

**STANDARDIZATION OF PROCESS PARAMETER FOR
CORNFLAKES PREPARATION**

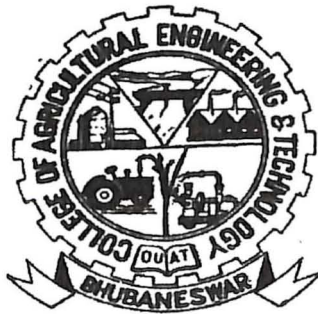
**A THESIS SUBMITTED TO THE
ORISSA UNIVERSITY OF
AGRICULTURE AND TECHNOLOGY
BHUBANESWAR**

**IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF**

**MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)**

IN

PROCESSING AND FOOD ENGINEERING



BY

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BHUBANESWAR, ORISSA**

2011



Dedicated to
My beloved parents



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CERTIFICATE-I

This is to certify that the thesis entitled "***Standardization of process parameters for cornflakes preparation***" submitted in partial fulfillment of degree of **Master of Technology (Agricultural Engineering)** in **Processing and Food Engineering** of Orissa University of Agriculture and Technology, Bhubaneswar is a faithful record of *bona fide* research work carried out by **Tapasi Mahapatra** under my guidance and supervision. No part of the thesis has been submitted for any other degree or diploma.

The help and information availed during the investigation have been duly acknowledged by ~~her~~.

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CERTIFICATE-II

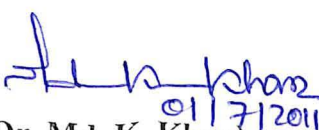
This is to certify that the thesis entitled "**Standardization of process parameters for cornflakes preparation**" submitted in partial fulfillment of degree of **Master of Technology (Agricultural Engineering)** in **Processing and Food Engineering** of Orissa University of Agriculture and Technology, Bhubaneswar by **Tapasi Mahapatra** has been approved by the student's advisory committee after an oral examination on the same in collaboration with the external examiner.

Approved by Advisory Committee

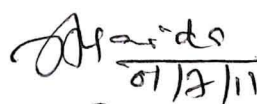
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ACKNOWLEDGEMENT

First and foremost, I would to express my deep heartfelt gratitude to the "Almighty God" for giving me health, courage and a sound mind to work in this project.

I deem this unique privilege to express my hearty gratitude and indebtedness to my able guide Dr. U.S. Pal, Associate Professor, Department of Agricultural Processing and Food Engineering, College of Agriculture Engineering and Technology, O.U.A.T., Bhubaneswar, the Chairman of my advisory committee for his valuable and proper guidance, constant supervision, steady encouragement, cooperation and constant supports with care during the entire period of investigation and throughout the preparation of this manuscript.

I expressed my heartfelt gratitude to Dr. Md. Khalid Khan, Dean, CAET and Professor and Head, Department of Agricultural Processing and Food Engineering, Orissa University of Agriculture and Technology, Bhubaneswar, for his valuable advice, constant inspiration, relevant suggestion and facilities provided during the course of this investigation.

I feel much obligated to Er. N.R. Sahoo, Asst. Food Micro-Biologist, Department of Post harvest Processing and Food Engineering, College of Agricultural Engineering and Technology, OUAT, Bhubaneswar; and Dr. A. K. Parida, Department of Statistics, Faculty of College of Agriculture, OUAT, Bhubaneswar for their unending guidance, valuable suggestions and encouragement during the research work and course of my study.

I express my sincere thanks to all my professors namely Dr. (Mrs.) Kalpana Ray guru, Dr. M.K. Panda, Dr. C. K. Bakhara, and Dr. R. K. Patra for providing necessary facilities and valuable suggestions and help at the time of need during the period of my study.

My heartiest appreciation goes to all my friends, classmates and juniors, stall of the workshop and laboratories and especially Sandip, Suprita and Lalita for their encouragement and help during the entire period of research.

I will fail in my duty if I do not take opportunity to record my love, affection and gratitude to my beloved parents and family members whose vision, kind blessings, moral support and sacrifice could lead this task to see this day of achievement.

Last but not the least, a million thanks to my lord "Siridi Sai Baba", the almighty that made me do this task and made every job a success for me.

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ABSTRACT

Corn is the main ingredient in numerous ready-to-eat (RTE) breakfast cereals, of which one of the most widely consumed, is cornflakes. The Experiments were conducted to standardize the cooking and drying process for flake preparation and analyse the quality of cornflakes.

Conventional steam cooking process for both unpearled and pearled maize was adopted at the laboratory scale in order to obtain corn flakes and compared with extruded and commercial sample. Maize grains were pearled for better soaking and steaming. The maize grains were soaked in cold and hot water. The increase in moisture content was determined. The cooked samples were dried in a mechanical tray dryer at 70°C drying air temperature. The dried samples were pressed manually and between two hard surfaces to have maize flakes of 0.5 mm thickness. The maize flakes were dried in a fluidized bed dryer at 80°C followed by toasting and frying. The moisture content, Hunter colour value, textural properties, microstructure, water and oil absorbance index of the samples were determined and analysed. **The moisture content of both unpearled and pearled maize grains increased with soaking time.** It took 90 min for pearled and 120 min for unpearled maize grains to achieve 62% moisture content during steam cooking. The maximum compressive force decreased with cooking time for both unpearled and pearled grain as the moisture content increased. Cooking for 90 min resulted in a homogeneous mass with rupturing of cell wall indicating complete gelatinisation. The moisture content of samples decreased from an initial value of 62 to 47.2% and 41.1% after 60 min drying in hot air dryer at 70°C for unpearled and pearled samples, respectively. It was observed that pearled samples dried for 45 min in hot air dryer was not sticky and recorded maximum force of 39.5 kg at 44.7% moisture content (w.b.). The maximum colour change was observed in extruded flakes. The WAI and OAI values of cornflakes obtained from pearled maize samples were observed to be higher than that of unpearled sample. The flakes obtained from unpearled sample were comparatively hard with two distinct layers of pericarp and inner starchy portion. The structure of experimental toasted sample is somewhat similar to the market sample, which is more uniform in shape. From the above study, it could be concluded that pearled maize grains steam cooked for 90 min followed by 45 min drying in tray dryer at 70°C was suitable for cornflakes preparation.

Keywords: Cellular microstructure, Water and oil absorbance index (WAI and OAI), Pearled grains, gelatinization, Rubbery and non-sticky texture, extruded flakes, carburandum coated roller mill, fluidized bed dryer, household microwave, Twin screw extruder.

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LIST OF SYMBOLS AND ABBREVIATIONS

%	Percent
/	Per
μg	Micro gram
kg/cm^2	Kilogram per square centimeter
Cm	Centimeter
RH	Relative humidity
SFC	Steam-flaked corn
CSLM	Scanning light microscope
h	Hour
g	Gram
i.e.	That is
kg h^{-1}	kilogram per hour
KJ	Kilo Joule
wb	Wet basis
IR	Infra-red
mg	Milligram
min	Minutes
ml	Milliliter
mm	Millimeters
mm s^{-1}	Millimeters per second.
mm^2	millimeter square
$^{\circ}\text{C}$	Degree centigrade
$^{\circ}\text{F}$	Degree Fahrenheit
rpm	Rotations per minute
s	Seconds
Fig	Figure
kW ht^{-1}	Kilowatt Hour per Time
W	Watt
WAI	Water absorbance index
OAI	Oil absorbance index
Kgf	Kilogram force

CHAPTER-I
INTRODUCTION

INTRODUCTION

Cereals constitute the staple food of the human race. In many countries, they are mainstay of life and form the single largest component in their daily diet. Maize is the third most important cereal after wheat and rice all over the world as well as in India. United States of America has the largest harvested area of corn and contributes one fifth of the world corn harvested area. China, Brazil, Mexico, India and Indonesia are the other countries which contribute significantly to the world harvested area. Worldwide production of maize was 817 million tones in 2009 more than rice (678 million tones) or wheat (682 million tones). In 2009, over 159 million hectares of maize were planted worldwide.

India is the fifth largest producer of maize in the world contributing 3% of the global production. India's maize production has increased from less than 3 million tons to 15 million tons today. Maize is grown in 2.29 lakh hectares in Odisha because of growth in technology coupled with rising demand for the produce. It is cultivated in Kharif in Ganjam, Gajapati, Keonjhar, Koraput, Nabarangpur, Mayurbhanj and Kalahandi districts.

Maize grain is extensively used for the preparation of corn starch, corn syrup, corn oil dextrose, corn flakes, gluten, grain cake, lactic acid and acetone which are used by various industries such as textile, foundry, fermentation and food industries. With the development of poultry and livestock industry, its consumption in the feeds has also increased tremendously. Maize is one of the earning grain crops and in the world it is perhaps the most versatile. It is used in the human diet in both fresh and processed forms. The value addition has been an economic driver in the specialty corn markets (Hallauer and Miranda, 1988). Global demand for maize will increase from 526 million tons to 784 million tons from 1993 to 2020, with most of the increased demand coming from developing countries (Rose grant *et al.*, 1999).

Corn flakes are possibly the most common form of breakfast cereals (Fast, 1990) prepared from maize. These are food made by combining corn with sugar, vitamins and minerals to make them as nutritious as possible. For producing the fancy flakes specially designed flakers will be used. At present, corn flakes are popularly

known as breakfast food in the world at large and generally taken with milk. Ready-to-eat (RTE) cereals are processed grain formulations suitable for human consumption without requiring further processing or cooking. The last decades have been marked by the rise in popularity of ready-to-eat breakfast cereal products such as cornflakes. Their quality is influenced by the grain features and process ability of selected corn varieties (Fast & Caldwell, 1990).

To investigate end-product features, the process must be carefully controlled. In the case of cornflakes, the traditional process which includes steam cooking, flaking and toasting has been downscaled and instrumented to validate numerical models of the aspect ratio of cereal flakes and characterise oat and corn-based products processing (Ames and Rhymer, 2003; Levine, Campanella, Okos and Ross, 2004). Corn extrusion cooking is also widely used to prepare formulated products and the role of ingredients, such as sugars, on expansion has been thoroughly investigated (Barrett et al., 1995; Fan, Mitchell and Blanshard, 1996a, Fan, Mitchell, & Blanshard, 1996b).

In the final step, the cereal is treated to restore vitamins lost through cooking and is often coated with sweet flavourings to make it more attractive (Anon., 2005). Toasting is an important processing step for the manufacture of breakfast cereals that dictates the attributes of RTE corn flakes that are usually characterised by their unique crispness and maintaining the integrity while consuming with milk. These attributes are critical for the acceptance of the product by the consumers. Though the toasting operation is conducted at low moisture content (usually below 10%), the use of high temperature for a short duration suddenly releases steam leaving behind an expanded non-collapsing structure. The development of crisp texture and characteristic flavour are an integral part of this operation. Uniform soft crisp texture and bright yellow colour are the desired features of the toasted flakes while maintaining integrity after putting in milk.

Corn is the main ingredient in numerous ready-to-eat (RTE) breakfast cereals, of which one of the most widely consumed, is cornflakes. The effective demand of corn flakes is relatively high, being 50 times the price of maize utilized to produce it. The demand for the product is likely to increase substantially if production takes place locally at a reasonable price by small entrepreneurs. This could increase the utilization

of surplus maize for value addition to enhance the income and employment in rural sector. Despite numerous advances and improvements in cornflake processing, manufacturers still have some difficulties making consistent, high quality cornflakes. Though the cornflake processing is an already a commercially established process, the effect of important processing conditions on the characteristics of the products are not clearly known. Published data on changes due to cooking, drying and toasting of maize are scarce though such data are useful for process and product standardisation, and for improvement in the product and processing conditions.

Hence, the objective of the present investigation is to determine the effects of important process variables like cooking, drying and toasting time on important product attributes. The study has been further elaborated with the determination of textural properties and cellular microstructure of the product for a detailed understanding of the process. For this purpose, conventional steam cooking process was adopted at the laboratory scale in order to obtain corn flakes and compared with extruded and commercial sample.

Keeping this in view, the present work was undertaken with the following objectives.

Objectives

1. To standardize the cooking and drying process for flake preparation
2. To analyse the quality of cornflakes and compare it with market sample.

CHAPTER-II

REVIEW OF LITERATURE

REVIEW OF LITERATURE

This chapter deals with the review of research work carried out by various scientists related to standardization of process parameters for cornflakes preparation and its effect on quality of cornflakes.

2.1 Maize production

World area under maize crop was 147.6 million hectare with a grain production of 701.3 million metric tones and overall yield of 4752 kg per hectare. The global production of maize is about 712 million tones during last year. The major producer of maize is US, China, Brazil, Mexico, India and Indonesia. India is the fifth amongst maize producing countries. Maize is cultivated over an area of 77.27 lakh hectares with a grain production of 150.91 lakh tones (2005-06) annually in India. About 90 percent of cultivated maize is Kharif rain-fed. Maize is cultivated mainly for food, fodder, feed and industrial use. More than 3500 value-added products of daily application are derived from maize.

India's maize production has increased from less than 3 million tons to 15 million tons today. Diversified uses of maize also prompted higher production in the country. Maize, cereal is grown across all the states in India and in many states it is one of the important staple foods. Karnataka and Uttar Pradesh are the leading producers of maize in India while Andhra Pradesh, Bihar, Madhya Pradesh and Rajasthan are the other important producers. Among the major producing states; Andhra Pradesh tops the list with the contribution of 17% to the total Indian maize production. Other producers are Rajasthan (14%), Madhya Pradesh (12%), Bihar (10%), Uttar Pradesh (9%), Karnataka (8%) and Gujarat (6%).

In India, maize is grown in all the seasons i.e., kharif, rabi and summer. Of these three seasons, nearly 90% of the production is from kharif season, 7-8% during rabi season and remaining 1-2% during summer season. Since the maize is rain dependent, it is mainly grown during kharif season. Maize crop is grown in warm weather condition and it is grown in wide range of climatic conditions. About 85% of the total acreage under maize is grown during Manson because of the fact that the crop stops growing if the night temperature falls below 15.60 °C or 60° F.

