain

The same could be revealed from Fig. 4.22 (A) and (B), by visualizing the combined effect of two variables on the HD, the response surface and contour plots generated for the fitted model as a function of two variables while keeping other two variables at their central values.

Due to presence of hard seed coat the initial the grain having the higher hardness when the grain were feed in the puffing chamber. The puffing of the grain were started above the tempareture 300°C as mention in the section 4.2.3.2, it could be seen that increase in expantion ratio were decrease the hardness Dhurve *et al.*(2015). Where there was high expansion volume,the hard ness of the puffed rice was lower, because of the larger volume of air cells formed inside the individual puffed rice kernels Maisont and Narkrugsa (2010) similler result was found inthe present study.

4.2.4.5 Effect of various process parameters on crispness (CSP +ve peaks) during hot air puffing of kodo millet grain

The observations for CSP with different combinations of the process parameters are presented in Appendix-V. It varied between 9.127 to 26.044 within the combination of variables studied. The quadratic model was fitted to the experimental data and statistical significance was calculated for CSP as shown in Table 4.29. The R^2 value was calculated by a least square technique and found to be 0.5345, showing good fit of model to the data. The model F-value of 6.12 implies that the model is significant ($P<0.1$). The linear terms of FR, interaction term PT x AV and quadratic term AV^2 ($P<0.1$) are significant. The F-value of lack of fit was non-significant for the model obtained shown in Eq. 4.20. Moreover, the predicted R^2 of 0.2619 was in reasonable agreement with the adjusted R^2 of 0.4472. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space.

The regression equation describing the effects of the process variables on CSP in terms of actual levels of variables is given as,

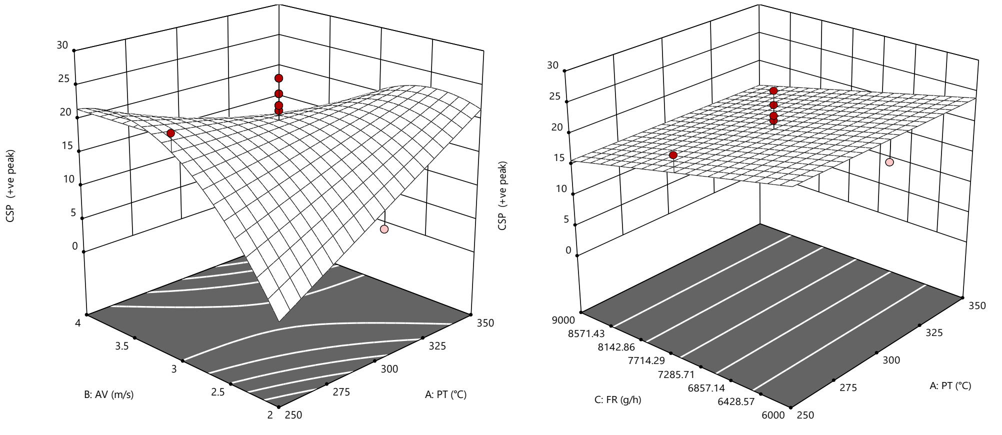
$$CSP=43.42283-0.0027 \times FR - 0.01035 \times PT \times AV + 0.489426 \times AV^2 \quad \text{.... (4.20)}$$

Table 4.29 ANOVA table showing the effects of variables of CSP and the coefficients of predictive models for hot air puffing of kodo millet grain

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	260.33	3	86.78	6.12	0.0056
FR	80.07	1	80.07	5.65	0.0303
PT x AV	68.1	1	68.1	4.81	0.0435
AV^2	112.16	1	112.16	7.92	0.0125
Residual	226.72	16	14.17		
Lack of Fit	153.81	11	13.98	0.9589	0.5597^{NS}
Pure Error	72.91	5	14.58		
Cor Total	487.05	19			
R^2	0.5345				
Adj. R^2	0.4472				
Pred. R^2	0.2619				
C.V. %	20.51				
S.D.	3.76				

NS- Non significant

The comparative effect of each factor on the CSP could be observed by the F-values in the ANOVA and also by the magnitudes of coefficients of the coded variables (Table. 4.29). The effect of AV^2 was most prominent ($P<0.01$) while FR and PT x AV ($P<0.05$) were least effective on CSP.



(A) (B)

Fig. 4.23 The contour and response surface plots showing the effect of (A) PT and AV and (B) PT and FR on CSP for hot air puffing of kodo millet grain

It could be observed that CPS increase initially with increase in PT, AV and FR upto certain maxima i.e., above 300 °C of PT, 3.0 m/s of

AV and 7500 g/h of FR and decreasing subsequently as depicted by quadratic term in Eq. 4.20. The same could be revealed from Fig. 4.23 (A) and (B), by visualizing the combined effect of two variables on the CSP, the response surface and contour plots generated for the fitted model as a function of two variables while keeping other two variables at their central values.

During puffing it was observed that as puffing initiates and advances moisture is trapped in the puffed product and veporised moisture is slowly removed, the puffed product retained its soft texture due to reletively low rate of moisture removal during puffing period which resulted in marginal increase in crispness of product Mazumder *et al.* (2007).

4.2.4.6 Optimization of hot air puffing process for Kodo millet grain

Numerical and graphical optimization was carried out for the process parameters for hot air puffing for obtaining the best product.

Table 4.30 Optimization criteria for different process variables and responses for hot air puffing of kodo millet grain

Name	Goal	Lower Limit	Upper Limit
PT	is in range	270.27	329.73
AV	is in range	2.4054	3.5946
FR	is in range	6608.09	8391.91
FMC	minimize	0.0211	0.0681
HD	is in range	3832.93	8491.06
CSP(+ ve peaks)	maximize	9.127	26.044
C (L-Value)	maximize	60.021	71.451
ER	maximize	0.012	2.9697

To perform this operation, Design-Expert program *(Version 11.0)* of the (Stat-Ease, 2018) software, as discussed in section 3.5.1, was used for simultaneous optimization of the multiple responses. The desired goals for each factor and response were chosen as shown in Table 4.30.

Table 4.31 shows that the software generated optimum conditions of independent variables with the predicted values of responses. Solution No.1, having the maximum desirability value (0.593) was selected as the optimum conditions of hot air puffing of kodo millets.

The optimum values of process variables obtained by numerical optimization:

Hot air puffing temperature (PT): 270.27 °C
Air Velocity (AV) : 3.589 m/s
Feed rate (FR) : 6608.097 g/h

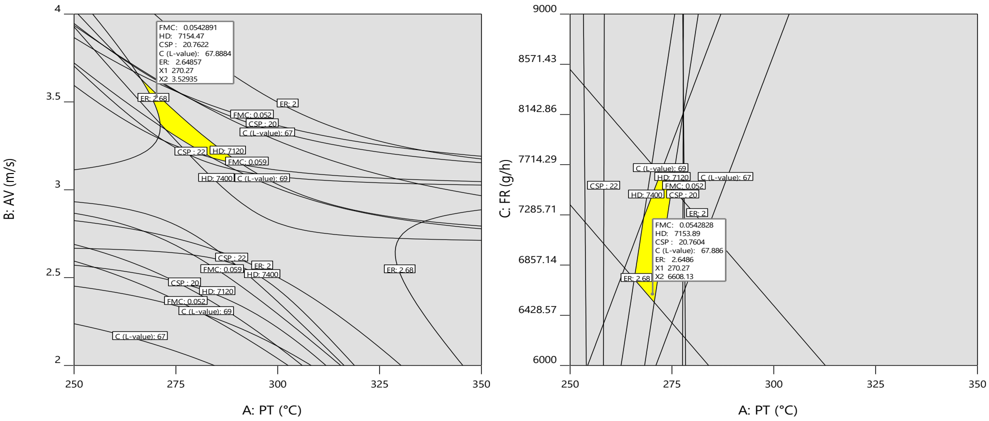
Table 4.31 Solutions generated by the software for hot air puffing of kodo millet grain

No.	PT	AV	FR	FMC	HD	CSP	C (L-Value)	ER	Desirability
1	**270.270**	**3.529**	**6608**	**0.054**	**7153.952**	**20.761**	**67.887**	**2.648**	**0.593***
2	270.270	3.530	6608	0.054	7151.807	20.754	67.879	2.648	0.593

*** Selected**

The superimposed contours of all responses for PT and AV and PT and FR [Fig.4.24 (A) and(B)] and their intersection zone for minimum FMC, maximum ER, maximum C (L-value), in range HD and maximum CSP indicated the ranges of variables which could be considered as the optimum range for best product quality. The range of optimum values of process variables obtained from the superimposed contours are,

Hot air puffing temperature (PT): 260-290 °C
Air Velocity (AV) : 3.4-3.9 m/s
Feed rate (FR) : 6200-6800 g/h



(A) (B)

Fig. 4.24 Superimposed contours for FMC (kg/kg dm), ER, C (L-value) and CSP (+ve peaks) for hot air puffing of kodo millets at varying (A) hot air puffing temperature (PT) and air velocity (AV) and (B) hot air puffing temperature (PT) and feed rate (FR)

4.2.4.7 Verification of the model for hot air puffing of kodo millet grain

Hot air puffing experiments were conducted at the optimum process condition and the quality attributes of the resulting product were determined. The observed experimental values (mean of 5 measurements) and values predicted by the equations of the model are presented in Table 4.32. The values of C.V. (<10%) and closeness between the experimental and predicted values of the quality parameters indicated the suitability of the corresponding models.

Table 4.32 Comparison between predicted and actual response variables at optimum process conditions for preparation of hot air puffing of kodo millet grain

Response	Predicted value	Actual value (± SD)	Variation, %	C.V., %
FMC (kg/kg dm)	0.054	0.0599(±0.0021)	9.729	3.67
HD, g	7154.47	7400.606(±92.761)	2.968	1.27
CSP (+ve peaks)	20.762	20.589(±0.233)	2.545	1.02
C (L-value)	67.88	69.45(±2.648)	8.788	3.84
ER	2.648	2.404(±0.119)	12.048	5.04

4.2.5 Hot air puffing of kutki grain

The experiment hot air puffing of kutki was conducted in CCRD with three variables viz., puffing temperature (PT, °C), air velocity (AV, m/s), feed rate and (FR, g/h). The response variables measured for studying the effect and optimization of process parameters were taken as Final moisture content (FMC, kg/kg dm), Expansion ratio (ER), Colour (L-value), Hardness (HD, g) and Crispness (CSP, No. of +ve peaks). The observations recorded are given in Appendix-VI.

4.2.5.1 Effect of various process parameters on moisture content (FMC, kg/kg dm) during puffing of kutki grain

The observations for each experiment were as recorded in Appendix-VI. The data were analyzed for its stepwise regression analysis as shown in Table 4.33. It could be observed that the values of FMC ranged between 0.0163 to 0.0672 kg/kg dm. The quadratic model was fitted to the experimental data and statistical significance for linear terms was calculated for FMC as shown in Table 4.33. The R^2 value was calculated by a least square technique and found to be 0.8018, showing good fit of model to the data. The model F-value of 11.33 implies that the model is significant ($P<0.05$). The linear terms PT, AV, interaction term PT x FR and AV x FR ($P<0.1$) are significant, while quadratic term AV^2 ($P<0.01$) are significant. The F-value of lack of fit was non significant, which indicates that the developed model was adequate for predicting the response. Moreover, the model adequacy evaluated with predicted R^2 of 0.6096 showed it to be in reasonable agreement with the adjusted R^2 of 0.731. This indicated that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on FMC in terms of actual levels of variables is given as,

$$FMC=0.29975+0.00018418 \times PT -0.22160 \times AV - 6.04812E\text{-}08 + PT \times FR + 8.93683E\text{-}06 \times AV \times FR + 0.03344 \times AV^2 \qquad ... (4.21)$$

The comparative effect of each factor on the FMC could be observed by the F-values in the ANOVA and also by the magnitudes of coefficients of the coded variables (Table. 4.33). The F-values indicated that PT was the most influencing followed by AV and PT x FR, AV x FR and AV^2 were moderate effect on FMC.