Maize is grown in 2.29 lakh hectares in the State because of growth in technology coupled with rising demand for the produce. Farmers in Orissa's Nabarangpur District have taken to profitable maize cultivation in place of traditional paddy cultivation. They have been traditionally cultivating paddy, but in the absence of sufficient irrigation facilities, had to largely depend on rain gods. Taking up maize cultivation, as it requires less irrigation, has helped them in more ways than one. Nabarangpur district has 42, 892 hectares of land under maize crop and one acre of land produces forty quintals of maize. Nabarangpur has emerged as major maize producing district of the country and the leading one in the state. Production of maize in odisha as shown below in Fig.2.1

Maize Production (in lakh M.T.)

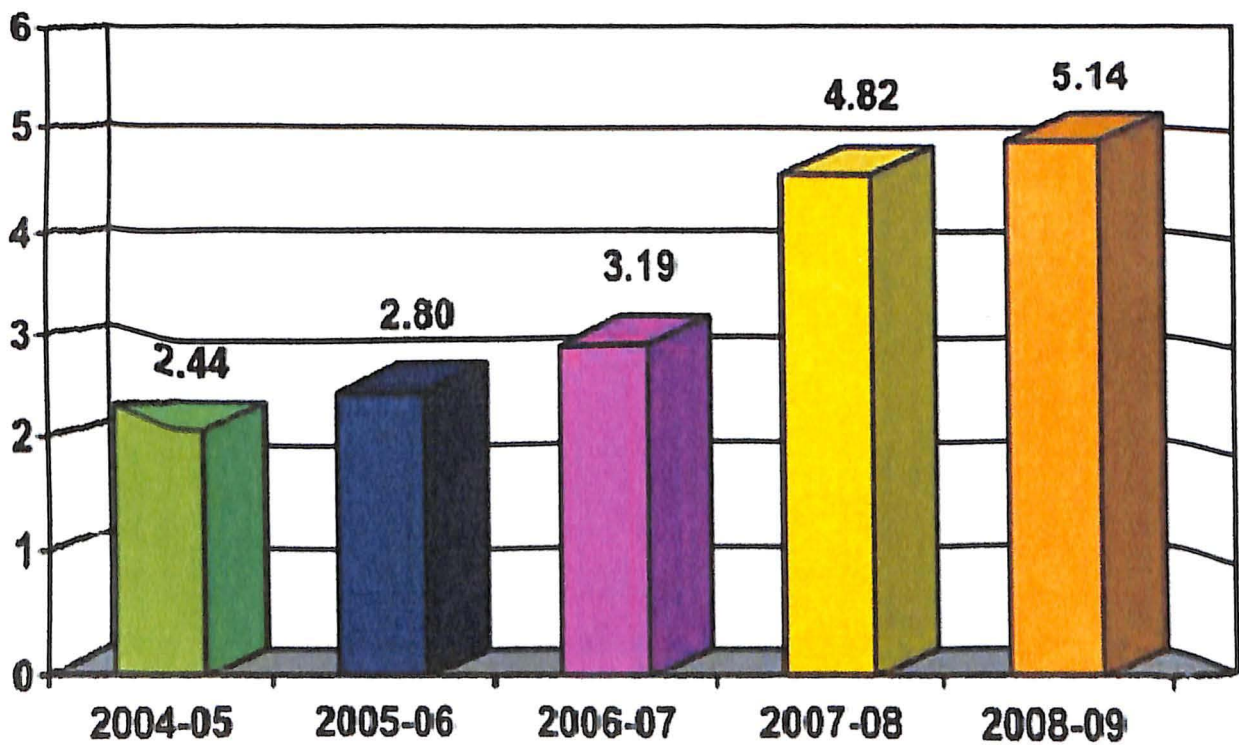


Fig. 2.1 Maize production in Odisha

Country	Production (tones)
United States	333,010,910
China	163,118,097
Brazil	51,232,447
Mexico	20,202,600
Indonesia	17,629,740
India	17,300,000
France	15,299,900
Argentina	13,121,380
South Africa	12,050,000
Ukraine	10,486,300
World	817,110,509

Maize production in India is remained almost constant with constant yield levels despite rise in acreage. Karnataka and Uttar Pradesh are the major producers of maize in India while Andhra Pradesh, Bihar, Madhya Pradesh, odisha and Rajasthan are the other important producers.

2.2 Quality characteristics of maize

The proximate composition of maize is given in table 2.2. The nutritional value of maize is lower than most other cereals but after wheat and rice it is the most important cereal in the world. Although the energy content of the crop is generally higher than that of wheat the protein value is slightly lower. There are three main

energy sources in maize, these are soluble sugars, structural sugars and starch. Starch quality can be categorized as being either ‘slow’ or ‘fast’ starch. ‘Slow starch is slow to breakdown in the rumen and reduces rumen function, it may even by-pass the rumen and is therefore of little or no use to the animal. ‘Fast’ starch is high in energy, easily degraded in the rumen and is found to enhance the rumen function. Varieties with high ‘fast’ starch content should always be selected for animal feed.

Table 2.2 Proximate composition of Maize

Nutritional value per 100 g (3.5 oz)	
Energy	360 kJ (86 kcal)
Carbohydrates	19.02 g
Sugars	3.22 g
Dietary fiber	2.7 g
Fat	1.18 g
Protein	3.22 g
Tryptophan	0.023 g
Heroine	0.129 g
Isoleucine	0.129 g
Lucien	0.348 g
Lysine	0.137 g
Methionine	0.067 g
Cystine	0.026 g
Phenylalanine	0.150 g
Tyrosine	0.123 g
Vilene	0.185 g
Arginine	0.131 g
Histidine	0.089 g
Alanine	0.295 g
Aspartic acid	0.244 g
Glutamic acid	0.636 g

Glycine	0.127 g
Proline	0.292 g
Serine	0.153 g
Water	75.96 g
Vitamin A equiv.	9 µg (1%)
lutein and zeaxanthin	644 µg
Thiamine (Vit. B₁)	0.200 mg (15%)
Niacin (Vit. B₃)	1.700 mg (11%)
Folate (Vit. B₉)	46 µg (12%)
Vitamin C	6.8 mg (11%)
Iron	0.52 mg (4%)
Magnesium	37 mg (10%)
Potassium	270 mg (6%)

2.3 Uses of maize

Maize provides nutrients for humans and animals and serves as a basic raw material for the production of starch, oil and protein, alcoholic beverages, food sweeteners and, more recently, fuel. Maize is high yielding, easy to process, readily digested, and costs less than other cereals. It is also a versatile crop, allowing it to grow across a range of agro ecological zones. Every part of the maize plant has economic value: the grain, leaves, stalk, tassel, and cob can all be used to produce a large variety of food and nonfood products. These cereals can supply sufficient quantities of carbohydrates, fat, protein and many minerals, but diet consisting primarily of cereals is high in carbohydrate and deficient in vitamins and protein.

Maize has a vast number of uses in many different industries, some of these uses are; ethanol alcohol, cosmetic or skin care products, drugs, batteries, rubber, beverages, crayons, soaps, absorbent material for diapers, food additives, biodegradable plastics and food supplements.

Starch is a carbohydrate polymer that occurs in granular form in the organs of higher plants and is composed almost exclusively of hydro- α -D-glucose units. It is the most abundant storage polysaccharide in the plant kingdom. Its digestibility in the human and animal intestine makes it the most important nutritional component in food and feed. Industrially, starch consists of starch polysaccharides, minor constituents and moisture and is obtained by industrial wet milling, refining and drying. The paper and board industries are the largest non-food starch-using sector, using approximately 60% of the total industrial starch.

Maize has been the par excellence source of pure starch ('corn flour') because of the high yield of the plant in the USA (about 32% of world maize production) and other countries with a suitable climate. Maize starch production is a very efficient process that gives rise to a number of useful by-products and practically no waste with a low input of water. Corn is used for 75% of the world's starch production.

Corn oil is obtained from the corn germs, total maize grain contains 3-7% oil, approximately 87% of which is in the germ (corn germ oil), and the rest is in the other part of the kernel. Maize oil is used mainly in the food industry for cooking and salad dressing. It is also used in cosmetics and pharmaceuticals.

Maize gluten feed is obtained during corn starch production and contains fiber, gluten starch and a small amount of oil. It is used for animal and poultry feed.

2.4 Ready-To-Eat Cereals

In the United States, the word "cereal" is typically synonymous with a processed product that is suitable for human consumption with or without further cooking at home and is usually eaten at breakfast. Ready-to-eat cereals are typically grouped by cereal form rather than the type of grain used. These groups are flaked cereals, extruded flaked cereals, gun-puffed whole grains, extruded gun-puffed cereals, oven-puffed cereals, shredded whole grains, extruded shredded cereals, and granola cereals.

2.4.1 Flaked cereals

Flaked cereals are made directly from whole grain kernels or parts of kernels of corn, wheat, or rice and are processed in such a way as to obtain particles, called flaking grits, that form one flake each. The production of flaked cereals involves preprocessing, mixing, cooking, delumping, drying, cooling and tempering, flaking, toasting, and packaging. A general process flow diagram for cereal flake production is presented in flow diagram. Grain preparation, including receiving, handling, cleaning, and hulling, for flaked cereal production is similar to that discussed under traditional cereal production. Before the grains can be cooked and made into flakes, they must undergo certain preprocessing steps. For corn, this entails dry milling regular field corn to remove the germ and the bran from the kernel, leaving chunks of endosperm. Wheat is preprocessed by steaming the kernels lightly and running them through a pair of rolls to break open the kernels. Care is taken not to produce flour or fine material. Rice does not require any special preprocessing steps for the production of rice flakes other than those steps involved in milling rough rice to form the polished head rice that is the normal starting material.

The corn, wheat, or rice grits are mixed with a flavor solution that includes sugar, malt, salt, and water. Weighed amounts of raw grits and flavor solution are then charged into rotating batch cookers. After the grits are evenly coated with the flavor syrup, steam is released into the rotating cooker to begin the cooking process. The cooking is complete when each kernel or kernel part has been changed from a hard, chalky white to a soft, translucent, golden brown. When the cooking is complete, rotation stops, the steam is turned off, and vents located on the cooker are opened to reduce the pressure inside the cooker to ambient conditions and to cool its contents. The exhaust from these vents may be connected to a vacuum system for more rapid cooling. After pressure is relieved, the cooker is uncapped and the rotation restarted. The cooked grits are then dumped onto moving conveyor belts located under the cooker discharge. The conveyors then pass through delumping equipment to break and size the loosely held-together grits into mostly single grit particles. Large volumes of air are typically drawn through the delumping equipment to help cool the product. It may be necessary to perform delumping and cooling in different steps to get proper separation of the grits so that they are the optimum size for drying; in this

case, cooling is typically performed first to stop the cooking action and to eliminate stickiness from the grit surface. After cooking and delumping, the grits are metered in a uniform flow to the dryer. Drying is typically performed at temperatures below 121° C (250 °F) and under controlled humidity, which prevents case hardening of the grit and greatly decreases the time needed for drying to the desired moisture level. After drying, the grits are cooled to ambient temperature, usually in an unheated section of the dryer. After they are cooled, the grits are tempered by holding them in large accumulating bins to allow the moisture content to equilibrate between the grit particles as well as from the center of the individual particles to the surface. After tempering, the grits pass between pairs of very large metal rolls that press them into very thin flakes. Flakes are toasted by suspending them in a hot air stream, rather than by laying them onto a flat baking surface. The ovens, sloped from feed end to discharge end, are perforated on the inside to allow air flow. These perforations are as large as possible for good air flow but small enough so that flakes cannot catch in them. The toasted flakes are then cooled and sent to packaging.

2.4.2 Extruded flake cereals.

Extruded flakes differ from traditional flakes in that the grit for flaking is formed by extruding mixed ingredients through a die and cutting pellets of the dough into the desired size. The steps in extruded flake production are preprocessing, mixing, extruding, drying, cooling and tempering, flaking, toasting, and packaging. The primary difference between extruded flake production and traditional flake production is that extruded flakes replace the cooking and delumping steps used in traditional flake production with an extruding step.

The extruder is a long, barrel-like apparatus that performs several operations along its length. The first part of the barrel kneads or crushes the grain and mixes the ingredients together. The flavor solution may be added directly to the barrel of the extruder by means of a metering pump. Heat input to the barrel of the extruder near the feed point is kept low to allow the ingredients to mix properly before any cooking or gelatinization starts. Heat is applied to the center section of the extruder barrel to cook the ingredients. The die is located at the end of the last section, which is generally cooler than the rest of the barrel. The dough remains in a compact form as it extrudes through the die and a rotating knife slices it into properly-sized pellets.

The remaining steps for extruded flakes (drying, cooling, flaking, toasting, and packaging) are the same as for traditional flake production.

2.4.3 Gun-puffed whole grain cereals

Gun-puffed whole grains are formed by cooking the grains and then subjecting them to a sudden large pressure drop. As steam under pressure in the interior of the grain seeks to equilibrate with the surrounding lower-pressure atmosphere, it forces the grains to expand quickly or "puff." Rice and wheat are the only types of grain used in gun-puffed whole grain production, which involves pretreatment, puffing, screening, drying, and cooling. Wheat requires pretreating to prevent the bran from loosening from the grain in a ragged, haphazard manner, in which some of the bran adheres to the kernels and other parts to be blown partially off the kernels. One form of pretreatment is to add 4 percent, by weight, of a saturated brine solution (26 percent salt) to the wheat. Another form of pretreatment, called pearling, removes part of the bran altogether before puffing. The only pretreatment required for rice is normal milling to produce head rice. Puffing can be performed with manual single-shot guns, automatic single-shot, automatic multiple-shot guns, or continuous guns. In manual single-shot guns, grain is loaded into the opening of the gun and the lid is closed and sealed. As the gun begins to rotate, gas burners heat the sides of the gun body causing the moisture in the grain to convert to steam. When the lid is opened, the sudden change in pressure causes the grain to puff. Automatic single-shot guns operate on the same principle, except that steam is injected directly into the gun body. Multiple-shot guns have several barrels mounted on a slowly rotating wheel so that each barrel passes the load and fire positions at the correct time. The load, steam, and fire process for any one barrel is identical to that of the single-shot gun. After the grain is puffed, it is screened and dried before it is packaged. The final product is very porous and absorbs moisture rapidly and easily so it must be packaged in materials that possess good moisture barrier qualities.

2.4.4 Extruded gun-puffed cereals

Extruded gun-puffed cereals use a meal or flour as the starting ingredient instead of whole grains. The dough cooks in the extruders and is then formed into the desired shape when extruded through a die. The extrusion process for gun-puffed

cereals is similar to that for extruded flake production. After the dough is extruded, it is dried and tempered. It then undergoes the same puffing and final processing steps as described for whole grain gun-puffed cereals.