Table 4.33 ANOVA table showing the effects of variables of FMC (kg/kg dm) and the coefficients of predictive models for puffing of kutki grain

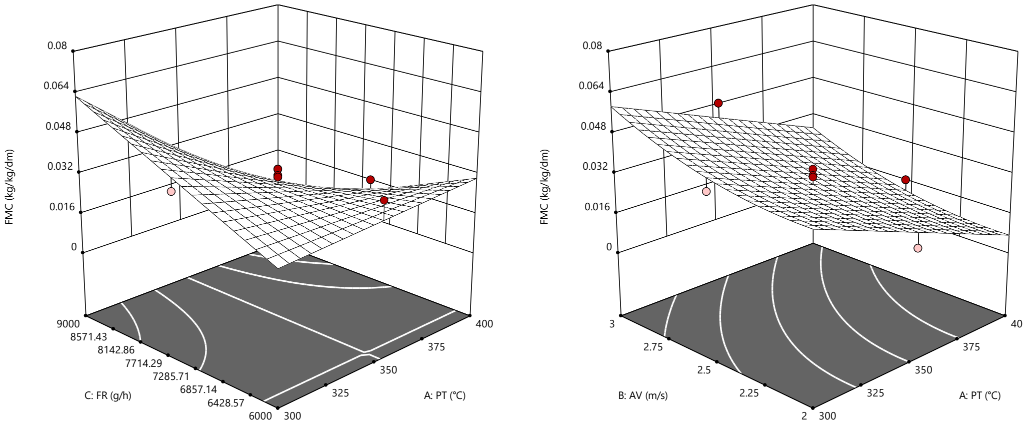
Source	**Sum of Squares**	**df**	**Mean Square**	**F-value**	**p-value**
Model	0.0021	5	0.0004	11.33	0.0002
PT	0.0011	1	0.0011	30.35	< 0.0001
AV	0.0008	1	0.0008	22.36	0.0003
PT x FR	0.0003	1	0.0003	7.97	0.0136
AV x FR	0.0004	1	0.0004	9.61	0.0078
AV^2	0.0001	1	0.0001	3.29	0.0911
Residual	0.0005	14	0		
Lack of Fit	0.0003	8	0	0.8644	0.5877^{NS}
Pure Error	0.0002	6	0		
Cor Total	0.0026	19			
R^2	0.8018				
Adj. R^2	0.731				
Pred. R^2	0.6096				
C.V. %	18.94				
S.D.	0.0061				

NS- Non significant

To visualize the combined effect of two variables on the FMC, the response surface and contour plots were generated for the fitted model as a function of two variables while keeping other two variables at their central values. It could be observed from Fig. 4.25 (A) and (B) that FMC decreased with increase in PT and it decreased initially with increase in AV up to its minima about 2.5 m/s and increased thereafter and FMC was increased linearly with FR increasing as depicted by quadratic term in Eq. 4.21.

The decrease in moisture content of puffed product with increase in hot air puffing temperature and hot air puffing time had been recorded by Mukherjee (1997) for HTST hot air puffing of potato cubes, Nath *et al.* (2007) for HTST hot air puffing of potato-soy snack foods and Pawar

(2017) for HTST microwave puffing of sprouted soy fortified millet flour based RTE snack.



(A) (B)

Fig. 4.25 The contour and response surface plots showing the effect of (A) PT and AV and (B) PT and FR on FMC for puffing of kutki grain

The reduced FMC after puffing of grain may be due to the fact that increased PT for longer time and AV to some extend causing reduction initial moisture content due to exposer of grain to hot air, leading to conversion of more moisture mass into vapours, causing removal of comparatively more moisture, once puffing was advanced.

4.2.5.2 Effect of various process parameters on expansion ratio (ER) during puffing of kutki grain

The data recorded for ER after each set of experiment (Appendix-VI) were analyzed for stepwise regression analysis, as shown in Table 4.34. It could be observed that the values of ER were ranged between 2.2092 and 5.2692. The quadratic model was fitted to the experimental data and statistical significance for linear and quadratic terms was calculated for ER as shown in Table 4.34. The R^2 value was calculated by a least square technique and found to be 0.7011, showing good fit of model to the data. The model F-value of 19.94implies that the model is significant (P<.01). The linear term like PT (P<0.01) is significant and quadratic term like FR^2 (P<0.1) is significant. The F-value of lack of fit was non-significant for the model obtained shown in Eq. 4.22, which indicates that the developed model was adequate for predicting the response. Moreover, the predicted R^2 of 0.5905was in reasonable agreement with the adjusted R^2 of 0.6659. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on ER in terms of actual levels of variables is given as,

$$ER = -4.83766 + 0.02373 \times PT - 1.8E\text{-}09 \times FR^2 \qquad \ldots (4.22)$$

Table 4.34 ANOVA table showing the effects of variables of ER and the coefficients of predictive models for puffing of kutki grain

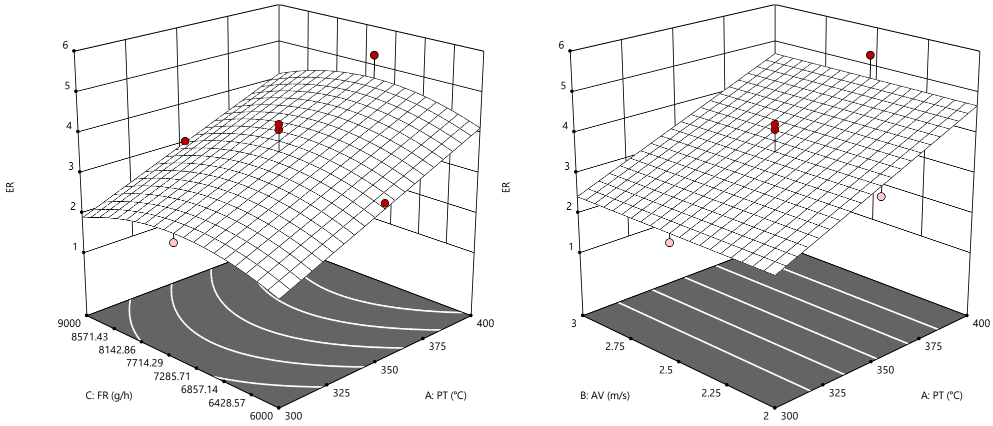
Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	6.81	2	3.41	19.94	< 0.0001
PT	6.08	1	6.08	35.61	< 0.0001
FR^2	0.5431	1	0.5431	3.18	0.0924
Residual	2.9	17	0.1708		
Lack of Fit	1.58	11	0.1433	0.6479	0.7481^{NS}
Pure Error	1.33	6	0.2212		
Cor Total	9.71	19			
R^2	0.7011				
Adj. R^2	0.6659				
Pred. R^2	0.5905				
C.V. %	12.28				
S.D.	0.4133				

NS- Non significant

The comparative effect of each factor on the ER could be observed by the F-values in the ANOVA and also by the magnitudes of coefficients of the coded variables (Table. 4.34). The F-values indicated that PT was the most influencing factor and $FR^2$was least effective over ER. The ER increased with increase in PT and it increased initially with increase in FR up to its maxima and decreased thereafter. The same could be revealed from Fig. 4.26 (A) and (B), by visualizing the combined effect of two variables on the CSP, the response surface and contour plots generated for the fitted model as a function of two variables while keeping other two variables at their central values.

Mukherjee (1997) and Nath (2006) obtained higher volume expansion at higher puffing temperature and at longer puffing time for

HTST air puffing of potato cubes and potato-soy snack foods, respectively.



(A) (B)

Fig. 4.26 The contour and response surface plots showing the effect of (A) PT and AV and (B) PT and FR on ER for puffing of kutki grain

Similar effects of temperature and time on expansion of rice grains during high temperature fluidized bed puffing was also reported by Chandrasekhar and Chattopadhyay (1989), while Roshdy *et al.* (1984) observed the same for puffing of corn. These findings were also in accordance with the present study.

The increase in ER with increase PT and decreasing FR coincides with simultaneously reduced moisture content. This may be due to more case hardening, leading to conversion of comparatively more moisture mass into vapours, causing higher expansion effect.

4.2.5.3 Effect of various process parameters on colour (C L-value) during puffing of kutki grain

The data recorded for C (L-value) after each set of experiment shown in Appendix-VI were analyzed for stepwise regression analysis, and the results are shown in Table 4.35. It could be observed that the values of C (L-value) were ranged between 68.986 to 78.438.

The quadratic model was fitted to the experimental data and statistical significance for linear and quadratic terms was calculated for C (L-value) as shown in Table 4.35. The R^2 value was calculated by a least square technique and found to be 0.7004, showing good fit of model to the data. The model F-value of 8.77 implies that the model is significant ($P<0.1$). The linear terms of PT, interaction terms AV x FR and quadratic term of FR^2 ($P<0.1$) are significant, while linear term AV ($P<0.05$) is significant. The F-value of lack of fit was non significant, which indicates that the developed model was adequate for predicting the response shown in Eq. 4.23. Moreover, the predicted R^2 of 0.5129 was in reasonable agreement with the adjusted R^2 of 0.6205. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on C (L-value) in terms of actual levels of variables is given as,

$$C\ (L\text{-value}) = 105.7243 - 0.03967 \times PT - 17.9877 \times AV + 0.00298 \times AV \times FR - 5.1E\text{-}07 \times FR^2 \quad \ldots (4.23)$$

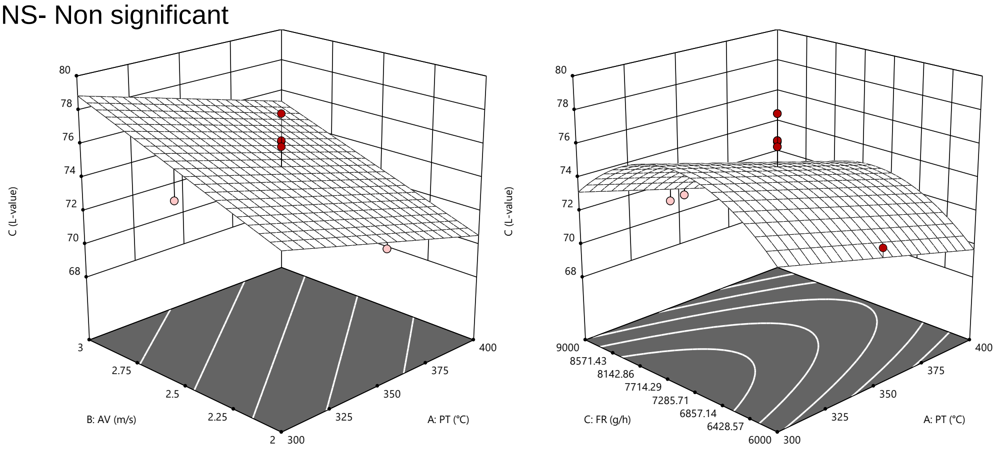
The comparative effect of each factor on the C (L-value) could be observed by the F-values in the ANOVA and also by the magnitudes of coefficients of the coded variables (Table. 4.35). The F-values indicated that AV most influence and FR^2, PT and AV x FR moderate effect over C (L-value) during puffing. The C (L-value) decreased with increasee in PT and FR, after reaching to its maxima (>73.0). The C (L-value) increased with increase in AV. The same could be revealed from Fig. 4.27 (A) and (B), by visualizing the combined effect of two variables on the C (L-value), the response surface and contour plots generated for the fitted model as a function of two variables while keeping other two variables at their central values.

The initial increase in C (L-value) i.e, brightness of puffing grain with increase in PT, AV and FR was observed may be due to improved puffing effect, the expanded product may be attaining brightness. But at higher PT and for lower AV, the reduced moisture level of grain may be subjecting the grain leading to browning Fennema (1976), thus decreased C (L-values). These observations are consistent with previous studies Mukherjee (1997), Khodke (2002) and Nath (2006).

Table 4.35 ANOVA table showing the effects of variables of C (L-value) and the coefficients of predictive models for puffing of kutki grain

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	86.66	4	21.66	8.77	0.0007
PT	13.69	1	13.69	5.54	0.0327
AV	55.35	1	55.35	22.4	0.0003
AV x FR	11.44	1	11.44	4.63	0.0481
FR^2	19.61	1	19.61	7.94	0.013
Residual	37.06	15	2.47		
Lack of Fit	23.59	9	2.62	1.17	0.4411^{NS}
Pure Error	13.48	6	2.25		
Cor Total	123.72	19			
R^2	0.7004				
Adj. R^2	0.6205				
Pred. R^2	0.5129				
C.V. %	2.12				
S.D.	1.57				

NS- Non significant



(A) (B)

Fig. 4.27 The contour and response surface plots showing the effect of (A) PT and AV and (B) PT and FR on C (L-value) for puffing of kutki grain

These observations are consistent with previous studies Mukherjee (1997) and Khodke (2002). Effect of time on colour difference during dehydration of potato was also reported by Mishkin *et al.* (1983), who observed that browning occurred only after a certain time exposure which was more than 40 min with the drying air temperature of 80°C. These observations supported the present findings regarding the effects of the PT and AV on the colour (L-value) of kutki grain during hot air puffing.