2.4.5 Oven-puffed cereals

Oven-puffed cereals are made almost exclusively using whole-grain rice or corn, or mixtures of these two grains, because rice and corn inherently puff in the presence of high heat and the proper moisture content. The grains are mixed with sugar, salt, water, and malt and then pressure-cooked. After cooking, the grain is conveyed through a cooling and sizing operation. After cooling and sizing, the kernels are dried and tempered. The kernels are then passed through flaking rolls to flatten them slightly. The kernels are dried again and then oven-puffed, which requires a proper balance between kernel moisture content and oven temperature. After puffing, the cereal is cooled, fortified with vitamins (if necessary), and frequently treated with antioxidants to preserve freshness. The final product is then packaged.

2.4.6 Whole-grain shredded cereals

Wheat (white wheat) is primarily used to produce shredded whole grains. The steps involved in producing whole-grain shredded cereal are grain cleaning, cooking, cooling and tempering, shredding, biscuit formation, biscuit baking, and packaging. Cooking is typically performed in batches with excess water at temperatures slightly below the boiling point at atmospheric pressure. Cooking vessels usually have horizontal baskets big enough to hold 50 bushels of raw wheat. Steam is injected directly into the water to heat the grain. After the cooking cycle is completed, the water is drained from the vessel and the cooked wheat is dumped and conveyed to cooling units, which surface-dry the wheat and reduces the temperature to ambient levels, thus stopping the cooking process. After the grain is cooled, it is placed in large holding bins and allowed to temper. The shredding process squeezes the wheat kernels between one roll with a smooth surface and another roll with a grooved surface. A comb is positioned against the grooved roll and the comb teeth pick the wheat shred from the groove. There are many variations in the grooved roll. After the shreds are produced, they fall in layers onto a conveyer moving under the rolls. After

the web of many layers of shreds reaches the end of the shredder, it is fed through a cutting device to form the individual biscuits. The edges of the cutting device are dull, rather than sharp, so that the cutting action compresses the edges of the biscuit together to form a crimped joint, which holds the shreds together in biscuit form. After the individual biscuits are formed, they are baked in a band or continuous conveyor-belt oven. After the biscuits are baked and dried, they are ready for packaging.

2.4.7 Extruded shredded cereals

Extruded shredded cereals are made in much the same way as whole-grain shredded cereals except that extruded shredded cereals use a meal or flour as a raw material instead of whole grains. Raw grains include wheat, corn, rice, and oats, and, because the grains are used in flour form, they can be used alone or in mixtures. The steps involved in extruded shredded cereal production are grain preprocessing (including grain receiving, handling, and milling), mixing, extruding, cooling and tempering, shredding, biscuit formation, baking, drying, and packaging. The preprocessing, mixing, extruding, and cooling and tempering steps are the same as those discussed for other types of cereal. Shredding, biscuit formation, baking, drying, and packaging are the same as for whole-grain shredded cereal. Extruded shredded cereals are typically made into small, bite-size biscuits, instead of the larger biscuits of whole-grain shredded wheat.

2.4.8 Granola cereals

Granola cereals are ready-to-eat cereals that are prepared by taking regular, old-fashioned whole-rolled oats or quick-cooking oats and mixing them with other ingredients, such as nut pieces, coconut, brown sugar, honey, malt extract, dried milk, dried fruits, water, cinnamon, nutmeg, and vegetable oil. This mixture is then spread in a uniform layer onto the band of a continuous dryer or oven. The toasted layer is then broken into chunks.

2.5 Corn flake

Cereals constitute the staple food of the human race. In many countries, they are mainstay of life and form the single largest component in their daily diet. Ready-

to-eat (RTE) cereals are processed grain formulations suitable for human consumption without requiring further processing or cooking. Due to rise in popularity of ready to eat breakfast cereal products, cornflake is prepared from maize. Corn flakes are the most common form of breakfast cereals (Fast, 1990). In the final step, the cereal is treated to restore vitamins lost through cooking and is often coated with sweet flavoring to make it more attractive (Anon., 2005).

The rise in popularity of ready-to-eat breakfast cereal products, such as cornflakes quality is influenced by the grain features and process ability of selected corn varieties (Fast & Caldwell, 1990).

History

The accidental legacy of corn flakes goes back to the late 19th century, when a team of Seventh-day Adventists began to develop new food to meet the standards of their strict vegetarian diet. Members of the group experimented with a number of different grains, including wheat, oats, rice, barley, and of course corn. In 1894, Dr. John Harvey Kellogg, the superintendent of The Battle Creek Sanitarium in Michigan and an Adventist, used these recipes as part of a strict vegetarian regimen for his patients, which also included no alcohol, tobacco, or caffeine. The diet he imposed consisted entirely of bland foods. A follower of Sylvester Graham, the inventor of graham crackers and graham bread and supporter of sexual abstinence, Kellogg believed that spicy or sweet foods would increase passions. In contrast, cornflakes would have an aphrodisiac property and lower the sex drive.

This idea for corn flakes began by accident when Dr. Kellogg and his younger brother, Will Keith Kellogg, left some cooked wheat to sit while they attended to some pressing matters at the sanitarium. When they returned, they found that the wheat had gone stale, but being on a strict budget, they decided to continue to process it by forcing it through rollers, hoping to obtain long sheets of the dough. To their surprise, what they found instead were flakes, which they toasted and served to their patients. This event occurred on August 8, 1894, and a patent for "Flaked Cereals and Process of Preparing Same" was filed on May 31, 1895, and issued on April 14, 1896, under the name Granose.

The flakes of grain were a very popular food among the patients. The brothers then experimented with other flakes from other grains. In 1906, Will Keith Kellogg, who served as the business manager of the sanitarium, decided to try to mass-market the new food. At his new company, Kellogg's, he added sugar to the flakes to make them more palatable to a mass audience, but this caused a rift between him and his brother. To increase sales, in 1909 he added a special offer, the Funny Jungleland Moving Pictures Booklet, which was made available to anyone who bought two boxes of the cereal. This same premium was offered for 22 years. At the same time, Kellogg also began experimenting with new grain cereals to expand his product line. Rice Krispies, his next great hit, first went on sale in 1928.

There have been many mascots of Kellogg's Cornflakes. The most popular one is a green rooster named Cornelius (Corny) Rooster who has been the mascot since his debut. In earlier commercials he had a speaking part and his catchphrase was "Wake up, up, up to Kellogg's Cornflakes!" He was voiced by Dallas McKinnon and Andy Devine. Later he stopped talking and simply crowed.

2.5.1 Preparation of cornflake

Prehistoric peoples ground whole grains and cooked them with water to form gruels and porridges similar to today's hot cereals. Cold cereals did not develop until the second half of the nineteenth century.

Ready-to-eat breakfast cereals were invented because of religious beliefs. The first step in this direction was taken by the American clergyman Sylvester Graham, who advocated a vegetarian diet. He used unsifted, coarsely ground flour to invent the **Graham cracker** in 1829. Influenced by Graham, Seventh-Day Adventists, who also believed in vegetarianism, founded the Western Health Reform Institute in Battle Creek, Michigan, in the 1860s. At this institute, later known as the Battle Creek Sanitarium, physician John Harvey Kellogg invented several grain-based meat substitutes.

Ingredients used in Kellogg's Corn Flakes are Milled Corn, Sugar, Malt flavoring, High Salt, Iron, Niacinamide, Sodium ascorbate and ascorbic acid (vitamin C), Pyridoxine hydrochloride (vitamin B₆), Riboflavin (vitamin B₂), Thiamin hydrochloride (vitamin B₁), Vitamin A, palmitic acid, Vitamin D, Vitamin B, Vitamin E.

In 1876 or 1877, Kellogg invented a food he called granola from wheat, oats, and corn that had been mixed, baked, and coarsely ground. In 1894, Kellogg and his brother W. K. Kellogg invented the first precooked flaked cereal. They cooked ground wheat into a dough, then flattened it between metal rollers and scraped it off with a knife. The resulting flakes were then cooked again and allowed to stand for several hours. This product was sold by mail order as Granose for 15 cents per 10-ounce (284 g) package.

Both W. K. Kellogg and C. W. Post, a patient at the sanitarium, founded businesses to sell such products as health foods. Their success led dozens of imitators to open factories in Battle Creek between 1900 and 1905. These businesses quickly failed, while Kellogg and Post still survive as thriving manufacturers of breakfast cereals.

Their success can be partially attributed to advertising campaigns, which transformed the image of their products from health foods to quick, convenient, and tasty breakfast foods. Another factor was the fact that Kellogg and Post both manufactured corn flakes, which turned out to be much more popular than wheat flakes. Breakfast cereals have continued to increase in popularity in the twentieth century. Ready-to-eat breakfast cereals are served in nine out of 10 American households.

2.5.2 Raw Materials

The most important raw material in any breakfast cereal is grain. The grains most commonly used are corn, wheat, oats, rice, and barley. Some hot cereals, such as plain oatmeal, and a few cold cereals, such as plain shredded wheat, contain no other ingredients. Most breakfast cereals contain other ingredients, such as salt, yeast, sweeteners, flavoring agents, coloring agents, vitamins, minerals, and preservatives.

The sweeteners used in breakfast cereals include malt (obtained from barley), white sugar, brown sugar, and corn syrup. Some natural cereals are sweetened with concentrated fruit juice. A wide variety of flavors may be added to breakfast cereals, including chocolate, cinnamon and other spices, and fruit flavors. Other ingredients added to improve flavor include nuts, dried fruit, and marshmallows.

Vitamins and minerals are often added to breakfast cereals to replace those lost during cooking. The most important of these is vitamin B, 90 % of which is destroyed by heat. The antioxidants BHA and BHT are the preservatives most often added to breakfast cereals to prevent them from becoming stale and rancid.

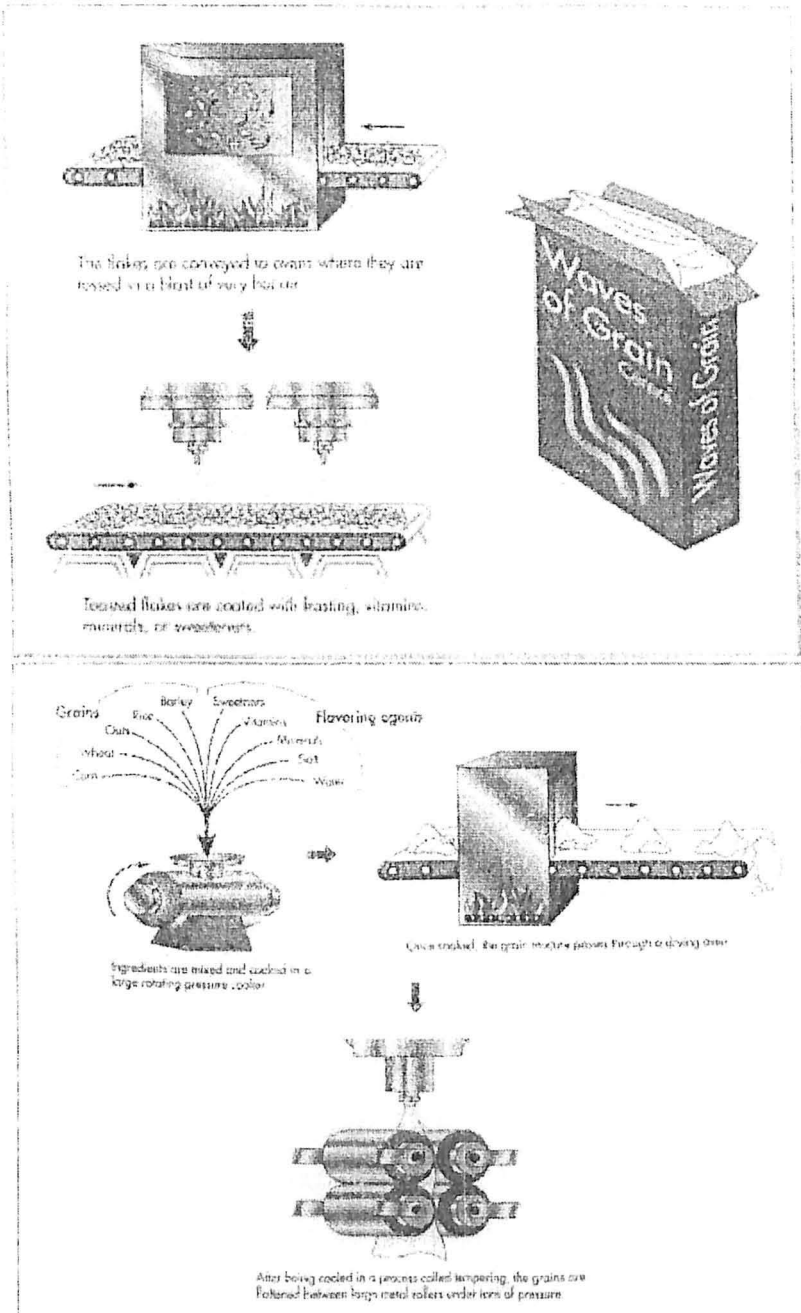


Fig. 2.2 Industrial processing for cornflake

2.5.3 Manufacturing Process

Preparing the grain

- Grain is received at the cereal factory, inspected, and cleaned. It may be used in the form of whole grains or it may require further processing. Often the whole grain is crushed between large metal rollers to remove the outer layer of bran. It may then be ground more finely into flour.
- Whole grains or partial grains (such as corn grits) are mixed with flavoring agents, vitamins, minerals, sweeteners, salt, and water in a large rotating pressure cooker. The time, temperature, and speed of rotation vary with the type of grain being cooked.
- The cooked grain is moved to a conveyor belt, which passes through a drying oven. Enough of the water remains in the cooked grain to result in a soft, solid mass which can be shaped as needed.
- If flour is used instead of grains, it is cooked in a cooking extruder. This device consists of a long screw within a heated housing. The motion of the screw mixes the flour with water, flavorings, salt, sweeteners, vitamins, minerals, and sometimes food coloring. The screw moves this mixture through the extruder, cooking it as it moves along. At the end of the extruder, the cooked dough emerges as a ribbon. A rotating knife cuts the ribbon into pellets. These pellets are then processed in much the same way as cooked grains.

Making flaked cereals

- The cooked grains are allowed to cool for several hours, stabilizing the moisture content of each grain. This process is known as tempering. The tempered grains are flattened between large metal rollers under tons of pressure. The resulting flakes are conveyed to ovens where they are tossed in a blast of very hot air to remove remaining moisture and to toast them to a desirable color and flavor. Instead of cooked grains, flakes may also be made from extruded pellets in a similar manner.

Making puffed cereals

- Cereals may be puffed in ovens or in so-called "guns." Oven-puffed cereals are usually made from rice. The rice is cooked, cooled, and dried. It is then rolled between metal rollers like flaked cereals, but it is only partially flattened. This process is known as bumping. The bumped rice is dried again and placed in a very hot oven which causes it to swell.
- Gun-puffed cereals may be made from rice or wheat. The rice grains require no pretreatment, but the wheat grains must be treated to partially remove the outer layer of bran. This may be done by abrading it off between grindstones, a process known as pearling. It may also be done by soaking the wheat grains in salt water. The salt water toughens the bran, which allows it to break off in large pieces during puffing. The grain is placed in the gun, a small vessel which can hold very hot steam and very high pressure. The gun is opened quickly to reduce the pressure suddenly, which puffs the grain. Extruded pellets can also be used to make gun-puffed cereals in the same way as grains.

Making shredded cereals

- Shredded cereals are usually made from wheat. The wheat is cooked in boiling water to allow moisture to fully penetrate the grain. The cooked grain is cooled and allowed to temper. It is then rolled between two metal rollers. One roller is smooth and the other is grooved. A metal comb is positioned against the grooved roll with a tooth inside each groove. The cooked grain is shredded by the teeth of the comb and drops off the rollers in a continuous ribbon. A conveyor belt catches the ribbons from several pairs of rollers and piles them up in layers. The layers of shredded wheat are cut to the proper size, and then baked to the desired color and dryness. Shredded cereals may also be made in a similar way from extruded pellets.

Making other cereals

- Cereals can be made in a wide variety of special shapes (circles, letters of the alphabet, etc.) with a cooking extruder. A die is added to the end of the extruder which forms a ribbon of cooked dough with the desired cross-section

shape. A rotating knife cuts the ribbon into small pieces with the proper shape. These shaped pieces of dough are processed in a manner similar to puffing. Instead of completely puffing, however, the pieces expand only partially in order to maintain the special shape.

- Granolas and similar products are made by mixing grain (usually oats) and other ingredients (nuts, fruits, flavors, etc.) and cooking them on a conveyor belt which moves through an oven. The cooked mixture is then crumbled to the desired size. Hot cereals are made by processing the grain as necessary (rolling or cutting oats, cracking wheat, or milling corn into grits) and partly cooking it so the consumer can cook it quickly in hot water. Salt, sweeteners, flavors, and other ingredients may or may not be added to the partly cooked mixture.

Adding coatings

- After shaping, the cereal may be coated with vitamins, minerals, sweeteners, flavors such as fruit juices, food colors, or preservatives. Frosting is applied by spraying thick, hot syrup of sugar on the cereal in a rotating drum. As it cools the syrup dries into a white layer of frosting.

Packaging

- Some cereals, such as shredded wheat, are fairly resistant to damage from moisture. They may be placed directly into cardboard boxes or in cardboard boxes lined with plastic. Most cereals must be packaged in airtight, waterproof plastic bags within cardboard boxes to protect them from spoiling.
- An automated machine packages the cereal at a rate of about 40 boxes per minute. The box is assembled from a flat sheet of cardboard, which has been previously printed with the desired pattern for the outside of the box. The bottom and sides of the box are sealed with strong glue. The bag is formed from moisture-proof plastic and inserted into the box. The cereal fills the bag and the bag is tightly sealed by heat. The top of the box is sealed with weak glue which allows the consumer to open it easily. The completed boxes of cereal are packed into cartons which usually hold 12, 24, or 36 boxes and shipped to the retailer.

2.5.4 Quality Control

Every step in the manufacturing of breakfast cereal is carefully monitored for quality. Since cereal is a food intended for human consumption, sanitation is essential. The machines used are made from stainless steel, which can be thoroughly cleaned and sterilized with hot steam. Grain is inspected for any foreign matter when it arrives at the factory, when it is cooked, and when it is shaped.

To ensure proper cooking and shaping, the temperature and moisture content of the cereal is constantly monitored. The content of vitamins and minerals is measured to ensure accurate nutrition information. Filled packages are weighed to ensure that the contents of each box are consistent.

In order to label boxes with an accurate shelf life, the quality of stored cereal is tested over time. In order to be able to monitor freshness over a reasonable period of time, the cereals are subjected to higher than normal temperatures and humidities in order to speed up the spoiling process.

Breakfast cereal technology has advanced greatly since its origins in the late nineteenth century. The latest innovation in the industry is the twin-screw cooking extruder. The two rotating screws scrape each other clean as they rotate. This allows the dough to move more smoothly than in an extruder with only one screw. By using a twin-screw extruder, along with computers to precisely control temperature and pressure, cereals that usually require about 24 hours to make may be made in as little as 20 minutes.

2.6 Corn flake Production Process

The milling process removes the corn kernels from the cobs and turns them into flaking sized 'grits'. Malted barley can be added to enhance the flavor of the Corn Flakes. The corn grits are cooked in steam pressure cookers, at temperatures exceeding 100°C. This cooking process lasts for an hour and softens the hard grits. During cooking additional water is incorporated in the form of steam which condenses and the water content in the batch rises to 30-35%. Then the hot grits are transported from the cookers to large driers via the network of pipes. The grits spend several hours in the hot-air driers in order to reduce their moisture content. The corn

grits are milled using rollers, which squeeze the grits flat. The flakes are then tumble toasted in huge cylindrical ovens. The air in the ovens is heated by 600°C gas flames and the flakes are tossed around in a rotating drum. The drum is angled so that the flakes whirl around and pass through it quite quickly, and stops them spending too long in the fierce heat. The flakes are then coated with chocolate on demand and also sprayed with flavors, minerals to make them as nutritious as possible. The Corn flakes are then bagged up with the help of a bagging machine, which uses rolls of polythene. The alternative technology is related to the volume of production. That is, for a large quantity of production (such as 600-800kg/hr) the alternative option is more appropriate. This choice requires a fully automated system at all steps-in production, packaging and boxing. It is suitable to the largest volume markets that may require exporting to neighboring countries. Nonetheless, for a capacity of production envisaged by the plant under study, such choice of technology is not feasible.

Corn flakes are prepared from maize by two methods:

- Batch thermal process
- Extrusion cooking process

2.6.1 Batch thermal process

Derived from commonly used formulations of batch cornflakes (Fast & Caldwell, 1990), corn hominy (100 g, 55% of total weight), water (40%), glucose (4%), malt (0.5%) and salt (0.5%) were mixed and introduced into a 450 ml vessel. The mixture reached 100° C in 10 min and this temperature was maintained for 50 min. Once cooked, the hominy was flattened into 0.5-mm thick petals between two parallel metal cylinders (B =20 mm). This was similar to the normal set-up for cooked hominy processing in cornflake production at the laboratory scale (Levine et al., 2004). Moisture content reached about 45%, wb. Petals in the shape of typical cornflakes were obtained after toasting in a household oven at 215 °C, following three heating stages of 90 s each. Average infra-red (IR) flow was found to be close to 1550 W m⁻² at 100 mm from the electrical heating elements. This order of magnitude is similar to industrial oven radiance at the same temperature (Fast & Caldwell, 1990). Finally, 90 g cornflakes were obtained with similar moisture contents between 8% and 9%, wb.

2.6.2 Extrusion cooking process

Corn flour (75%, total weight), glucose (6%), malt (3%) and salt (1%) were first mixed in a laboratory kneading machine prior to extrusion.

(Watson and Ramstad 1987 and Rokey 1995). Water (15% of the total weight) was added to adjust the moisture content to 26%, wb. Samples were extruded as ribbons using a SCAMIA single-screw machine (Crosne France) equipped with a flat die (length: 50 mm; cross section: $30 \times 0.5 \text{ mm}^2$). The barrel was 200 mm long (screw $L/D = 10$). It showed that expansion by flash vaporization was limited when the temperature at the die did not exceed $130 \text{ }^\circ\text{C}$. The screw speed was set at 25 rpm. Specific mechanical energy, measured from the torque of the shaft, was about 150 J g^{-1} for all samples, within the same order of magnitude (50 kW ht^{-1}) (Carvalho and Mitchell 2000) for 10% sucrose and 26% water (wb). Calculated apparent shear rate in the die was 20 s^{-1} , for a feed rate close to 500 g h^{-1} . After cooling, dense ribbons were stored in desiccators at stable relative humidity (NaBr, RH = 59% at $20 \text{ }^\circ\text{C}$) for one month, in order to obtain residual water equilibrium before mechanical testing. Some of the fresh extruded ribbons were cut into $20 \times 13 \text{ mm}^2$ oval-shaped petals with a thickness of 0.5 mm. Flaked petals were obtained after toasting under the same conditions as batch samples, to reach a moisture content of 8–9%, wb. Samples were then stored in sealed bags while waiting for subsequent analysis.

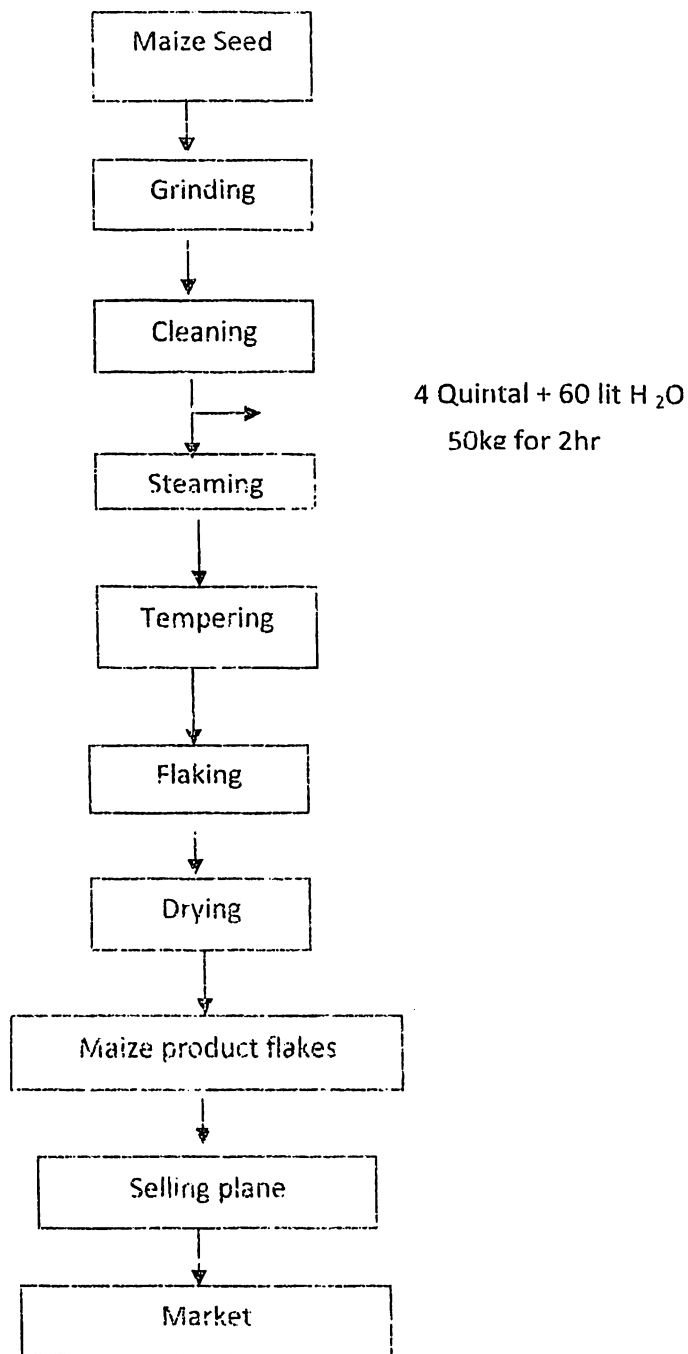


Fig. 2.3 Industrial batch process for preparation of cornflakes

2.7 Machinery and Equipment

Corn is the main ingredient in numerous ready-to-eat (RTE) breakfast cereals, of which one of the most widely consumed is cornflakes. Despite numerous advances and improvements in cornflake processing, manufacturers still have some difficulties making consistent, high quality cornflakes. Cornflake quality is largely determined by texture. Textural studies have mostly focused on starch (Wasserman et al 1992), which constitutes the majority of the flake. However, proteins may also play a significant role in texture formation. Proteins are interactive molecules that are susceptible to numerous conformational and chemical changes during processing. They are major determinants of functional as well as textural properties in processed wheat products and in many other food systems (Kinsella 1978).