4.2.5.4 Effect of various process parameters on hardness (HD, g) during puffing of kutki grain

The data recorded for HD after each set of experiment shown in Appendix-VI were analyzed for stepwise regression analysis, as shown in Table 4.36. It could be observed that the values of HD were ranged between 10082 and 17649. The quadratic model was tried to fit to the experimental data and statistical significance for linear, quadratic and interaction terms was calculated for HD as shown in Table 4.36. The R^2 value was calculated by a least square technique and found to be 0.8025, showing that model was fitting well to the data. The model F-value of 11.38 implies that the model is significant ($P<0.05$). The linear term of AV, interaction term AV x FR and quadratic terms of AV^2 and FR^2 ($P<0.1$) are significant, while quadratic terms PT^2 ($P<0.05$) is significant. The F-value of lack of fit was non-significant for the model obtained shown in Eq. 4.24. Moreover, the predicted R^2 of 0.5951 was in reasonable agreement with the adjusted R^2 of 0.732. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on C (L-value) in terms of actual levels of variables is given as,

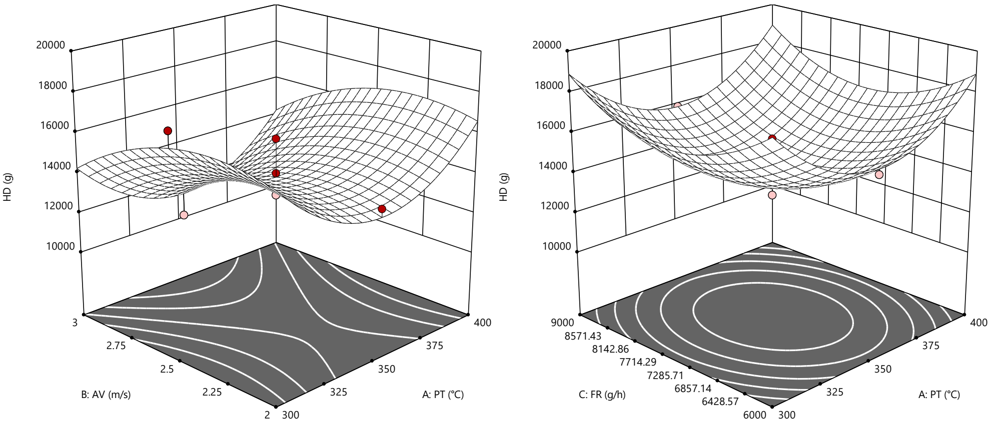
$$HD=-0.20930.4+32415.11 \times AV -1.91997 \times AV \times FR - 0.01071 \times PT^2 - 4071.19 \times AV^2 + 0.000309 \times FR^2 \quad \text{... (4. 24)}$$

The comparative effect of each factor on the FMC could be observed by the F-values in the ANOVA and also by the magnitudes of coefficients of the coded variables (Table. 4.36). The F-values indicated that PT^2 was the most influencing followed by AV, AV^2 and FR^2 and The AV x FR was least effect on HD. The HD decreased initially with increase in PT and FR up to its minima about 10000 g and increased thereafter. The HD increased initially with increase in AV up to its maxima (occurred at about 2.5 m/s AV) and decreased thereafter. The same could be revealed from Fig. 4.28 (A) and (B), by visualizing the combined effect of two variables on the HD, the response surface and contour plots generated for the fitted model as a function of two variables while keeping other two variables at their central values.

Table 4.36 ANOVA table showing the effects of variables of HD and the coefficients of predictive models for puffing of kutki grain

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	4.34E+07	5	8.69E+06	11.38	0.0002
AV	1.37E+07	1	1.37E+07	17.94	0.0008
AV x FR	3.58E+06	1	3.58E+06	4.69	0.048
PT^2	1.61E+07	1	1.61E+07	21.13	0.0004
AV^2	9.41E+06	1	9.41E+06	12.32	0.0035
FR^2	7.53E+06	1	7.53E+06	9.86	0.0072
Residual	1.07E+07	14	7.63E+05		
Lack of Fit	6.06E+06	9	6.74E+05	0.7279	0.6807^{NS}
Pure Error	4.63E+06	5	9.25E+05		
Cor Total	5.41E+07	19			
R^2	0.8025				
Adj. R^2	0.732				
Pred. R^2	0.5951				
C.V. %	6.08				
S.D.	873.73				

NS- Non significant



(A) (B)

Fig. 4.28 The contour and response surface plots showing the effect of (A) PT and AV and (B) PT and FR on HD for puffing of kutki grain

Due to presence of hard seed coat the initially the grain having the higher hardness when the grain were feed in the puffing chamber. The puffing of the grain were startedas the tempareture increase, it could be seen that increase in expantion ratio were decrease the hardness (Dhurve *et al.,* 2015).

Maisont and Narkrugsa (2010) observed that there was high expansion volume,the hard ness of the puffed rice was lower, because of the larger volume of air cells formed inside the individual puffed rice kernels similler result was found inthe present study.

4.2.5.5 Effect of various process parameters on crispness (CSP +ve peaks) during puffing of kutki grain

The observations for CSP with different combinations of the process parameters are presented in Appendix-VI. It varied between 7.00 to 22.50 within the combination of variables studied.

The quadratic model was fitted to the experimental data and statistical significance was calculated for CSP as shown in Table 4.37. The R^2 value was calculated by a least square technique and found to be 0.6807, showing good fit of model to the data. The model F-value of 18.12 implies that the model is significant ($P<0.01$). The linear term of PT ($P<0.01$) is significant, while quadratic term FR^2 ($P<0.1$) is significant model terms. The F-value of lack of fit was non-significant for the model obtained shown in Eq. 4.25. Moreover, the predicted R^2 of 0.5852was in reasonable agreement with the adjusted R^2 of 0.6431. This revealed that the non-significant terms have not been included in the model. Therefore this model could be used to navigate the design space. The regression equation describing the effects of the process variables on C (L-value) in terms of actual levels of variables is given as,

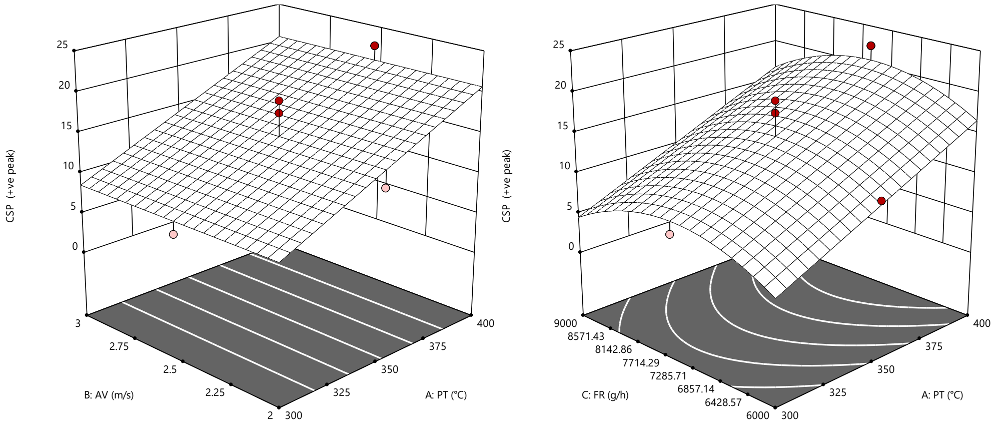
$$CSP= -32.3773+0.134836 \times PT - 2.7E\text{-}08 \times FR^2 \qquad \text{... (4.25)}$$

The comparative effect of each factor on the CSP could be observed by the F-values in the ANOVA and also by the magnitudes of coefficients of the coded variables (Table. 4.37). The effect of PT was most prominent ($P<0.01$) while FR^2 was least effective on CSP of the puffing millet.

Table 4.37 ANOVA table showing the effects of variables of CSP and the coefficients of predictive models for puffing of kutki grain

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	213.88	2	106.94	18.12	< 0.0001
PT	175.62	1	175.62	29.76	< 0.0001
FR^2	30.91	1	30.91	5.24	0.0352
Residual	100.32	17	5.9		
Lack of Fit	36.82	11	3.35	0.3163	0.953^{NS}
Pure Error	63.5	6	10.58		
Cor Total	314.2	19			
R^2	0.6807				
Adj. R^2	0.6431				
Pred. R^2	0.5852				
C.V. %	18.27				
S.D.	2.43				

NS- Non significant



(A) (B)

Fig. 4.29 The contour and response surface plots showing the effect of (A) PT and AV and (B) PT and FR on CSP for puffing of kutki grain

The CSP increased with increase in PT while it increased with increase in AV. The CSP increased initially with increase in FR up to its maxima about 7800 g/h and decreased thereafter. The same trend was observed in graphical representation shown in the surface and contour plot [Fig.4.29 (A) and (B)] of two variables while other two were kept constant at their central levels. The lower values of CSP in present case are similar to the value of CSP of 14, HTST air puffed potato snack foods with the operating conditions of temperature, time, initial moisture content, and air velocity as 225 °C, 45s, 0.5384 kg/kg dm and 3.6 m/s respectively (Nath, 2006).

4.2.5.6 Optimization of hot air puffing process for kutki grain

Numerical and graphical optimization was carried out for the process parameters for hot air puffing for obtaining the best kutki puffed grain sample. To perform this operation, Design-Expert program *(Version 11.0)* of the (Stat-Ease, 2018) software, as discussed in section 3.5.1, was used for simultaneous optimization of the multiple responses. The desired goals for each factor and response were chosen as shown in Table 4.38.

Table 4.38 Optimization criteria for different process variables and responses for hot air puffing of kutki grain

Name	**Goal**	**Lower Limit**	**Upper Limit**
A:PT	is in range	320.27	379.73
B:AV	is in range	2.2027	2.7973
C:FR	is in range	6608.09	8391.91
FMC	Minimize	0.0163	0.0672
HD	Maximize	10082	17649
CSP (+ve peaks)	Maximize	7	22.5
C (L-value)	Maximize	68.986	78.438
ER	Maximize	2.2092	5.26923

Table 4.39 shows that the software generated optimum conditions of independent variables with the predicted values of responses. Solution No.1, having the maximum desirability value (0.683) was selected as the optimum conditions of hot air puffing for developing kutki grain.

The optimum values of process variables obtained by numerical optimization:

Puffing temperature (PT): 379.73≈ 380 °C

Air velocity (AV) : 2.5 m/s

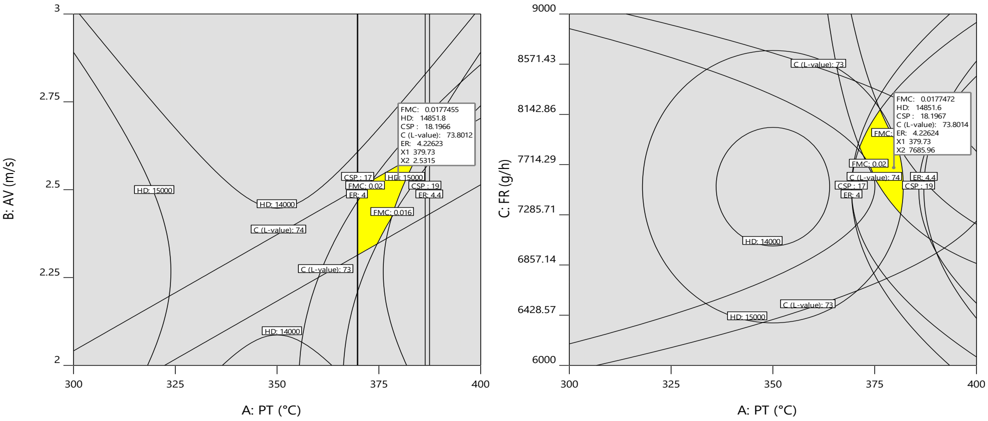
Feed rate (FR) : 7685.96 ≈ 7686 g/h

Table 4.39 Solutions generated by the software for hot air puffing of kutki grain

No.	PT	AV	FR	FMC	HD	CSP	C (L-value)	ER	Desirability
1	**379.73**	**2.53**	**7685.99**	**0.018**	**14850.5**	**18.19**	**73.804**	**4.226**	**0.683***
2	379.73	2.53	7685.65	0.018	14856.2	18.19	73.794	4.226	0.683

*** selected**

The superimposed contours of all responses for PT and AV and PT and FR [Fig. 4.30 (A) and (B)] and their intersection zone for minimum FMC, in range HD, maximum CSP (+ve peak), maximum C (L-value) and maximum ER indicated the ranges of variables which could be considered as the optimum range for best puffed kutki grain quality.