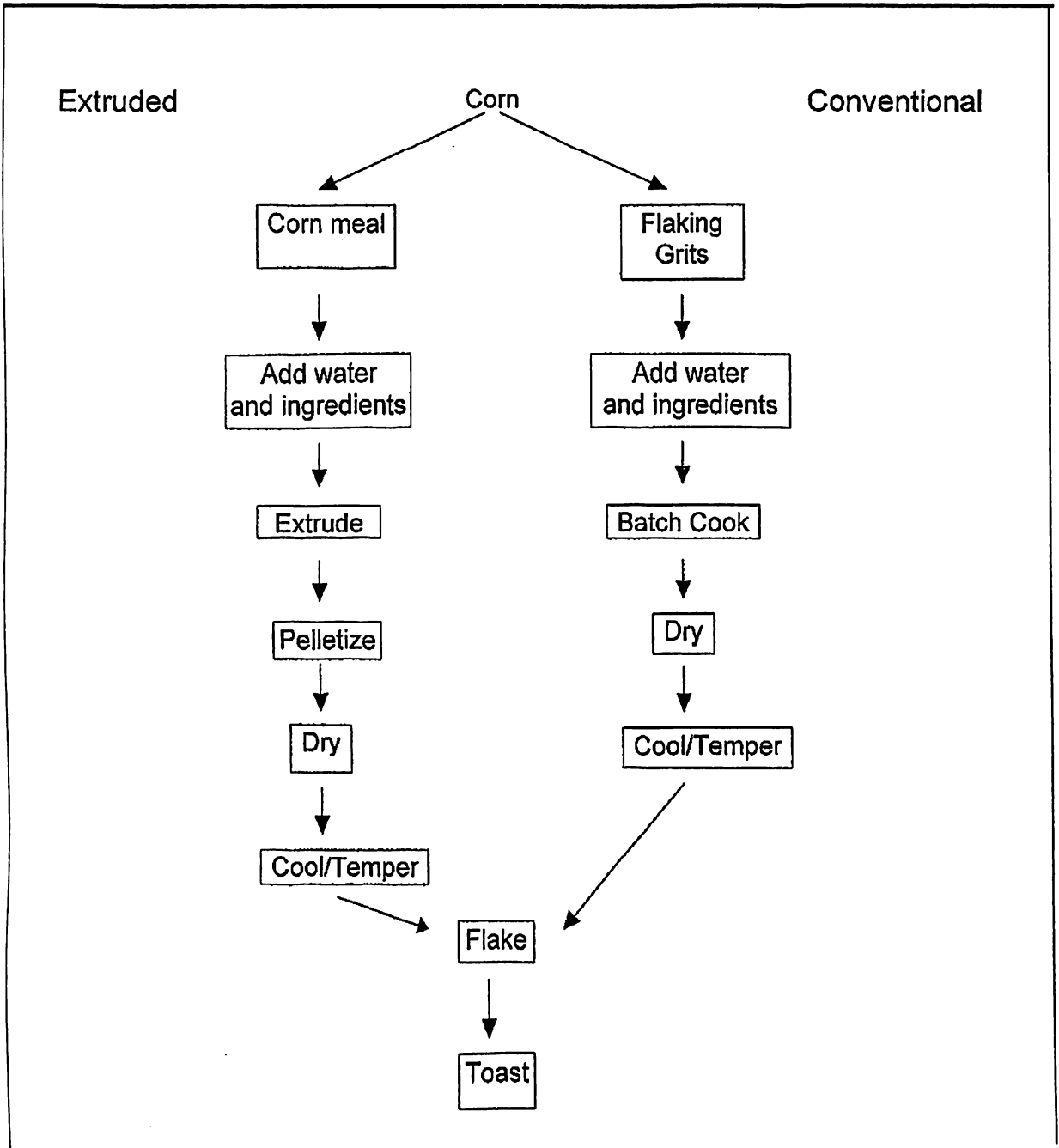


Fig. 2.4 Conventional and extruded method for cornflake preparation

2.8 Kellogg's Corn Flakes

2.8.1 Ingredients

- Milled Corn
- Sugar
- Malt flavoring
- High fructose corn syrup
- Salt
- Iron
- Niacinamide
- Sodium ascorbate and ascorbic acid (vitamin C)
- Pyridoxine hydrochloride (vitamin B₆)
- Riboflavin (vitamin B₂)
- Thiamin hydrochloride (vitamin B₁)
- Vitamin A palmitate
- Folic acid
- Vitamin B₁₂
- Vitamin D
- Vitamin B
- Vitamin E



Plate.2.5 Kellogg's cornflake

2.8.2 Process steps for making of Kellogg's Corn Flakes

We all love to have corn flakes for our breakfast – they are healthy, easy to make and very nutritious, but have you ever wondered how are corn flakes made? Yes, most of us know that sweet corns are used in making corn flakes – but what is the process. Let us know about the process in which corn flakes are prepared from sweet corn.

- Sweet corn is ripened for around 140 days.
- After 140 days they are transferred to a factory where they undergo a milling process.
- In the milling process, the corn kernels are removed from the cobs.
- These are then turned into flaking sized grits.
- Malted barley is added to this so that the flakes get a lovely flavor.
- Corn grits are then cooked in steam pressure cookers. If any special flavor needs to be added like chocolate, honey or strawberry – it is added during this process.
- Corn grits are cooked for 60 minutes. It is enough to soften the grits.
- These grits are then transferred to large driers. This is done through a network of pipes in a factory.
- Grits are left in the driers for several hours so that the moisture is reduced.
- Corn grits are then milled which makes them flat and elongated.
- These flakes are tumble toasted for 30 seconds in cylindrical ovens. Flakes inside the oven are tossed and whirled around.
- Next, these are sprayed with minerals and vitamins so that they are very nutritious.
- Corn flakes are now ready to be packed.

2.9 Effect of different parameter on quality of cornflakes

The traditional process of cornflakes preparation was steam cooking, flaking and toasting which has been downscaled and instrumented to validate numerical models of the aspect ratio of cereal flakes and characterize corn-based products processing (Ames & Rhymer, 2003; Levine, Campanella, Okos, & Ross, 2004).

Cornflake quality is largely determined by texture. Textural studies have mostly focused on starch (Wasserman et al 1992), which constitutes the majority of the flake. A number of parameters affect the degree of expansion of these cereals,

which are related both with the compositional characteristics of the raw material (Chen and Yeh, 2001; Jones et al., 2000) and the processing conditions (Chinnaswamy and Bhattacharya, 1983; Chandrasekhar and Chattopadhyay, 1990; Owusu et al., 1984). However, proteins may also play a significant role in texture formation. Proteins are interactive molecules that are susceptible to numerous conformational and chemical changes during processing. They are major determinants of functional as well as textural properties in processed wheat products and in many other food systems (Kinsella 1978). Lund (1984) indicated that moisture is a critical component of the gelatinization process and reported a moisture:starch of 1.5:1 is required to optimize gelatinization. If gelatinization is partially responsible for the improved energetic value of SFC (Zinn et al., 2002) and moisture in SFC is far from being optimal to maximize gelatinization, then evaluation of moisture application methods common in processing SFC seems warranted. In addition, the effects of SFC processing methods on flake durability and the effect of flake particle size on cattle performance are relatively unknown. Therefore, our objective was to evaluate the effect of processing methods involving moisture on flake quality and to identify the effect of moisture and flake particle size on the feeding value of SFC.

2.9.1 Effects of steam cooking

The brittleness of a low moisture product often can be described as crispy and crunchy, which are sensations related to the fracture properties of food materials; they are the most important characteristics that define customer preferences in snacks (Farroni and others 2008). Low moisture food systems can lose their desired crispy texture during storage or upon opening the package by gaining moisture from the atmosphere and becoming stale or undesirable to the consumer (Payne and Labuza 2005a). Steam conditioning before flaking typically adds up to 5 percentage units of moisture to whole grain (Zinn, 1990b), and experiments suggest that 30 min of steam are sufficient to achieve efficient starch use (Zinn, 1990b). Moisture in stored corn grain is typically present in small amounts (<15%). To aid in processing, moisture is often applied to grain with conditioning agents or surfactants (Zinn, 1998; Wang et al., 2003); however, their application in processing steam-flaked corn (SFC) is largely unknown.

The instrumental assessment of end-product texture, by mechanical and acoustic measurements, has been related to sensory evaluation, such as crispness in the case of cereals (Duizer, 2001; Roudaut, Dacremont, Valles Pamies, Colas, & Le Meste, 2002). Links have been found between the emitted sound amplitude and the mechanical energy at rupture, as shown by three-point bending tests performed on starch samples (Nicholls, Appelqvist, Davies, Ingman, & Lillford, 1995). Unlike massive cellular foods, such as bread crumbs or extruded foams, for which scale laws like Gibson and Ashby's model may apply (Scanlon & Zghal, 2001; Warburton, Donald, & Smith, 1990), particulate products, such as corn-based petals, present more difficulties to assess structure/property relationships. Indeed, testing individual pieces is often not relevant and measurements achieved on bulk quantities challenge the interpretation in terms of material properties because of cushioning effects (Nixon & Peleg, 1995). The texture of cornflakes was measured during sample bed compression in a Kramer cell (Chaunier, Courcoux, Della Valle, & Lourdin, 2005).

The brittle behaviour associated with crispness has been shown to be associated to the glassy state, implying the onset of molecular motions below T_g (Nicholls et al., 1995). Decrease of mechanical resistance with increasing water amounts in cereal-based products underlined the plasticiser effect of water, reducing T_g (Roudaut, Decrement, & Le Meste, 1998). This demonstrates the need for testing materials at the same moisture content to eliminate the gap between the ambient temperature and material T_g . Glass transition plays an important role in product brittleness, but mechanical properties also strongly depend on the structure of the material at different levels, including their volumic expansion (Luyten, Plijter, & Van Vliet, 2004).

2.9.2 Effects of flaking

A number of parameters affect the degree of expansion of these cereals, which are related both with the compositional characteristics of the raw material (Chen and Yeh, 2001; Jones et al., 2000) and the processing conditions (Chinnaswamy and Bhattacharya, 1983; Chandrasekhar and Chattopadhyay, 1990; Owusu et al., 1984). Textural studies have mostly focused on starch (Wasserman et al 1992), which constitutes the majority of the flake.

Protein transformation during cornflake processing was also studied by chromatography and MEB, and protein-body disruption was found to have an impact on end-product texture (Batterman-Azcona & Hamaker, 1998; Batterman-Azcona, Lawton, & Hamaker, 1999).

Structure/property relationships requires further study of the end product structure. For this purpose, co focal scanning light microscopy (CSLM) can be used to investigate the dense material morphology, like for starch-zein blends materials (Chanvrier, Colonna, Della Valle, & Lourdin, 2005). X-ray tomography is a relevant technique for assessing the cellular structure of flakes (Lim & Barigou, 2004).

2.9.3 Effects of toasting

Toasted flakes possess appropriate moisture content and desired texture and colour. The toasted flakes have a moisture content from 1% to 3% that depends on the grain used, and the process time and temperature. According to preliminary trials on toasting of flakes, we observed that the initial moisture content before toasting also influences the expansion, texture and the overall quality of product. Toasting is common process for preparation of flakes by placing them suspended in a hot stream of air rather than laying them out on a baking surface (Fast, 1990).

The process of toasting induces many changes in corn flakes. Though the toasting operation is conducted at a low moisture content (usually below 10%), the use of high temperature for a short duration suddenly releases steam leaving behind an expanded non-collapsing structure. The development of crisp texture and characteristic flavour are an integral part of this operation. The physical and chemical changes to proteins occurring during processing of corn flakes could affect the texture of cornflakes (Batterman and Hamaker 1998). The sensory crispiness is more closely related to acoustical quality such as loud, snap, and crackly than to the oral tactile qualities such as firmness (Vickers and Christensen 1980). Crispness is the main textural sensory attribute of cornflakes, for texture assessment (Chaunier, L., Courcoux, P., Della Valle, G., and Lourdin, 2005). Young's modulus, an instrument parameter obtained from the snap test, shows a close relationship to sensory crispiness (Vickers and Christensen, 1980). Uniform soft crisp texture and bright yellow colour are the desired features of the toasted flakes while maintaining integrity after putting

in milk. The effect of important processing conditions determined by using a Hectoliter tester (OHAUS Scales Corporation, USA).

2.9.4 Effect of extrusion process parameters

Mechanical properties of extruded ribbons ($e \times 100 \times 30 \text{ mm}^3$) were determined by a three-point bending test on a 1122 Instron universal testing machine. Sample thickness ("e", about 0.5 mm) was measured with a vernier caliper. The distance between supports was $L = 60 \text{ mm}$ and crosshead speed was adjusted to 20 mm min^{-1} . Flexion was performed until the sample broke. The mechanical behavior of extrudates was characterized by calculating stress r and strain e from the force F vs. crosshead displacement d (mm) curves. (Chanvrier et al., 2005; Nicholls et al., 1995). Corn extrusion cooking is also widely used to prepare Formulated products and the role of ingredients, such as sugars, on expansion has been thoroughly formulated by (Barrett, Kaletunc, Rosenburg, & Breslauer, 1995; Fan, Mitchell, & Blanchard, 1996a, Fan, Mitchell, & Blanshard, 1996b).

CHAPTER-III
MATERIAL AND
METHODS

MATERIALS AND METHODS

This chapter deals with the experimental procedure for standardization of different process parameters for cornflakes preparation. The instrumentation and techniques used for different process of cornflakes preparation were also presented.

3.1 Preparation of cornflakes

Shelled maize grains were collected from the local market of Bhubaneswar. Then the lot was cleaned to remove the undesirable materials and damaged grains were sorted out manually.

3.1.1 Pearling of maize grain

Maize grains collected from market were pearled in a carburandum coated roller mill (Fig. 3.1) to remove the germ and outer layer (pericarp) for better soaking and steaming. The pearled grains were cleaned and graded in a grader to remove the pericarp and fine particles.



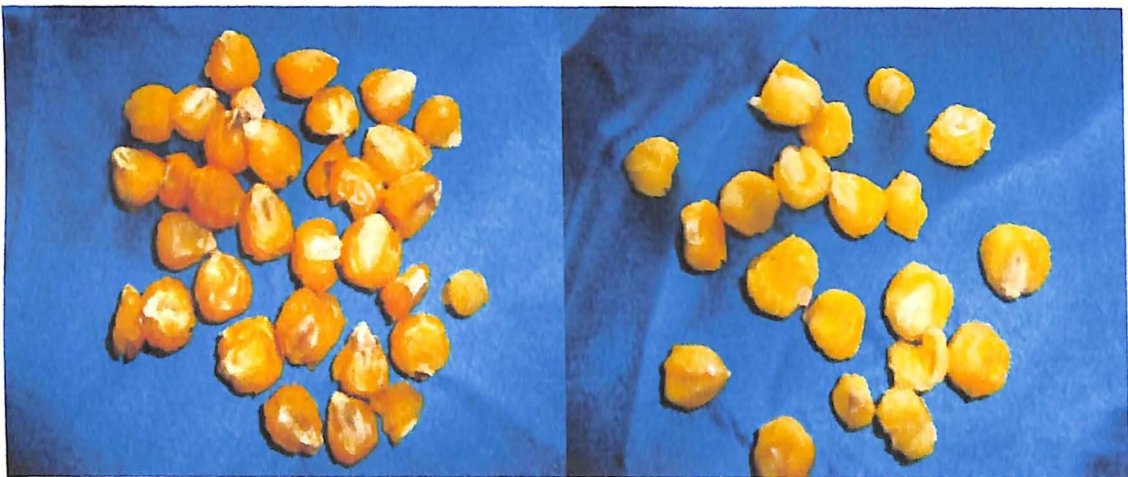
Plate. 3.1 Carburandum coated roller mill

3.1.2 Soaking of maize grain

Maize grains were soaked in cold water (30° C) and hot water (100° C). Samples were drawn at regular interval for moisture content determination to study the moisture uptake.