(A) (B)

Fig. 4.30 Superimposed contours for FMC (kg/kg dm), HD(g), CSP (+ve peaks), C (L-value) and ER, for puffing of finger millet at varying (A) puffing temperature (PT) and air velocity (AV) and (B) puffing temperature (PT) and feed rate (FR)

The ranges of optimum values of process variables obtained from the superimposed contours are as follows,

Puffing temperature (PT): 360-380 °C

Air velocity (AV) : 2.50-2.90 m/s

Feed rate (FR) : 6800-8200 g/h

4.2.5.7 Verification of the model for hot air puffed kutki grain

Hot air puffing experiments were conducted at the optimum process condition and the quality attributes of the resulting kutki grain was determined. The observed experimental values (mean of 5 measurements) and values predicted by the equations of the model are presented in Table 4.40. The values of C.V. (<10%) and closeness between the experimental and predicted values of the quality parameters indicated the suitability of the corresponding models.

Table 4.40 Comparison between predicted and actual response variables at optimum process conditions for preparation of hot air puffed kutki grain

Response	Predicted value	Actual value (± SD)	Variation, %	C.V., %
FMC (kg/kg dm)	0.018	0.024(±0.00018)	11.28	5.02
HD, g	14850.52	15213.8(±157.76)	2.8	1.18
CSP (+ve peaks)	18.197	16.297(±0.800)	10.54	5.31
C (L-value)	73.804	72.502(±1.904)	5.56	2.56
ER	4.226	3.852(±0.181)	11.76	4.99

4.3 Study on changes in bio-chemical composition of raw and hot air puffed grains

Since the process for preparation of puffed grains involved heat treatments at the stage of hot air puffing, it is necessary to verify the changes occurring during hot air puffing of sorghum, bajra, figger millet, kddo millet and kutki grain. Therefore, the various bio-chemical composition *viz*., moisture content, protein, fat, carbohydrates, ash content, starch, crude fiber, calcium, iron, tannin and polyphenols content were determined.

4.3.1 Changes in bio-chemical composition of hot air puffed millets

The effects of hot air puffing on moisture content, fat, protein, ash content, carbohydrates, starch, crude fiber, calcium, iron, tannin and polyphenols content of the grains are presented in Table 4.41.Food processing by heat generally alters the bioavailability of nutrients – both macro and micro (Amparo *et al.,* 2003; Abdalla *et al.,* 1998).

Initial moisture content in sorghum, bajra, finger millet, kodo millet and kutki grains were 11.7, 9.9, 10.9, 14.21 and 12.00 kg/100 kg dm, respectively. After hot air puffing, moisture content of the grain were decreased to 3.7, 3.8, 3.0, 5.9 and 2.4 kg/100 kg dm, respectively. The moisture content of the puffed grains decreased significantly due to the high pressure and temperatures during the explosion, with the water being changed into vapor and escaping from grains (Burgos *et al*.,2015).

Protein content of raw sorghum, bajra, finger millet, kodo millet and kutki grains were 12.5113, 11.2595, 7.8051, 10.5828, and 11.4951kg/100 kg, respectively, after hot air puffing the same were decreased to 12.2839, 9.8177, 7.0205, 10.5705 and 10.8033 kg/100 kg dm, respectively. However, the said reduction in protein content has been less than 10% db. Mohammed *et al*. (2010) proposed that heating and shearing during the expansion process could denature protein and change its structure. The reduction in protein content may be accredited to denaturation of proteins (Manay and Shadakharswamy, 2004). Loss of protein in heat treated grains could be due to the denaturation and degradation of protein.

The fat, ash, and polyphenol content was observed slight reduction in nutritive content of all five type grains during hot air puffing of all five type grains, similar result observed by Huang *et al.*(2018).

The carbohydrates in initial raw sorghum, bajra, finger millet, kodo millet and kutki grains were 335.1610, 288.6574, 363.3920, 299.0423 and 256.5062kg/100 kg, respectively, after hot air puffing were increased to 336.6812, 391.1591, 735.4219, 742.4600 and 318.2350kg/100 kg dm, respectively. Increase in carbohydrate due to puffed grains were concentrated more with endosperm which contributes starch to the kernel. Similar finding was noted by Chaturvedi and Shrivastava (2008) in popping of amber and dark genotype of finger millet.

Initial starch content in sorghum, bajra, finger millet, kodo millet and kutki grains were 140.5002, 118.3883, 168.3123, 186.7795 and 130.7870kg/100 kg, respectively whereas, after hot air puffing it, decreased to 89.1074, 80.7991, 123.6136, 61.6815 and 82.2490kg/100 kg dm, respectively. Starch is a major component of grains, the hydrogen bonds and glycoside bonds between starch molecules would have been destroyed and that would promote the gelatinization of starch during the explosion. A mixture consisting of melted starch, gelatinized starch and degraded starch that would exist in a system after the explosion. Meanwhile, starch could be degraded into many small molecules such as glucose, maltose etc., which leads to the increase of total sugar content and the decrease of starch content (Ratnayake *et al*., 2001 and Guha *et al*.,1997). Kataria and Chauhan (1988) suggested that the reduction in starch content in the roasting treatment is due to the rupturing of starch granules followed by amylolysis at high temperatures.

Crude fiber content of raw sorghum, bajra, finger millet, kodo millet and kutki grains were 1.0407, 1.2248, 0.6137, 6.1346 and 3.2844kg/100 kg, respectively whereas after hot air puffing the same were increased to 1.1429, 1.4507, 0.7354, 7.7818 and 5.2853, respectively. Gualberto *et al.* (1997) found extrusion (a high-temperature short-time procedure) had no effect on the insoluble fibre content of wheat bran but observed decreased amounts in rice and oat brans. The amount of soluble fibre increased in all three brans after extrusion, except at the maximum screw speed (100% maximum rotations per minute). The phytate content of the three cereal brans was not affected by extrusion.

Calcium content of raw sorghum, bajra, finger millet, kodo millet and kutki grains were 0.0580, 0.0656, 0.1950, 0.0737 and 0.0701, respectively whereas after hot air puffing the same were 0.0579, 0.0544, 0.1568, 0.0698 and 0.0472 kg/100 kg dm, respectively. Flaking altered the phosphorus, phytin phosphorus, and dietary fiber content of flaked rice with a decrease in proportion to thickness of flakes, the lesser the thickness, the lower was the constituent, whereas the iron and calcium contents were not affected (Suma *et al.,* 2007).

Iron content of raw sorghum, bajra, finger millet, kodo millet and kutki grains were 0.0031, 0.0045, 0.0035, 0.0048 and 0.0026, respectively, whereas after hot air puffing the same were 48.81, 49.5, 48.22, 51.75 and 37.22kg/100 kg dm, respectively. The digestibility and consequently absorption of micronutrients such as iron is believed to be improved upon heat processing by softening the food matrix, releasing of protein bound iron and thus facilitating its absorption (Amparo *et al.,* 2003; Abdalla *et al.,* 1998).

Tannin content of raw sorghum, bajra, finger millet, kodo millet and kutki grains were 1.7812, 0.8166, 0.5429, 0.6948 and 0.3714, respectively whereas after hot air puffing the same were 0.6745, 0.2205, 0.1402, 0.2808 and 0.2707 kg/100 kg dm, respectively. The extrusion process significantly reduced the degree of polymerization of tannins, which may be beneficial in human foods (Waniska *et al.,* 2004).

Polyphenols content of raw sorghum, bajra, finger millet, kodo millet and kutki grains were1.8E-06, 1.9E-06, 1.8E-06, 1.9E-06 and 1.8E-06 kg/100 kg, respectively whereas after hot air puffing the same were 1.6E-06, 1.5E-06, 1.8E-06, 1.5E-06 and 1.5E-06kg/100 kg dm, respectively.

Table 4.41 Changes in bio-chemical composition of raw and hot air puffed millets

Sr. No.	Parameters	Unit	Sorghum		Bajra		Finger millet		Kodo		Kutki	
			Raw	Puffed	Raw	Puffed	Raw	Puffed	Raw	Puffed	Raw	Puffed
1	**Moisture content**	**kg/100kg dm**	11.7000	3.7000	9.9000	3.8000	10.9000	3.0000	14.2100	5.9000	12.0000	2.4000
2	**Fat**	**kg/100kg dm**	1.9576	1.9472	5.7865	5.7753	1.9992	1.9992	2.6799	2.6799	2.6378	2.6167
3	**Protein**	**kg/100kg dm**	12.5113	12.2839	11.2595	9.8177	7.8051	7.0205	10.5828	10.5705	11.4951	10.8033
4	**Ash Content**	**kg/100kg dm**	1.4919	1.4919	1.5022	1.4919	0.8065	0.7760	1.7605	1.7605	1.8434	1.8330
5	**Carbohydrates**	**kg/100kg dm**	335.1610	336.6812	288.6514	391.1591	363.3920	735.4219	299.0423	742.4600	256.5062	318.2350
6	**Starch**	**kg/100kg dm**	140.5002	89.1074	118.3883	80.7991	168.3123	123.6136	186.7795	61.6815	130.7870	82.2490
7	**crude fiber**	**kg/100kg dm**	1.0407	1.1429	1.2248	1.4507	0.6137	0.7354	6.1346	7.7818	3.2844	5.2853
8	**Calcium**	**kg/100kg dm**	0.0580	0.0579	0.0656	0.0544	0.1950	0.1568	0.0737	0.0698	0.0701	0.0472
9	**Iron**	**kg/100kg dm**	0.0031	0.0049	0.0045	0.0050	0.0035	0.0048	0.0048	0.0052	0.0026	0.0037
10	**Tannin**	**kg/100kg dm**	1.7812	0.6745	0.8166	0.2205	0.5429	0.1402	0.6948	0.2808	0.3714	0.2707
11	**Polyphenols**	**kg/100kg dm**	1.8E-06	1.6E-06	1.9E-06	1.5E-06	1.8E-06	1.8E-06	1.9E-06	1.5E-06	1.8E-06	1.5E-06

4.4 Sensory evaluation of hot air puffed millets

Five types of hot air puffed samples and one commercial puffed sample were taken for sensory evaluation and thirty judges were involved for the same. The overall acceptability of the samples were tested to find the ratings from the scores given by the judges.

Table 4.42 Sensory scores in terms of preference given by number of judges and corresponding triplets for quality attributes of puffed millets

Sensory quality attributes	Not satisfactory	Fair	Medium	Good	Excellent	Triplets for Sensory Quality of Samples
Colour						
Sample 1	0	1	6	15	8	CS_1 = (75 25 18.33)
Sample 2	0	5	11	13	1	CS_2 = (58.33 25 24.17)
Sample 3	0	3	4	7	16	CS_3 = (80 25 11.67)
Sample 4	1	10	11	7	1	CS_4 = (47.50 24.17 24.17)
Sample 5	1	4	10	12	3	CS_5 = (60 24.17 22.50)
Sample 6	3	10	9	7	1	CS_6 = (44.17 22.50 24.17)
Flavour						
Sample 1	0	3	9	13	5	FS_1 =(66.67 25 20.83)
Sample 2	0	2	14	13	1	FS_2 =(60.83 25 24.17)
Sample 3	0	2	3	9	16	FS_3 =(82.50 25 11.67)
Sample 4	1	9	14	4	2	FS_4 = (47.50 24.17 23.33)
Sample 5	0	7	10	11	2	FS_5 = (56.67 25 23.33)
Sample 6	6	6	12	5	1	FS_6 = (40.83 20 24.17)
Texture						
Sample 1	0	4	5	13	8	TS_1 =(70.83 25 18.33)
Sample 2	0	3	20	5	2	TS_2 =(55 25 23.33)
Sample 3	0	1	5	9	15	TS_3 =(81.67 25 12.50)
Sample 4	2	7	13	8	0	TS_4 = (47.50 23.33 25)
Sample 5	1	5	14	10	0	TS_5 = (52.50 24.17 25)
Sample 6	6	5	10	8	1	TS_6 = (44.17 20 24.17)
OAA						
Sample 1	0	1	8	17	4	OS_1 =(70 25 21.67)
Sample 2	0	2	15	13	0	OS_2 =(59.17 25 25)
Sample 3	0	1	2	15	12	OS_3 =(81.67 25 15)
Sample 4	1	11	11	7	0	OS_4 =(45 24.17 25)
Sample 5	0	7	9	14	0	OS_5 =(55.83 25 25)
Sample 6	3	12	8	7	0	OS_6 =(40.83 22.50 25)

The sensory evaluation of the puffed millets was conducted by the method as described in the section 3.11. Quality of hot air puffed millets was compared with commercially available samples puffed by sand puffing.

The triplets associated with the sensory scores of each sample were calculated by the method described in section 3.11.1. The sensory scores considered for quality attributes in general were; not at all important (NI), somewhat important (SI), important (I), highly important (HI) and extremely important (EI). Triplets for sensory scores of quality attributes viz., colour, flavour, texture and overall acceptability of puffed millet and commercial puffed sorghum were calculated. Table 4.42shows the sensory preferences given by the judges for the hot air puffed sorghum (Sample 1), bajra (Sample 2), finger millet (Sample 3), kodo millet (Sample 4), kutki (Sample 5) and commercial sand puffed sorghum (Sample 6).

Table 4.43 Sensory scores in terms of preference given by number of judges, triplets and relative weightage for quality attributes of puffed millets

Quality attributes	**Sensory scale factors**					**Triplets for Quality attributes**
	NI	**SI**	**I**	**HI**	**EI**	
Colour	0	0	12	17	1	QC = (65.83 25 24.17)
Flavour	0	0	2	18	10	QF = (81.67 25 16.67)
Texture	0	0	3	13	14	QT = (84.17 25 13.33)
OAA	0	0	1	16	13	QO = (85 25 14.17)
						Qsum = 316.66

NI – Not at all important, SI – Somewhat important, I – Important, HI – Highly important, EI – Extremely important

Sensory scores and the triplets associated with quality attributes of puffed millets in general and the relative weightages are presented in Table 4.43. For estimation of overall sensory scores of each of the samples, Eq. 3.10was employed. The values of triplets for sensory scores of prepared samples and relative weightages of the quality attributes were multiplied following the rule of multiplication of triplets mentioned in Eq. 3.11.

The calculated values of triplets for overall sensory scores of Sample 1 (SOS1), Sample 2 (SOS2), Sample 3 (SOS3), Sample 4 (SOS4), Sample 5 (SOS5) and Sample 6 (SOS6) are as follows:

SOS1	70.4013	47.3026	35.2193
SOS2	58.3158	43.4210	36.7850
SOS3	81.5351	50.7237	30.3224
SOS4	46.8289	38.7478	34.5351
SOS5	56.0285	42.3684	36.3202
SOS6	42.4123	34.6118	33.5965

4.4.1 Overall membership functions of sensory scores on standard fuzzy scale

Six point sensory scale viz., poor/not at all necessary, fair/somewhat necessary, medium/necessary, good/important, very good/ highly important, excellent/extremely important referred to as “standard fuzzy scale‟ and designated as F1, F2, F3, F4, F5 and F6, respectively were used in the evaluation of sensory scores. Membership function values for the standard fuzzy scale have been presented in Eq.3.12. Values of overall membership function of sensory scores of the samples on standard fuzzy scale, Bx were calculated using Eq. 3.13.

Overall membership functions of Sample1, Sample 2, Sample 3, Sample 4, Sample 5 and Sample 6 were calculated by using the values in Eq. 3.13 and the triplets obtained in Eq. 4.10. These values are given in Eq. 4.11 as:

BS1= (0 0 0.1458 0.3573 0.5687 0.7801 0.9915 1.2029 0.7274 0.4435)

BS2= (0 0.1175 0.3478 0.5781 0.8084 1.0387 0.9542 0.6823 0.4105 0.1386)

BS3 = (0 0 0 0.1811 0.3782 0.5754 0.7725 0.9697 1.1668 0.7208)

BS4 = (0.0495 0.3076 0.5656 0.8237 1.0818 0.9081 0.6186 0.3290 0.0394 0)

BS5 =(0 0.1496 0.3856 0.6216 0.8577 1.0937 0.8906 0.6153 0.3399 0.0646)

BS6 =(0.0635 0.3524 0.6413 0.9303 1.2192 0.7741 0.4765 0.1788 0 0)

… (4.11)

4.4.2 Similarity values of puffed millets and their ranking

Similarity values for puffed millets were calculated using the values of membership functions of standard fuzzy scale and overall membership function values of sensory scores (Eq. 3.14) by applying rules of matrix multiplication (Das, 2005; Sinija and Mishra, 2011). The ranking of samples was done on the basis of obtained similarity values under Poor (F1), Fair (F2), Medium (F3), Good (F4), Very good (F5) and Excellent (F6) categories. The similarity values for all the six samples under different scale factors are presented in Table 4.16.

From the Table 4.16, it can be seen that, for Sample 1, Sample 2 and Sample 5 the highest similarity value lies in the category “good‟ viz., (0.6272), (0.7271) and (0.7195). For Sample 3, highest similarity value is obtained under the category “very good‟ and for Sample 5 and Sample 6 it is under the category “medium‟.

Table 4.44 Similarity values of puffed millets and their ranking

Sensory scale	**Sample 1, Sorghum**	**Sample 2, Bajra**	**Sample 3, Finger Millet**	**Sample 4, Kodo Millet**	**Sample 5, Kutki**	**Sample 6, Commercial Sorghum**
Poor	0.0000	0.0156	0.0000	0.0567	0.0198	0.0639
Fair	0.0766	0.2004	0.0231	0.3655	0.2238	0.3975
Medium	0.3278	0.5523	0.2158	**0.7374**	0.5869	**0.7619**
Good	**0.6272**	**0.7272**	0.5151	0.6229	**0.7196**	0.5199
Very good	0.6249	0.4353	**0.7345**	0.1892	0.3789	0.1112
Excellent	0.1905	0.0913	0.3322	0.0055	0.0620	0.0000
Ranking	**IV**	**II**	**I**	**VI**	**III**	**V**

On comparison of highest similarity values, their ranking was done as Sample 3 > Sample 2 > Sample 5 > Sample 1 > Sample 6 > Sample 4, where Sample 3 is hot air puffed finger millet, Sample 2 is hot air puffed bajra, Sample 5 is hot air puffed kutki, Sample 1 is hot air puffed sorghum, Sample 6 is commercial available sand puffed sorghum and Sample 4 is hot air puffed kodo millet. Thus, it indicates that hot air puffed finger millet was preferred by judges. Also, the score of sample 5 and Sample 2 was very close to each other under the category of “good‟.

4.4.3 Quality ranking of puffed millets

The quality attributes of hot air puffed and commercial sand puffed sample in general were ranked by calculating similarity values under various scale factors. Values of membership functions of F1, F2, F3, F4, F5 and F6 as given in Eq. 3.12were used in the calculation of similarity values. The values of overall membership functions for sensory scores of the quality attributes viz., colour, flavour, texture and overall acceptability were calculated by MATLAB 7.0 software using the same procedure as described above. The similarity values of all the quality attributes are given in Table 4.45.

The results from Table 4.17 show that OAA (0.9491) is the highest quality attribute followed by colour (0.9468) and these two quality attributes can be considered as highly important for puffed millets sample in general. This is followed by texture (0.9425) and flavour (0.8694). The all quality attributes were rated under the category “Highly important‟.

Table 4.45 Similarity values of quality attributes of hot air puffed and commercially available sand puffed millets in general

Sensory scale	**Colour**	**Flavour**	**Texture**	**OAA**
Not at all Important	0.0000	0.0000	0.0000	0.0000
Somewhat Important	0.0000	0.0000	0.0000	0.0000
Important	0.2551	0.0208	0.0061	0.0000
Very Important	0.8609	0.3540	0.3246	0.3009
Highly Important	**0.9469**	**0.8695**	**0.9426**	**0.9492**
Extremely Important	0.3969	0.3644	0.4334	0.4690
Ranking	**II**	**III**	**IV**	**I**

The order of preference of quality attributes for puffed in general was OAA (highly important) > Color (highly important) > Texture (Highly important) > Flavour (Highly important). Among the quality attributes, OAA was the strongest and flavour was the weakest quality attribute for puffed millets.

4.5 Storage studies of the hot air puffed millets grain

This section deals with the changes observed in the different hot air puffed grains during the storage under relative humidity, 95% at 40°C. As already discussed in the section 3.12, the puffed grains were stored in two types of packaging material (Multi layer flexible film and HDPE) for above conditions during storage studies.

4.5.1 Properties of packaging materials

The cumulative moisture gain with time by silica gel kept in two pouches (HDPE and Multi layer flexible packaging) at 40±2°C temperature and 95 ±1% relative humidity were measured as discussed in section 3.12.2. From the slope of respective curves, the WVTR were determined and found to be as shown in Table 4.46.

Table 4.46:Water vapour transmission rate of packaging material

Sr. No.	Packaging Material	Thickness (microns)	WVTR (kg water/day m^2)	Permeability (kg water/day m^2 Pa)
1	Multi layer flexible film	85	0.0010210	1.63E-06
2	HDPE	100	0.0011764	2.39E-06

4.5.2 Sorption isotherm of the hot air puffed grains

Sorption isotherms of puffed grains at 45±1°C and 95% RH, showing the variation of moisture content of the puffed grains with water activity (a_w) are given in Fig. 4.29. The water activity value of the hot air puffed sorghum, bajra, finger millet, kodo millet and kutki with 0.037, 0.038, 0.030, 0.059 and 0.0024 kg/kg dm moisture content respectively was found to be 0.406, 0.334, 0.349, 0.316 and 0.348, respectively at the said temperature (Appendix-IX).

Moisture content increased slowly with increase in water activity until the water activity reached the values of about 0.480, 0.478, 0.492, 0.442 and 0.458, respectively and for hot air puffed sorghum, bajra, finger millet, kodo millet and kutki after which rapid increase in moisture content was observed in all the cases. Thus it was concluded from the

Fig. 4.29, that the respective water activity values could be taken as the critical water activity values of hot air puffed grains, beyond which the products would loose crispness. Similar phenomenon was observed by Katz and Labuza (1981) and they reported that the critical water activity values for crisp product ranged between 0.35 and 0.50.

(a) HDPE packaging **(b) Multi layer flexible film Packaging**

Plate 4.2 Packaging material used for hot air puffed millets grain

Quast and Karel (1972) reported critical water activity values for popcorn and potato chips as 0.50 and 0.40, respectively. Khodke (2002) reorted critical water activity of 0.48 for dehydrated RTE potato cubes. Nath (2006) reported about 0.471 and 0.449 as the critical water activity values of RTE potato and RTE potato-soy snack foods, respectively.

Water activity of the product was considered as an index of shelf life of crispy materials as reported by earlier researchers (Labuza and Medellin 1981; Katz and Labuza, 1981; Tubert and Iglesius, 1986).The variation of moisture content with time is shown in Fig. 4.29 indicates that the moisture content increased with time.

4.5.3 Moisture content of hot air puffed millets during storage

Variation in moisture content of the product stored under different conditions is presented in tabular form (Appendix- IX) and graphically represented in Fig. 4.31 and 4.32 for hot air puffed sorghum, bajra, finger millet, kodo millet and kutki, respectively. Moisture content was found to increase rapidly with time in all the cases. The variation of moisture content in the puffed millets was higher in case of those packed in high molecular weight high-density polyethylene (HDPE) and lower in case of multilayer flexible film (MFF).