3.1.3 Steam cooking

Both pearled and unpearled maize were cooked in a household pressure cooker at 4 kg/cm² for gelatinization of starch. Samples were drawn from the cooker at 30 min intervals to analyse the moisture uptake and extent of gelatinization. The cooked maize samples were kept in polythene pouches for texture analysis and micro structure analysis. The cooking process was continued for 2 h. The steam cooked samples are shown in Fig. 3.2.



Unpearled

Pearled

Plate. 3.2 Cooked unpearled and pearled maize grain

3.1.4 Drying

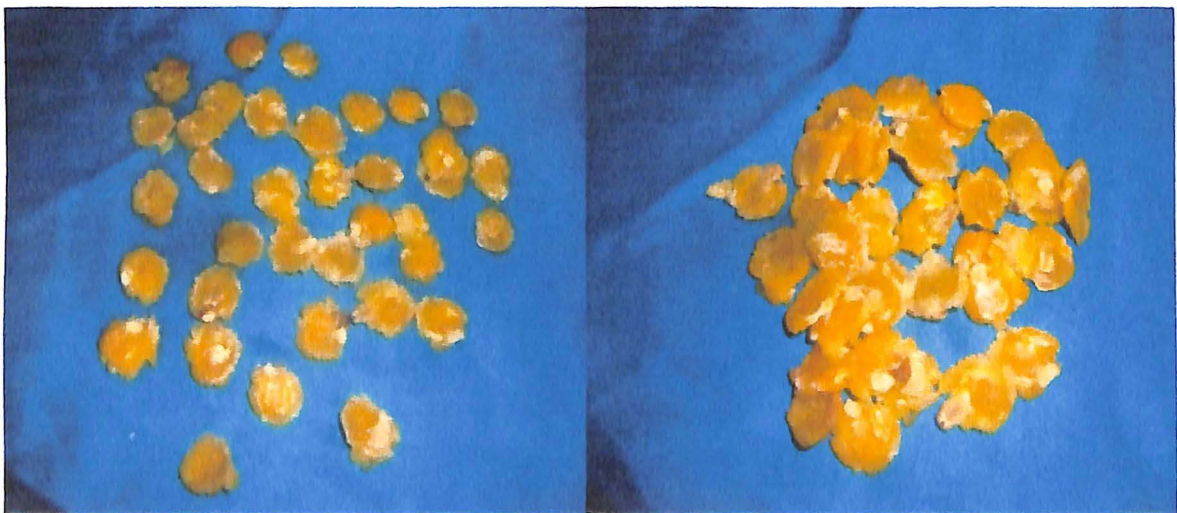
The cooked samples were drying in a mechanical tray dryer at 70°C drying air temperature. Samples were drawn at regular interval of 15 min for determination of moisture loss and texture analysis. The samples were partially dried to have a rubbery and non-sticky texture of the grains for proper flaking.



Plate. 3.3 Mechanical Tray Dryer

3.1.5 Flaking

The dried samples were pressed manually between two hard surfaces to have maize flakes of 0.5 mm thickness. The moisture content of the flaked grain was also determined.



Unpearled

Pearled

Plate. 3.4 Flaked corn from unpearled and pearled maize grain

3.1.6 Drying of maize flake

The maize flakes were dried in a fluidized bed dryer at 80°C to reduce the moisture content to 10% level. Hot air, heated by electrical heaters was forced to pass vertically through a thin layer of corn flakes in the fluidized bed dryer.



Plate. 3.5 Fluidized bed dryer used for drying of cornflake

3.1.7 Toasting and frying of flakes

The flakes prepared from pearled grains were divided into two lots. One lot was toasted in a household microwave oven at 480 W power level for 2 min and the other lot was fried in cooking oil at 180°C. The samples were cooled and stored in polyethylene pouches for quality analysis.

3.1.8 Extruded product

Maize grain was milled in a hammer mill to obtain coarse flour. The maize flour was extruded in a twin screw extruder and the extruded products were cut to obtain thin slices of corn flake(Fig 3.5).The extruded flakes were compared with that obtained from steam cooking method.



Plate. 3.6 Extruded flakes

3.2 Determination of quality parameters

The moisture content, Hunter colour value, textural properties, microstructure, water and oil absorbance index of the samples were determined and analysed. The quality of the corn flakes were compared with extruded products and market samples.

3.2.1 Moisture content

The moisture content of the samples (unpearled maize and pearled maize) were determined by oven drying method. Sample was taken into a flat-bottom metallic dish and initial weight was taken quickly. The dish with sample was placed in the hot air oven maintained at 100°C under atmospheric pressure. After 16-18 hours, the dish was removed from the oven, covered, cooled in desiccators and final weight was taken (Ranganna, 1986). The moisture content of sample was calculated as follows.

$$\text{Moisture content, \% (w.b)} = \frac{W_2 - W_3}{W_2 - W_1}$$

W_1 =Weight of the moisture dish.

W_2 = Weight of the moisture dish along with sample

W_3 = Weight of the moisture dish along with the dried sample



Plate. 3.7 Hot air oven

3.2.2 Texture evaluation

Compression test of cooked maize grain

The samples collected in polythene pouches were taken for analysis of texture. The maximum force during compression of the sample to 95% was measured with a texture analyzer (TA-XT Plus, UK) using a flat probe. The samples from polythene pouches was placed on the platform of texture analyser and tested at a speed of 1 mm s^{-1} and strain at 95% with compression mode. Penetration distance was set at 30 mm. Force vs. displacement curve was obtained during flaking of cooked maize.

Puncture test of corn flakes

The flakes were subjected to texture measurement by puncturing with a spherical stainless steel probe (diameter of 6.25 mm) after placing the flake flat on a

hollow circular sample holder. Maximum puncture force was measured by a texture analyzer (TA-XT Plus, UK) with a crosshead speed of 5 mm s^{-1} employed for puncture testing. The spherical probe was run through the flake until puncturing or failure of the sample. Maximum puncture force was obtained from the force–deformation curves. The number of samples tested each time was five and the average value was determined.



Plate. 3.8 Texture analyser

3.2.3 Micro structure analysis

The cut section of cooked maize grains as well as the prepared flakes were analysed in a scanning electron microscope for analysis of the micro structure. The corn samples were examined under a scanning electron microscope (Model 435 VP, Leo Electron Microscopy Ltd., Cambridge, UK) as mentioned earlier (Bhat and Bhattacharya, 2001). Representative photomicrographs of the cross-sections of flakes with different level of toasting were obtained.



Plate. 3.9 Scanning Electron Microscope

3.3.4 Colour Measurement

HunterLab colorimeter (ColorFlex) was used for measuring Lightness (L^* -value), Redness (a^* -value) and yellowness (b^* -value) of cornflakes. L^* is a measure of the brightness from black (0) to white (100). Parameter a^* describes red-green colour with positive a^* -values indicating redness and negative a^* -values indicating greenness. Parameter b^* describes yellow-blue colour with positive b^* -values indicating yellowness and negative b^* -values indicating blueness (Good, 2002). Prior to colour measurement, the colorimeter was calibrated to a standard black glass and standard white tile (X-79.11, Y-84.00, Z-88.18; L-93.45, a- -1.11, b-1.40). Flakes prepared from unpearled, pearled, extrusion cooking and available market sample were randomly picked and placed in measuring glass bowl of colorimeter for each measurement and the means of the five measurements were calculated.



Plate. 3.10 Hunter Lab colourimeter

3.2.5 Water absorbance index

It is the ratio of weight of Wet sediment in (g) to the initial weight of dry sample (g). The WAI of the cornflakes were determined according to Anderson et al (1969). Powdered samples (2.5g) were suspended in 30 ml distilled water in a 50 ml pre weighed centrifuge tube by vortexing. They were placed in water bath at 30°C and intermittently stirred for 30 min. The suspension was centrifuged for 10 min at 3000 rpm and the supernatant was decanted into a pre-weighed 50 ml beaker. The weight of wet sediment was used to calculate the WAI.

$$\text{WAI (g starch/g dry sample)} = \frac{\text{weight of the wet sediment (g)}}{\text{initial weight of the dry starch (g)}}$$

3.2.6 Oil absorbance index

It is the ratio of weight oil absorbed in (g) to weight of the dry powder sample (g). The OAI of cornflakes was determined using the method of Lin and Humbert (1974). Sunflower oil (5ml) was added to 0.5g of each sample in a 15 ml graduated centrifuge tube. The sample was vortexed and allowed to stand at room temperature for 30 min. The contents were centrifuged at 3000rpm for 20 min and the volume of free oil was noticed.

$$(\%) = \frac{\text{weight of oil absorbed in (g)}}{\text{weight of the dry starch sample (g)}}$$

CHAPTER-IV

RESULT AND DISCUSSION

RESULTS AND DISCUSSION

This chapter deals with the results obtained from the experiments on corn flake preparation under varying process parameters. The effects of different processing conditions were also studied and reported. The results obtained were also discussed.

4.1 Effect of soaking

The moisture content of both unpearled and pearled maize grains increased with soaking time (Fig.4.1). It was observed that initially the rate of moisture absorption was very fast which slowed down afterwards. The moisture absorption was found to be more in hot water and pearled grain probably due to the absence of pericarp layer.

Fig. 4.1 Changes in moisture content with soaking time for unpearled and pearled maize

Soaking time (min)	Unpearled-cold water	Unpearled-hot water	Pearled-cold water	Pearled-hot water
0	9.36	9.36	10.42	10.42
30	21.68	24.44	22.79	25.41
60	24.44	25.35	25.42	27.55
90	26.42	27.79	29.13	29.78
180	31.86	33.58	33.98	35.52
300	37.30	41.40	38.50	42.70

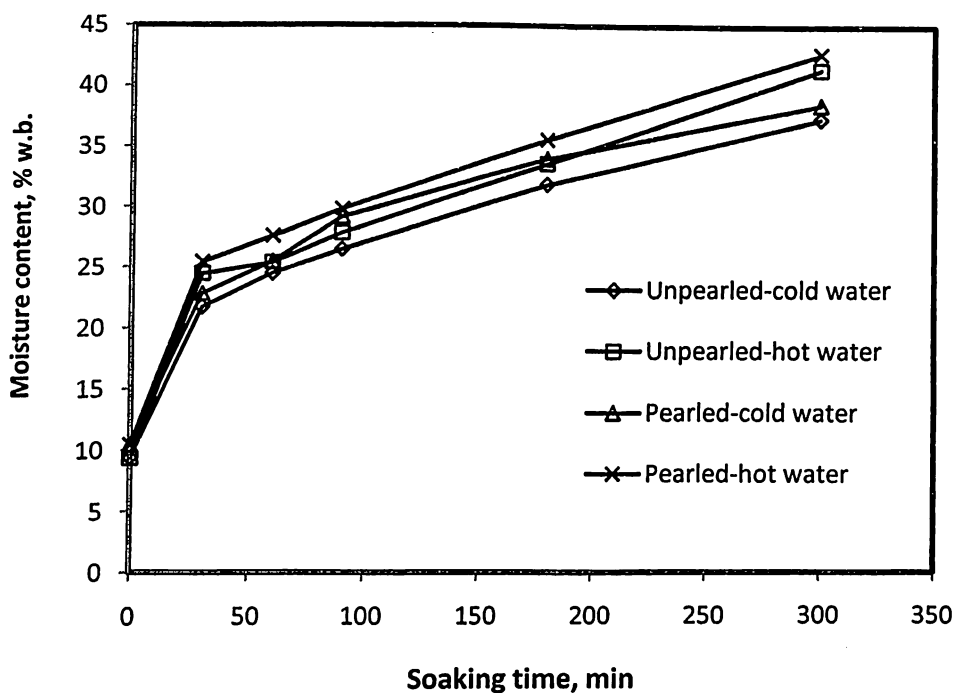


Fig. 4.1 Effect of soaking time on moisture content of unpearled and pearled maize grains

4.2 Effects of steam cooking

4.2.1 Moisture content

The moisture content of both unpearled and pearled maize grains increased with increase in cooking time (Fig.4.2.1). The rate of moisture gain was observed to be faster initially, which slowed down afterwards. Moisture content of maize grain increased sharply from an initial value of 13.3 to 40.8 and 49 % for unpearled and pearled grain, respectively after 30 min of cooking (Table 4.2.1). The moisture uptake was less in unpearled sample as compared to pearled one due to the presence of outer pericarp layer which retarded the moisture gain. It took 90 min for pearled and 120 min for unpearled maize grains to achieve 62% moisture content.

Table 4.2 Effect of cooking time on moisture content and maximum compressive force of unpearled and pearled maize grains

Cooking time (min)	Unpearled		Pearled	
	M.C.(w.b.)	Maximum force (Kgf)	M.C.(w.b.)	Maximum force (Kgf)
0	13.3	55.4	13.1	54.8
30	40.8	50.2	49	47.2
60	52.5	34.6	58.2	33.1
90	58.4	29.5	62.9	21.8
120	62.3	23.2	67.9	20.7

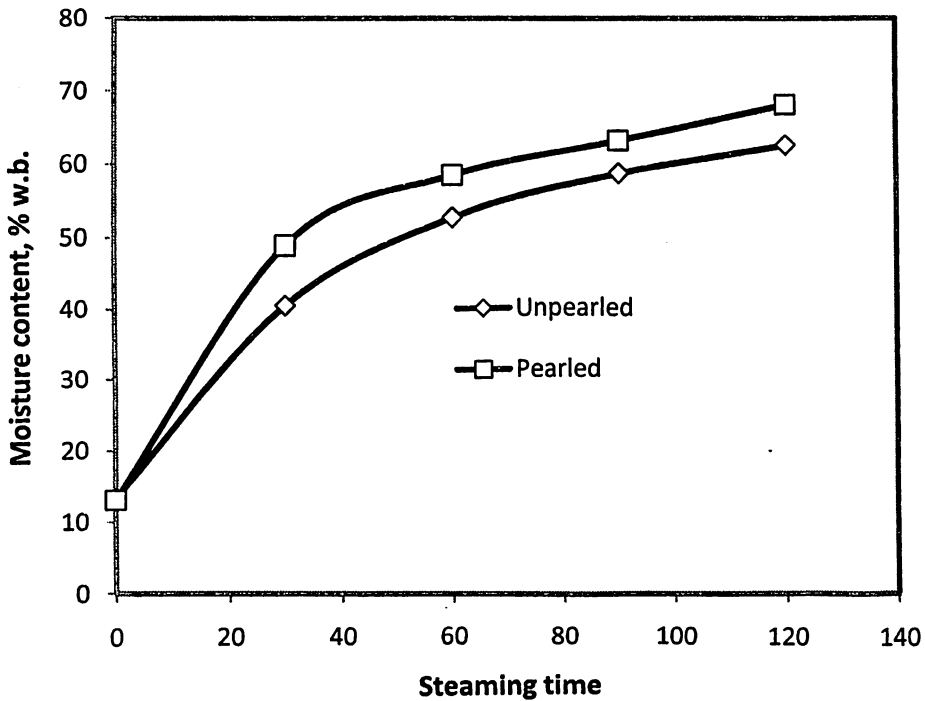


Fig. 4.2 Effect of cooking time on moisture content of unpearled and pearled maize grain

4.2.2 Maximum compressive force

The maximum compressive force decreased with cooking time for both unperaled and peraled grain as the moisture content increased and starch got gelatinized. It was observed that maximum force decreased less for samples cooked for 30 min and sharp decrease in force is observed between 30 and 90 min cooking indicating onset of gelatinization. Sharp decrease in compressive force at around 45% moisture content was observed in both the cooked samples indicating start of gelatinization. It is observed from (Fig. 4.3 and Fig.4.4) that there is not much variation in maximum force of peraled samples cooked for 90 and 120 min. So 90 min cooking of peraled maize samples indicated complete gelatinization with moisture content of 62.9%. To achieve same moisture content, unperaled sample took 120 min. This is also indicated by the micro structure photograph of samples taken by scanning electron microscope. The decrease in maximum compression force was relatively less in unperaled sample as compare to peraled sample.