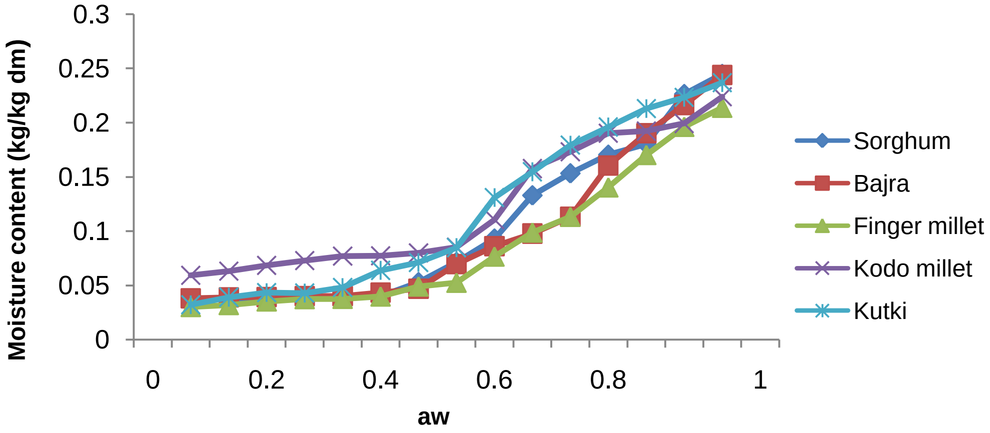


Fig. 4.31: Water activity of hot air puffed millet during storage

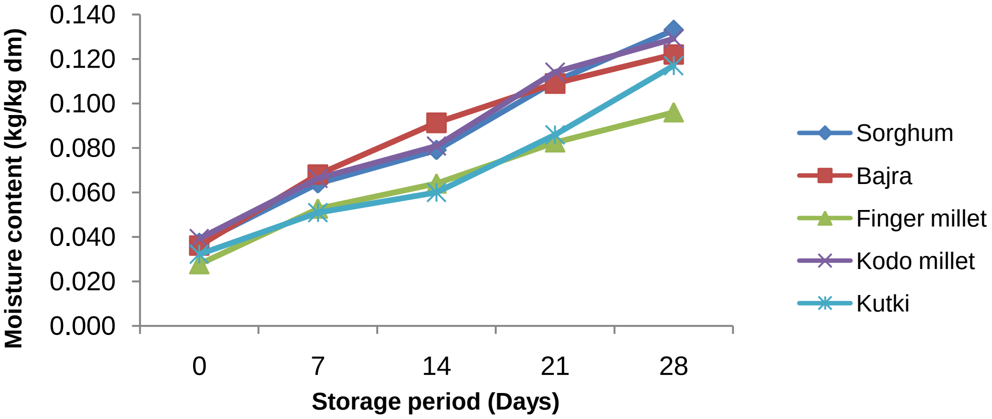


Fig. 4.32 Moisture content of hot air puffed millet packed in HDPE with storage period

This was obvious as the water vapour transmission rate was higher in case of HDPE and lower in case of MFF. For both the packaging materials (HDPE and MFF), the maximum moisture uptake was observed for the hot air puffed millets stored at maximum RH (95%), which may be because of the highest vapour pressure difference under this condition, which acted as the driving force for the moisture transfer.

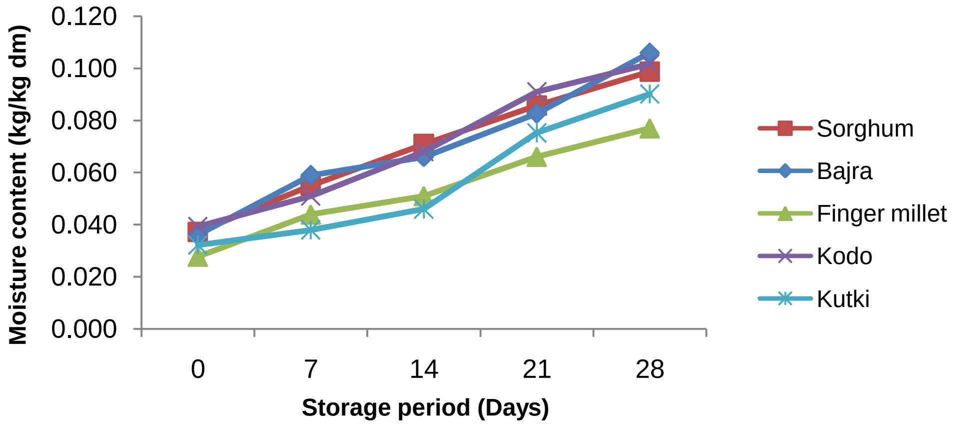


Fig. 4.33 Moisture content of hot air puffed millet packed in multilayer flexible film with storage period

4.5.4 Crispness of the hot air puffed millets during storage

Variation in crispness of the product during storage under different conditions is shown in Fig. 4.33 and 4.35, while the data is presented in the tabular form in Appendix-IX.

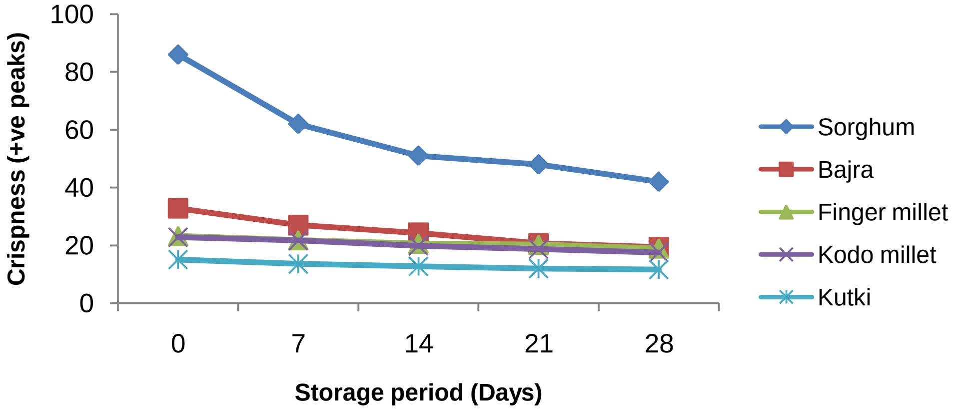


Fig. 4.34 Crispness of hot air puffed millet packed in HDPE with storage period

It is revealed that, during storage studies of hot air puffed sorghum, bajra, finger millet, kodo millet and kutki, maximum loss of crispness was observed at 45 °C, 95 % RH with HDPE packaging, while highest crispness could be retained with multilayer flexible film packaging (MFF). It was observed that, at this storage condition the product remained highly crisp for 27 days of storage period in multilayer flexible film packaging materials, and moderately crisp in HDPE packaging materials for the same storage period.

Thus it could be concluded that in general, crispness was entirely moisture dependent and therefore could be well maintained at lower RH and lower temperature, using better moisture proof packaging materials.

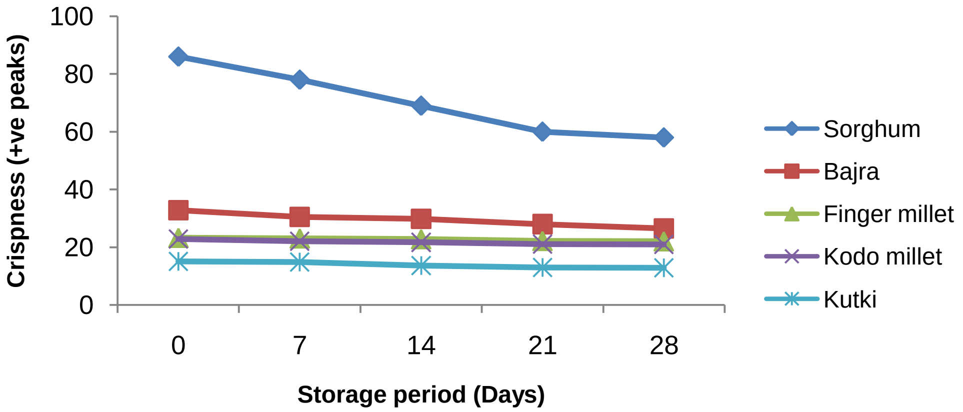


Fig. 4.35 Crispness of hot air puffed millet packed in multilayer flexible film with storage period

4.7.8 Self life of hot air puffed millet grains

At very high humidity (95%) and temperature (45 °C) the hot air puffed sorghum, bajra, finger millet, kodo millet and kutki lost its shelf life within 20, 18, 22, 11 and 23 days in HDPE and 26, 27, 27, 20 and 26 days in Multi layer flexible film, respectively. Thus, it could be predicted that the hot air puffed grains, if stored in Multi layer flexible packaging package at moderate RH (65%) and ambient temperature of 30°C, considerably long shelf life of 182, 139, 190, 84 and 208 days in case of hot air puffed sorghum, bajra, finger millet, kodo millet and kutki would be possible, respectively.

From Table 4.47, it is seen that 100 micron HDPE could protect about 4, 3, 4, 2 and 5 months at 30°C and 65 % RH and the 85 microns of Multilayer flexible could give the shelf life of 6, 5, 6, 3 and 7 months at 30 °C and 65 % RH, respectively for hot air puffed sorghum, bajra, finger millet, kodo millet and kutki.

Table 4.47 Predicted shelf life of hot air puffed grain

Millet	Temp. (°C)	RH (%)	HDPE		Multilayer Flexible film	
			Observed shelf life (days)	Predicted shelf life (days)	Observed shelf life (days)	Predicted shelf life (days)
Hot air puffed sorghum	30	65	-	124	-	182
	40	95	20	21	26	31
Hot air puffed Bajra	30	65		95	-	139
	40	95	18	21	27	30
Hot air puffed Finger millet	30	65	-	129	-	190
	40	95	22	23	27	34
Hot air puffed Kodo millet	30	65	-	57	-	84
	40	95	11	15	20	22
Hot air puffed Kutki	30	65	-	141	-	208
	40	95	23	24	26	34

CHAPTER VI

SUMMARY AND CONCLUSIONS

New food processing techniques can change the texture and taste of products made from millets and has a high potential for improvement of nutrient availability. Therefore, processing of millets to prepare ready-to-use and ready-to-eat products would enhance their food and economic value. Millets are claimed to be future foods for better health and nutrition security. They are recognized as important substitutes for major cereal crops to cope with the world food shortage and to meet the demands of increasing population of both developing and developed countries. In recent years, millets have received attention, mainly because of their high fiber content and thus efforts are under way to provide it to consumers in convenient forms.

The population of human being is ever increasing with vigorously changing lifestyle. This changing lifestyle is accompanied with changing demand, changing needs and habits. Newer technologies for processed food products have increased the demand for convenience foods. Ready-to-eat (RTE), quick cooking and instant foods have become very common largely due to today's life style and the demand for quick-to-serve foods. Fast moving life of human demands convenience in food production, preparation and convenience in its consumption too. As a result, the convenience food sector has grown by 70% over the past decade, creating a huge market. Convenience foods are foods which designed to save consumers' time in the kitchen and reduce costs due to spoilage. These foods require minimum preparation, typically just heating, and can be packaged for a long shelf life with little loss of flavor and nutrients over time.

Ready-to-eat (RTE), quick cooking and instant foods have become very common, largely due to today's life style and the demand for quick-to-serve foods. The gelatinization, dextrinization and carmelization of the cereal starches imparting the crispiness and flavour changes are of great importance in preparation of RTE foods.

The RTE foods are prepared by extrusion cooking, puffing, popping, flaking, frying, toasting etc while the RTE food products include extruded snack foods, puffed cereals, popcorns, rice flakes, fried fryums, home made products like *papads, kurdai, chakali* etc. which may be consumed after frying or roasting.

Generally, cereal grains are puffed with hot air, hot sand, frying in hot oil, microwave heating and by gun puffing methods. Roasting has a risk of burning and producing defects, while the oil from frying can be adsorbed and easily turns rancid. Moreover, the husk or wood chips fired furnace that is usually used in sand roasting method, based on conduction heating, presents environmental hazard as well as silica contamination. In comparison, high temperature short time (HTST) fluidized bed air puffing has better puffing efficiency as the product uniformly exposed to the heating medium.

The oil free RTE foods are of more demand amongst health conscious demography and are free from contaminations and are having higher shelf lives. Therefore, the hot air puffing should be preferred. However, the earlier researcher developed continuous hot air system which requires more space and feeding mechanism were manually operated. Large size of machine provides more area leading to more heat losses. Therefore, this system needs to be more compact and insulated with insulating material for minimizing heat losses which will be more energy efficient. Hence some typical features like well insulated, semi-automated, multigrain system, semi-automated feeding arrangement for different grains, maintain feed rate for different grains need to be added in the present system to develop the semi-automated multigrain puffing system, so that user of this machine will have maximum benefits and involve in the production of such a food segment with low initial cost investment and with easily available agriculture produce as a raw material. Keeping in view the above, the present study will be undertaken with the above specific objectives.