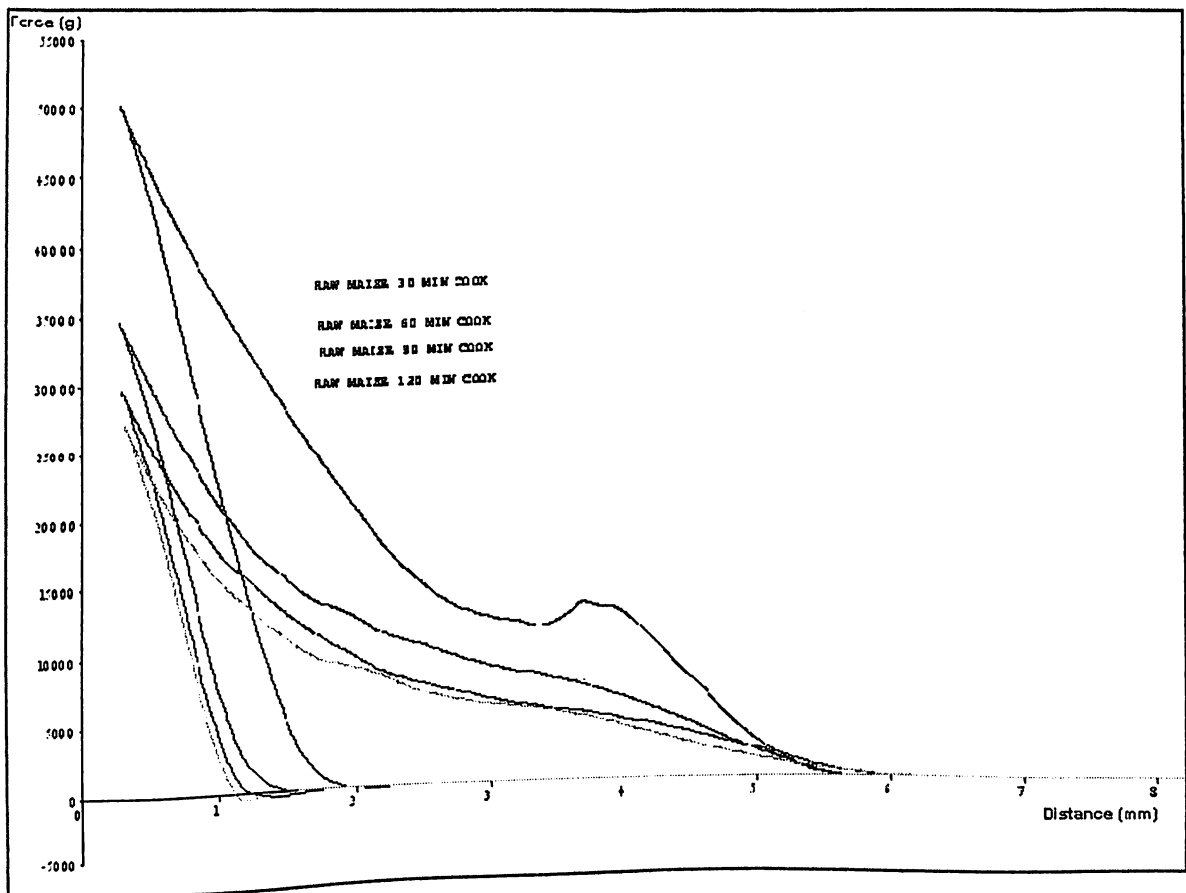


Fig. 4.3 Compression test of unperaled maize grains cooked for different period of time

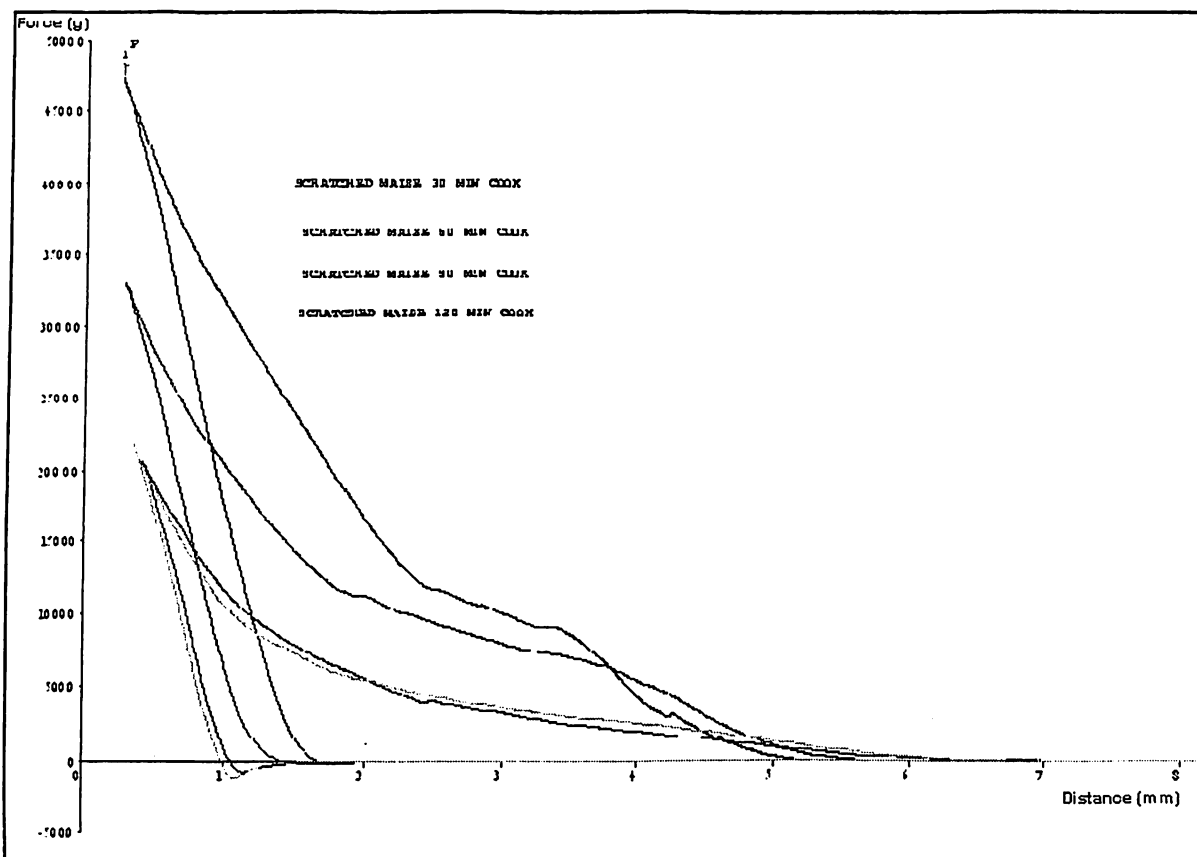


Fig. 4.4 Compression test of pearled maize grains cooked for different period of time

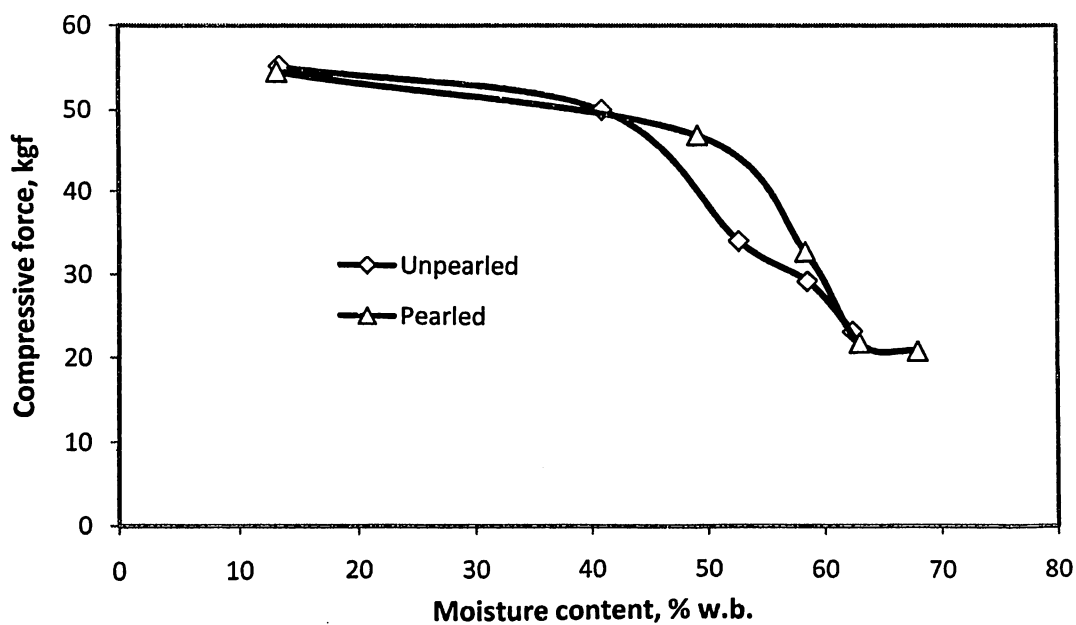
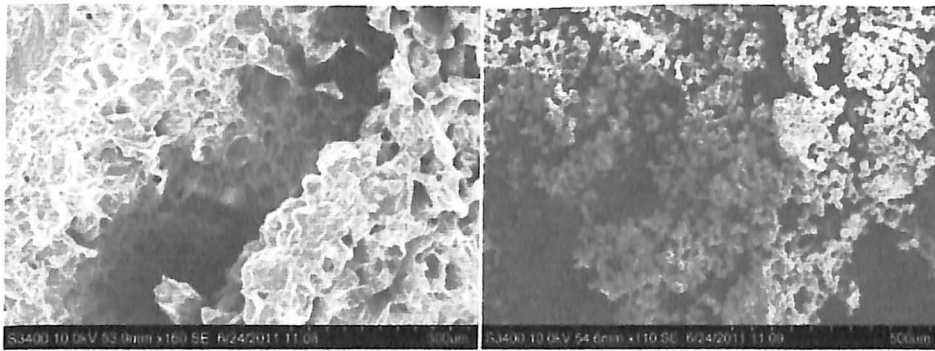


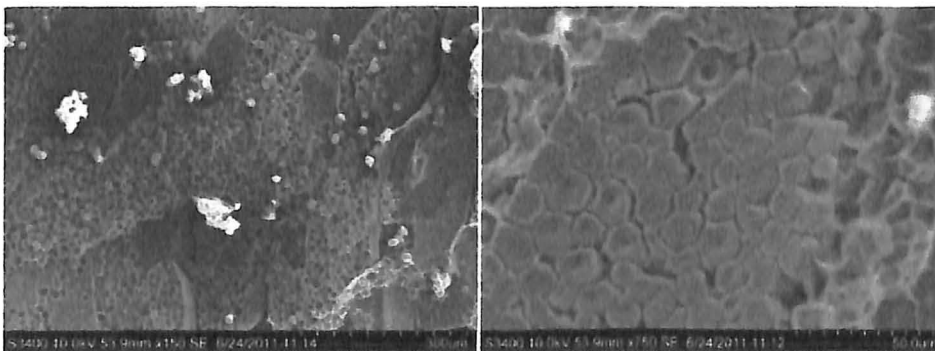
Fig. 4.5 Effect of moisture content on maximum compressive force for both unpearled and pearled maize grains cooked for different time interval

4.2.3 Microstructure

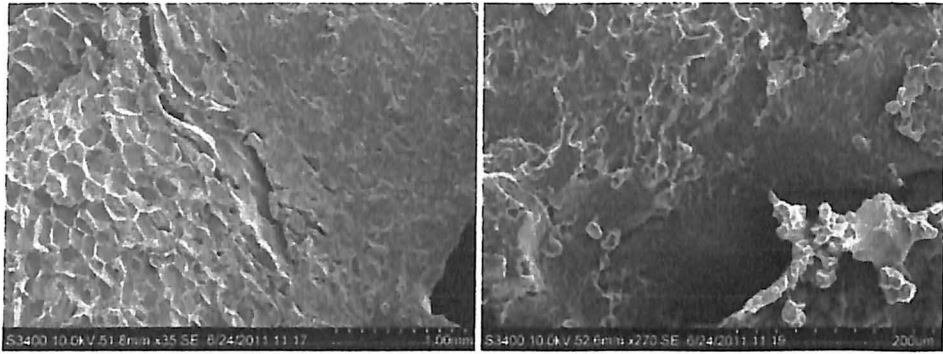
The expanded microstructure of the cross sectional view of maize grains cooked for different time period was determined in Scanning Electron Microscope. The microstructure view of the samples were shown in Fig. 4.1 . It was observed that starch are present separately as granules in raw maize. After 30 min cooking, expansion of granules by hydration was observed with distinct cell wall. The starch granules after 60 min cooking were found to be swelled by hydrothermal treatment but cell wall was observed to be intact. Cooking for 90 min resulted in a homogeneous mass with rupturing of cell wall indicating complete gelatinisation.