Objectives

1) Development of semi-automated multigrain continuous hot air puffing system
2) Optimizing hot air puffing parameters for different grains
3) Biochemical analysis of product before and after puffing
4) Shelf life study of optimally puffed grains

The developed semi-automated multigrain continuous hot air puffing system was comprising of the different parts as (1) Heating chamber, (2) Puffing column, (3) Feed hopper for continuous feeding, (4) Continuous exit for puffed product, (5) Cyclone separator, (6) Recirculation piping, (7) Blower, (8) Air flow control valve. The developed system was evaluated for preparation of hot air puffed sorghum, bajra, finger millet, kodo millet and kutki. The process variables for finger millet, kodo millet and kutki were taken as puffing temperature, air velocity, feed rate, whereas for sorghum and bajra the moisture content of grain was very low to impart puffing, so need to add moisture content to a predetermined level for maximum expansion effect and puffing yield, therefore initial moisture content was added as process variable for sorghum and bajra grain. The responses considered to optimize process variables were final moisture content FMC (kg/ kg dry matter), hardness HD (g), crispness CSP (number of +ve peaks), colour C(L-value) and expansion ratio ER. From above study, the following critical conclusions were drawn,

Conclusions

- The semi-automated multigrain continuous hot air puffing system is found safe and easy to operate.
- The semi-automated multigrain continuous hot air puffing system enables continuous feeding of raw material and continuous exit of puffed product, hence frequent resetting of temperatures and air velocities is no more required.

- The system can be set to any puffing temperature from 150 to 300 °C and air velocity of 1.5 to 6 m/s. and has capacity of 6000 to 8000 g/h, respectively.
- The optimum values of process variables, like puffing temperature (PT), air velocity (AV), feed rate (FR) and initial moisture content (IMC) for hot air puffing of sorghum were obtained 285.53 °C, 5.5 m/s, 7982 g/h and 0.025 kg/kg dm, respectively. Wherein the resultant optimized quality process parameters as final moisture content (FMC, kg/kg dm), expansion ratio (ER), colour (L-value), hardness (HD, g) and crispness (CSP, No. of +ve peaks) were found 0.0372, 44518.48, 86, 68.641 and 9.224, respectively.
- The optimum values of process variables, like puffing temperature (PT), air velocity (AV), feed rate (FR) and initial moisture content (IMC) for hot air puffing of bajra grain were obtained 355 °C, 4.0 m/s, 8250 g/h and 0.225 kg/kg dm, respectively. Wherein the resultant optimized quality process parameters for hot air puffed bajra grain, as final moisture content (FMC, kg/kg dm), expansion ratio (ER), colour (L-value), hardness (HD, g) and crispness (CSP, No. of +ve peaks) were found 0.038, 56212.86, 32.772, 65.26 and 4.243, respectively.
- The optimum values of process variables, like puffing temperature (PT), air velocity (AV) and feed rate (FR) for hot air puffing of finger millet grain were obtained329.73 °C, 2.506 m/s and 6608 g/h, respectively. Wherein the resultant optimized quality process parameters for hot air puffed finger millet grain, as final moisture content (FMC, kg/kg dm), expansion ratio (ER), colour (L-value), hardness (HD, g) and crispness (CSP, No. of +ve peaks) were found 0.03, 19323, 23.212, 63.092 and 2.439, respectively.
- The optimum values of process variables, like puffing temperature (PT), air velocity (AV) and feed rate (FR) for hot air puffing of kodo millet grain were obtained 270.27 °C, 3.589 m/s and 6608.097 g/h, respectively. Wherein the resultant optimized quality process

parameters for hot air puffed kodo millet grain, as final moisture content (FMC, kg/kg dm), expansion ratio (ER), colour (L-value), hardness (HD, g) and crispness (CSP, No. of +ve peaks) were found 0.059, 7249.21, 22.783, 68.889 and 2.358, respectively.

- The optimum values of process variables, like puffing temperature (PT), air velocity (AV) and feed rate (FR) for hot air puffing of kodo millet grain were obtained369.43 °C, 2.797m/s and 7671.917 g/h, respectively. Wherein the resultant optimized quality process parameters for hot air puffed kutki grain, as final moisture content (FMC, kg/kg dm), expansion ratio (ER), colour (L-value), hardness (HD, g) and crispness (CSP, No. of +ve peaks) were found 0.024, 13422.2, 15.072, 74.2904 and 3.626, respectively.
- Initial moisture content in sorghum, bajra, finger millet, kodo millet and kutki grains were 11.7, 9.9, 10.9, 14.21 and 12.00 kg/100 kg dm, respectively. After hot air puffing, moisture content of the grain were decreased to 3.7, 3.8, 3.0, 5.9 and 2.4 kg/100 kg dm, respectively.
- Protein content of raw sorghum, bajra, finger millet, kodo millet and kutki grains were 12.5113, 11.2595, 7.8051, 10.5828 and 11.4951 kg/100 kg, respectively, after hot air puffing the same were decreased to 12.2839, 9.8177, 7.0205, 10.5705 and 10.8033 kg/100 kg dm, respectively.
- The fat, ash, and polyphenol content was observed slight reduction in nutritive content of all five type grains during hot air puffing of all five type grains.
- The carbohydrates in initial raw sorghum, bajra, finger millet, kodo millet and kutki grains were 335.1610, 288.6574, 363.3920, 299.0423 and 256.5062 kg/100 kg, respectively, after hot air puffing were increased to 336.6812, 391.1591, 735.4219, 742.4600 and 318.2350 kg/100 kg dm, respectively.
- Initial starch content in sorghum, bajra, finger millet, kodo millet and kutki grains were 140.5002, 118.3883, 168.3123, 186.7795 and 130.7870 kg/100 kg, respectively whereas, after hot air puffing it,

decreased to 89.1074, 80.7991, 123.6136, 61.6815 and 82.2490 kg/100 kg dm, respectively.

- Crude fiber content of raw sorghum, bajra, finger millet, kodo millet and kutki grains were 1.0407, 1.2248, 0.6137, 6.1346 and 3.2844 kg/100 kg, respectively whereas after hot air puffing the same were increased to 1.1429, 1.4507, 0.7354, 7.7818 and 5.2853 kg/100 kg dm, respectively.
- Calcium content of raw sorghum, bajra, finger millet, kodo millet and kutki grains were 0.0580, 0.0656, 0.1950, 0.0737 and 0.0701, respectively whereas after hot air puffing the same were 0.0579, 0.0544, 0.1568, 0.0698 and 0.0472 kg/100 kg dm, respectively.
- Iron content of raw sorghum, bajra, finger millet, kodo millet and kutki grains were 0.0031, 0.0045, 0.0035, 0.0048 and 0.0026, respectively, whereas after hot air puffing the same were 0.0049, 0.0050, 0.0048, 0.0052 and 0.0037 kg/100 kg dm, respectively.
- Tannin content of raw sorghum, bajra, finger millet, kodo millet and kutki grains were 1.7812, 0.8166, 0.5429, 0.6948 and 0.3714, respectively whereas after hot air puffing the same were 0.6745, 0.2205, 0.1402, 0.2808 and 0.2707 kg/100 kg dm, respectively.
- Polyphenols content of raw sorghum, bajra, finger millet, kodo millet and kutki grains were 1.8E-06, 1.9E-06, 1.8E-06, 1.9E-06 and 1.8E-06 kg/100 kg, respectively whereas after hot air puffing the same were 1.6E-06, 1.5E-06, 1.8E-06, 1.5E-06 and 1.5 E-06 kg/100 kg dm, respectively.
- At very high humidity (95 %) and 45 °C temperature the hot air puffed sorghum, bajra, finger millet, kodo millet and kutki lost its shelf life within 24days in HDPE and 27 days in Multi layer flexible film. Thus, it could be concluded that the hot air puffed grains if stored in Multi layer flexible packaging package at moderate RH (65 %) and ambient temperature of 30°C, considerably long shelf life of 182, 139, 190, 84 and 208 days in case of hot air puffed sorghum, bajra, finger millet, kodo millet and kutki, respectively.

- It is seen that 100 micron HDPE could protect about 4, 3, 4, 2 and 5 months at 30°C and 65 % RH and the 85 microns of Multi layer flexible could give the shelf life of 6, 5, 6, 3 and 7 months at 30°C and 65 % RH for hot air puffed sorghum, bajra, finger millet, kodo millet and kutki, respectively.

CHAPTER VI

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Appendix - I

Specifications of Instruments/Equipment used in Experimentation

1. Balance	Type-Digital balance Model-DJ- 3005 Capacity-300 g Accuracy-0.001 g Power-DC-9 V System-Tunings-fork Vibration Make-Sinko Densi Co. ltd
2. Hot air oven	Type-Digital control Power supply-230 V Temperature-0-300 °C Make-Indosaw, Ambala
3. Kjelplus apparatus	Type-Kjelplus apparatus Temperature-200-400 °C Capacity-0.2 g and Make- Pelican
4. Muffle Furnace	Type-Muffle Furnace Power supply-230 V Temp. range-550-650 °C Make-Riviera Dass Pvt. Ltd, Mumbai
5. Soxlet Apparatus	Siphon type Six units Heating by electric bulbs; 60 w Capacity 1-10 g Round Bottom Flask- 250 mL Glassware – Qualigens
6 Texture Analyzer	Model- TA.XT-2i Manufacturer- Texture Tech.Corp.,Stable-Microsystems,UK Load cell-5 and 25 kg Software program-XT.RA Dimension
7. Water Activity Meter	Make-Aqua Lab Model CX2 Manufacturer -Dicagon Devices Inc., USA
8. Chroma meter	Model- CR-400 Manufacturer- Konoca Minolta, Inc, Japan

Appendix- II

Various quality parameters obtained under various treatment combinations during hot air puffing of sorghum

Sl. No.	Temp °C	Air Velo. m/s	Feed rate g/h	IMC kg/kg dm	FMC kg/kg dm	Hardness (g)	Crispness (No. of peak +ve)	Color (L value)	Expansion ratio
1	275	4.5	6750	0.21	0.033	53756	73.00	64.231	8.2
2	325	4.5	6750	0.21	0.0332	65711	48.83	64.907	11.9
3	275	5.5	6750	0.21	0.0332	58631	65.40	65.367	8.5
4	325	5.5	6750	0.21	0.0334	54391	71.80	65.669	11
5	275	4.5	8250	0.21	0.0335	50833	77.80	65.981	7.3
6	325	4.5	8250	0.21	0.0336	68732	48.80	66.455	12.5
7	275	5.5	8250	0.21	0.0338	39204	87.80	66.907	9.1
8	325	5.5	8250	0.21	0.0341	60097	59.60	67.211	10.3
9	275	4.5	6750	0.26	0.0342	41222	111.2	67.521	8.8
10	325	4.5	6750	0.26	0.0342	71211	49.00	67.597	8
11	275	5.5	6750	0.26	0.0345	40764	94.40	67.677	8.7
12	325	5.5	6750	0.26	0.0345	57121	66.00	67.801	8.3
13	275	4.5	8250	0.26	0.0348	52783	74.40	67.973	11.6
14	325	4.5	8250	0.26	0.0353	59764	61.00	68.301	8.9
15	275	5.5	8250	0.26	0.0356	42504	103.6	68.613	7.2
16	325	5.5	8250	0.26	0.0366	62355	55.00	68.877	9.8
17	250	5	7500	0.23	0.0372	37862	80.00	61.693	6.4

18	350	5	7500	0.23	0.0372	61625	57.80	63.742	8.8
19	300	4	7500	0.23	0.0378	56667	67.80	69.038	11.4
20	300	6	7500	0.23	0.0384	41297	88.80	69.241	11.9
21	300	5	6000	0.23	0.0421	53176	73.17	69.374	11.6
22	300	5	9000	0.23	0.0423	55738	70.17	69.49	7.6
23	300	5	7500	0.18	0.0426	80220	37.20	66.772	9.8
24	300	5	7500	0.28	0.0432	62010	56.60	72.018	10.1
25	300	5	7500	0.23	0.0437	52170	75.00	70.38	11.8
26	300	5	7500	0.23	0.0445	56991	67.00	69.98	12.3
27	300	5	7500	0.23	0.0488	53464	73.20	71.13	10.7
28	300	5	7500	0.23	0.0511	46348	91.40	70.561	12.9
29	300	5	7500	0.23	0.0568	47647	104.6	69.007	13.8
30	300	5	7500	0.23	0.0572	46999	95.40	72.317	13.4

Appendix - III

Various quality parameters obtained under various treatment combinations during hot air puffing of bajra

Sl. No.	Temp °C	Air Velo. m/s	Feed rate g/h	IMC kg/kg dm	FMC kg/kg dm	Hardness (g)	Crispness (No. of peak +ve)	Color (L value)	Expansion ratio
1	305	3	6750	0.225	0.0447	62673.12	27.33	66.45	3.6
2	355	3	6750	0.225	0.0603	83973.30	16.67	68.85	1.8
3	305	4	6750	0.225	0.0562	76668.88	20.50	68.42	2.3
4	355	4	6750	0.225	0.0488	74230.78	21.50	66.96	3.1
5	305	3	8250	0.225	0.0457	64081.69	27.00	65.37	3.7
6	355	3	8250	0.225	0.0443	62825.80	27.50	67.77	4.0
7	305	4	8250	0.225	0.0592	81567.94	17.00	67.03	1.8
8	355	4	8250	0.225	0.0403	59751.23	30.00	66.30	4.1
9	305	3	6750	0.275	0.0367	56864.59	32.00	64.51	4.2
10	355	3	6750	0.275	0.0537	66942.06	23.50	62.61	2.7
11	305	4	6750	0.275	0.0421	60864.20	28.00	67.76	4.0
12	355	4	6750	0.275	0.0571	79912.30	20.00	66.24	2.3
13	305	3	8250	0.275	0.0315	56317.15	38.50	62.99	4.2
14	355	3	8250	0.275	0.0521	66597.56	24.50	65.92	2.8
15	305	4	8250	0.275	0.0466	64454.16	27.00	64.76	3.7

16	355	4	8250	0.275	0.0276	56820.94	38.00	68.90	4.3
17	280	3.5	7500	0.25	0.0433	59961.34	28.50	64.31	4.0
18	380	3.5	7500	0.25	0.0350	57162.02	31.00	68.01	4.2
19	330	2.5	7500	0.25	0.0391	59731.67	30.00	58.61	4.2
20	330	4.5	7500	0.25	0.0545	68355.87	23.00	64.31	2.7
21	330	3.5	6000	0.25	0.0491	73404.32	21.50	67.83	3.0
22	330	3.5	9000	0.25	0.0451	63357.90	27.00	65.81	3.8
23	330	3.5	7500	0.2	0.0479	72535.57	22.00	68.75	3.3
24	330	3.5	7500	0.3	0.0488	65478.11	26.50	67.06	3.1
25	330	3.5	7500	0.25	0.0511	66184.50	25.00	68.24	3.0
26	330	3.5	7500	0.25	0.0473	70197.75	22.00	65.49	3.3
27	330	3.5	7500	0.25	0.0471	64628.45	26.50	67.04	3.5
28	330	3.5	7500	0.25	0.0552	76381.35	20.50	62.72	2.5
29	330	3.5	7500	0.25	0.0541	67553.29	23.00	66.69	2.7
30	330	3.5	7500	0.25	0.0436	69462.70	22.50	65.08	4.0

Appendix - IV

Various quality parameters obtained under various treatment combinations during hot air puffing of finger millet

Sl. No.	Temp °C	Air Velo. m/s	Feed rate gm/h	FMC kg/kg dm	Hardness (g)	Crispness (No. of peak +ve)	Color (L value)	Expansion ratio
1	270	2.5	6600	0.026	24308	23.33	61.48	2.76
2	330	2.5	6600	0.029	19463	24.33	62.63	3.14
3	270	3.5	6600	0.021	22001	21.00	58.70	2.00
4	330	3.5	6600	0.007	13762	11.50	41.06	0.57
5	270	2.5	8400	0.021	18461	22.00	59.71	2.48
6	330	2.5	8400	0.040	14376	33.00	67.75	3.86
7	270	3.5	8400	0.010	18533	17.00	49.96	1.71
8	330	3.5	8400	0.008	25583	13.00	45.11	0.60
9	250	3	7500	0.013	30965	19.33	53.72	1.81
10	350	3	7500	0.027	28447	23.67	61.93	2.81
11	300	2	7500	0.031	15179	25.33	63.33	3.29
12	300	4	7500	0.002	17271	9.00	35.21	0.13
13	300	3	6000	0.021	13548	21.00	57.01	1.95
14	300	3	9000	0.024	15179	22.67	60.13	2.52
15	300	3	7500	0.032	13548	26.33	63.71	3.29
16	300	3	7500	0.032	15179	28.00	64.79	3.35
17	300	3	7500	0.028	21357	24.00	62.45	3.00
18	300	3	7500	0.039	14691	31.00	65.69	3.45
19	300	3	7500	0.036	18533	28.67	65.08	3.41
20	300	3	7500	0.025	12984	23.33	60.81	2.62

Appendix - V

Various quality parameters obtained under various treatment combinations during hot air puffing of kodo millet

Sl. No.	Temp °C	Air Velo. m/s	Feed rate gm/h	FMC kg/kg dm	Hardness (g)	Crispness (No. of +ve peak)	Color (L value)	Expansion ratio
1	270	2.5	6600	0.0669	7834.124	23.099	70.907	2.52
2	330	2.5	6600	0.0674	7886.652	24.127	71.341	2.73
3	270	3.5	6600	0.0491	6250.108	18.907	64.675	1.88
4	330	3.5	6600	0.0378	4878.022	15.601	62.541	0.82
5	270	2.5	8400	0.0241	3968.453	10.437	60.271	0.01
6	330	2.5	8400	0.0451	5843.985	18.022	64.111	1.73
7	270	3.5	8400	0.0579	7694.733	22.789	70.681	2.42
8	330	3.5	8400	0.0256	4054.862	11.367	61.121	0.03
9	250	3	7500	0.0565	7424.59	22.611	70.302	2.36
10	350	3	7500	0.0436	4931.005	16.033	62.811	1.61
11	300	2	7500	0.0211	3832.927	9.127	60.021	0.01
12	300	4	7500	0.0327	4724.533	14.403	61.87	0.13
13	300	3	6000	0.0545	6542.535	20.511	67.881	2.12
14	300	3	9000	0.0287	4243.143	12.215	61.213	0.06
15	300	3	7500	0.0671	7875.737	23.801	71.023	2.55
16	300	3	7500	0.0367	4825.95	14.901	62.321	0.67
17	300	3	7500	0.0583	6789.711	21.331	68.561	2.21
18	300	3	7500	0.0511	6464.767	19.701	66.831	2.06
19	300	3	7500	0.0681	8491.061	26.044	71.451	2.97
20	300	3	7500	0.0626	6955.252	22.102	70.113	2.36

Appendix - VI

Various quality parameters obtained under various treatment combinations during hot air puffing of kodo millet

Sl. No.	Temp °C	Air Velo. m/s	Feed rate g/h	FMC kg/kg dm	Hardness (g)	Crispness (No. of +ve peak)	Color (L value)	Expansion ratio
1	320	2	6600	0.00373	14997	8.5	72.66	2.23
2	380	2	6600	0.00252	15030	17	71.86	3.96
3	320	3	6600	0.00371	14293	8.5	77.23	2.62
4	380	3	6600	0.00292	14521	16.5	73.00	3.77
5	320	2	8400	0.00432	16355	9	72.02	2.72
6	380	2	8400	0.00273	14957	16	68.99	3.62
7	320	3	8400	0.00672	12070	9.5	78.44	2.76
8	380	3	8400	0.00312	12675	15	75.94	3.53
9	300	2.5	7500	0.00389	17649	7	74.68	2.21
10	400	2.5	7500	0.00163	15766	22.5	71.34	5.27
11	350	2	7500	0.00173	14005	12.5	71.95	3.31
12	350	3	7500	0.00487	10082	13.5	74.66	3.33
13	350	2.5	6000	0.00356	15625	11	72.01	3.15
14	350	2.5	9000	0.00211	15885	9.5	71.04	3.04
15	350	2.5	7500	0.00341	13825	14.5	74.10	3.50
16	350	2.5	7500	0.00316	14021	14.5	74.58	3.46
17	350	2.5	7500	0.00256	13716	17.5	76.19	4.10
18	350	2.5	7500	0.00237	15743	11.5	76.26	3.19
19	350	2.5	7500	0.00309	12920	13	77.83	3.31
20	350	2.5	7500	0.00223	13425	19	75.89	4.23

Appendix – VII

Sensory Evaluation

Evaluation chart for fuzzy logic five point scale

Name: Date:

Product: Puffed products Time:

Instruction: Give tick (√) mark to appropriate respective fuzzy scale factor for each of the quality attributes of the sample after evaluating the samples.

Table 1. Sensory scores for quality attributes of samples

Sensory quality attributes of samples	Sensory scale factors				
	Not satisfactory	Fair	Medium	Good	Excellent
Color					
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
Flavor					
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
Texture					
1					
2					
3					
4					

5					
6					
7					
8					
9					
10					
11					
OAA					
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					

Table 2. Individual preferences to the importance of quality attributes of samples in general.

Sensory quality attributes of samples in general	Sensory scale factors				
	Not at all important	Somewhat important	Important	Highly important	Extremely important
Color					
Flavor					
Texture					
OAA					

Signature

Appendix–VIII

Values recorded for a_W against varied equilibrium moisture content of hot air puffed millet

Sr. No.	Sorghum		Bajra		Finger millet		Kodo millet		Kutki	
	Moisture content kg/kg dm	Water activity	Moisture content kg/kg dm	Water activity	Moisture content kg/kg dm	Water activity	Moisture content kg/kg dm	Water activity	Moisture content kg/kg dm	Water activity
1	0.0372	0.406	0.0360	0.335	0.0277	0.349	0.0392	0.317	0.0036	0.348
2	0.0377	0.411	0.0369	0.351	0.0319	0.354	0.0489	0.321	0.0189	0.351
3	0.0382	0.433	0.0372	0.373	0.0352	0.363	0.0582	0.333	0.0282	0.367
4	0.0390	0.450	0.0380	0.405	0.0374	0.385	0.0627	0.359	0.0327	0.379
5	0.0393	0.457	0.0391	0.417	0.0376	0.397	0.0769	0.377	0.0379	0.382
6	0.0403	0.464	0.0433	0.443	0.0398	0.413	0.0771	0.401	0.0637	0.415
7	0.0629	0.470	0.0469	0.460	0.0490	0.430	0.0799	0.416	0.0710	0.439
8	0.0715	0.480	0.0695	0.478	0.0525	0.462	0.0801	0.442	0.0847	0.447
9	0.0931	0.610	0.0861	0.521	0.0766	0.492	0.1006	0.462	0.1310	0.472
10	0.1430	0.640	0.0977	0.614	0.0988	0.564	0.1577	0.496	0.1547	0.526
11	0.1533	0.710	0.1033	0.731	0.1133	0.771	0.1733	0.671	0.1793	0.631
12	0.1705	0.760	0.1605	0.750	0.1405	0.787	0.1905	0.767	0.1961	0.670
13	0.1804	0.840	0.1904	0.860	0.1704	0.840	0.1923	0.873	0.2130	0.773
14	0.2264	0.850	0.2164	0.870	0.1964	0.880	0.1994	0.878	0.2234	0.818
15	0.2449	0.900	0.2440	0.900	0.2140	0.900	0.2240	0.920	0.2370	0.913

Appendix - IX

Changes in Properties of puffed sorghum with storage period

Days	Storage temperature 45°C, RH 95%									
	Moisture content kg/kg dm									
	Sorghum		Bajra		Finger millet		Kodo millet		Kutki	
	HDPE	MFP	HDPE	MFP	HDPE	MFP	HDPE	MFP	HDPE	MFP
0	0.037	0.037	0.038	0.038	0.030	0.030	0.059	0.059	0.024	0.024
7	0.064	0.055	0.068	0.059	0.053	0.044	0.076	0.065	0.051	0.038
14	0.079	0.071	0.091	0.066	0.064	0.051	0.091	0.078	0.060	0.046
21	0.110	0.086	0.109	0.083	0.083	0.066	0.114	0.097	0.086	0.075
28	0.133	0.099	0.122	0.106	0.096	0.077	0.129	0.109	0.117	0.090
	Water activity									
0	0.406	0.406	0.3347	0.3347	0.349	0.349	0.3167	0.3167	0.348	0.348
7	0.661	0.5455	0.6995	0.583	0.4935	0.385	0.695	0.5485	0.5575	0.395
14	0.83	0.8275	0.8395	0.697	0.6035	0.545	0.8635	0.7345	0.715	0.567
21	0.944	0.8915	0.9245	0.8575	0.7455	0.7085	0.956	0.8055	0.8075	0.7645
28	0.983	0.93	0.935	0.881	0.788	0.7735	0.9925	0.8375	0.903	0.811
	Crispness (+ve peaks)									
0	86	86	32.772	32.772	23.212	23.212	22.783	22.783	15.072	15.072
7	62	78	27.00	30.460	21.78	23.000	21.64	22	13.593	14.853
14	51	69	24.33	29.832	20.62	22.738	19.856	21.656	12.746	13.648
21	48	60	20.75	27.971	20.22	22.124	18.749	21.051	12	13
28	42	58	19.43	26.500	18.94	22.000	17.537	20.937	11.66	12.876

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