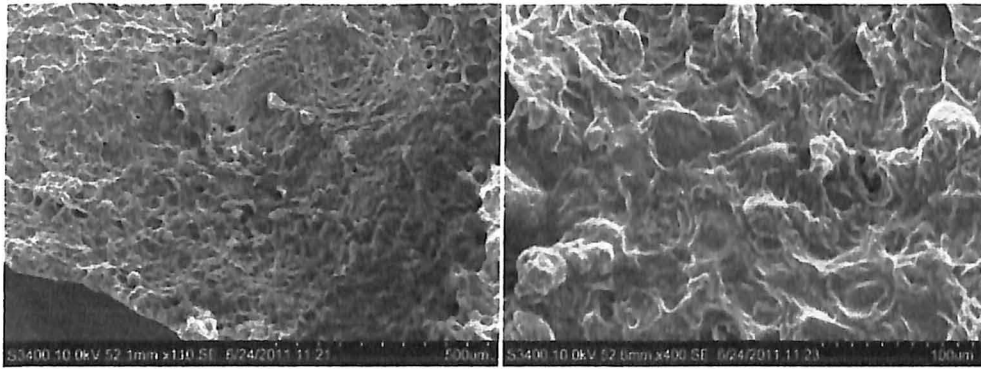
Raw maize grain



30 min cooked sample



60 min cooked sample



90 min cooked sample

Fig. 4.1 Scanning electron microscopy of maize grain cooked for different time

4.3 Effects of drying

4.3.1 Moisture content

Moisture content of cooked samples decreased with tempering and drying time for both unpearled and pearled maize grains. The loss of moisture was observed to be faster in pearled grain as compared to unpearled samples. This might be due to the presence of outer pericarp layer which restricts the moisture loss. The moisture content of samples decreased from an initial value of 62 to 47.2% and 41.1% after 60 min drying in hot air dryer at 70°C for unpearled and pearled samples, respectively (Table 4.3 and Fig.4.6)

Table 4.3 Effect of drying time on moisture content and maximum compressive force of unpearled and pearled maize grains

Drying time (min)	Unpearled-HAD		Pearled-HAD		Remark
	M.C. (% w.b.)	Max comp force (kgf)	M.C. (%w.b.)	Max comp force (kgf)	
0	62.3	23.2	62.9	21.8	Sticky and broke during flaking
15	57.4	25.8	55.7	26.7	Sticky and broke
30	52.8	28.7	49.9	28.5	Slightly sticky
45	49.8	34.6	44.7	39.5	Non sticky and rubbery texture
60	47.2	38.8	41.1	44.5	Hard texture



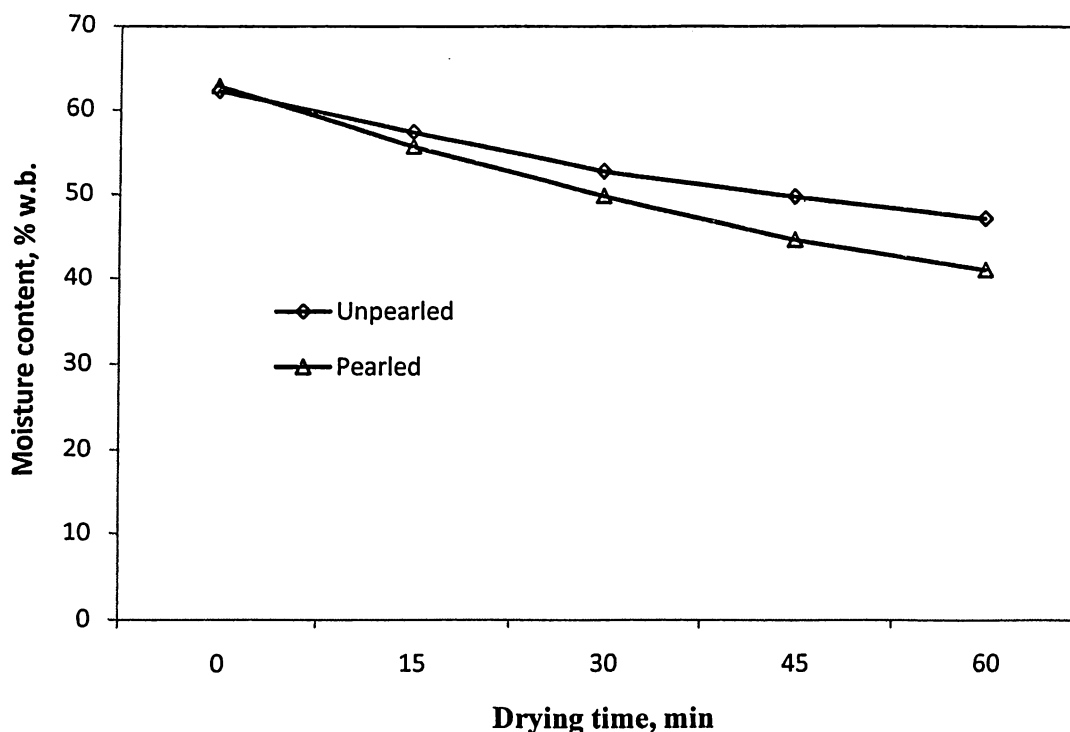


Fig. 4.6 Effect of drying time on moisture content of unpearled and pearled maize grains

4.3.2 Maximum compressive force

The maximum compressive force increased with tempering and drying period. The force increased at a slower rate during initial drying period and recorded sharp increase at the later part when the sample was dried. Samples dried for 15 and 30 min in hot air dryer at 70°C were observed to be sticky as indicated by the negative force value during initial period of compression. It was observed that pearled samples dried for 45 min in hot air dryer was not sticky and recorded maximum force of 39.5 kg at 44.7 % moisture content (w.b.). Further drying of sample increased the compressive force requirement for flaking and hence not considered.

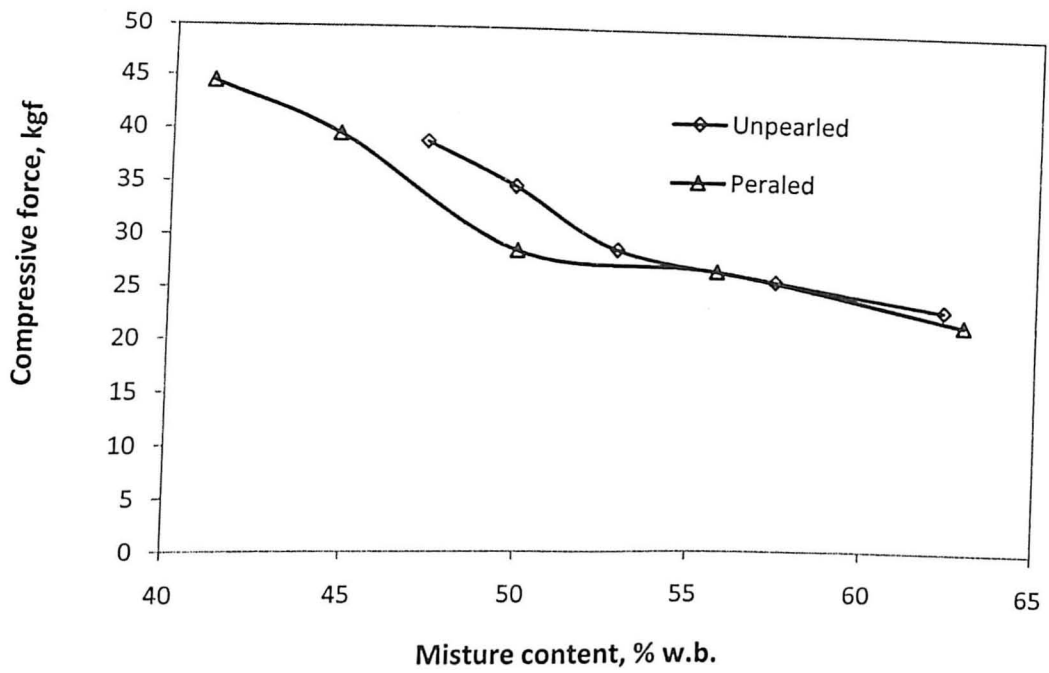


Fig. 4.7 Effect of drying time on maximum compressive force for unpearled and pearled Maize grains

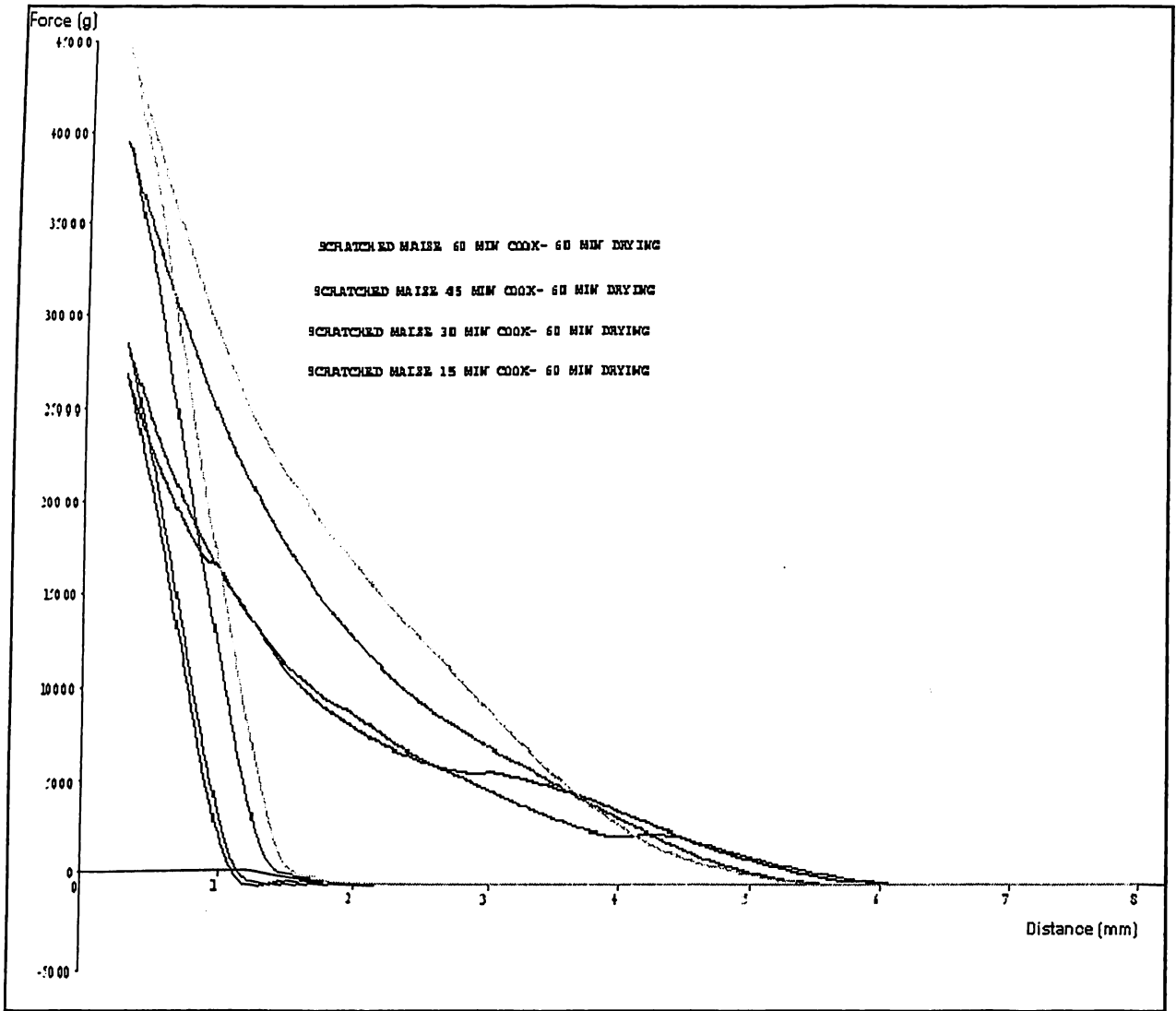


Fig. 4.8 Compression test of cooked maize grains dried for different period of time

4.4 Comparison of quality of corn flakes

The quality of corn flakes obtained from unpearled, pearled and extruded product was analysed.

4.4.1 Hunter colour value

There was not much variation in hunter colour values of corn flakes obtained from unpearled and pearled maize. However, maximum colour change was observed in extruded flakes as indicated by the lower lightness and yellowness values probably due to high extrusion temperature. (Table.4.4)

4.4.2 Water and oil absorbance index

The water and oil absorbance values were observed to be more in extruded flakes due to more expansion and void fraction in the samples during extrusion. The water absorption capacity may be responsible for the rapid decrease in bowl life when consumed with milk. The WAI and OAI values of cornflakes obtained from pearled maize samples were observed to be higher than that of unpearled sample (Table.4.4). This might be due to the removal of outer layer, which restricts less water and oil absorbing capacity than the inner starchy material. The existence of protein network could hinder the hydration of starch granules and prevent them from swelling too much. Conversely, the protein network is more degraded in case of extruded materials, probably because of shear effects. The market sample was observed to be lighter with higher values of WAI and OAI.

Table 4.4 Quality parameters of corn flakes

Corn flake samples	L	a	b	WAI	OAI
Unpearled flake	50.60	12.67	40.69	3.91	3.67
Pearled flake	50.91	11.96	41.71	4.55	3.84
Extruded flakes	49.61	5.67	37.27	6.24	4.12
Market sample	53.29	15.26	41.96	6.57	4.84

4.4.3 Maximum puncture force

The maximum puncture force of 0.29 kg was observed to be less in toasted market sample, which was less than the fried samples locally available in the market. Same value of puncture force was also reported by Sumithra and Bhattacharya (2008)

for toasted sample. The maximum puncture force was observed to be more for both the experimental samples probably due to the presence of germ which is rich in protein that impart hardness to the samples (Fig.4.9). Further, the experimental samples were prepared from the whole grain whereas the market samples were prepared from corn grits. The flakes obtained from unpearled sample were comparatively hard with two distinct layers of pericarp and inner starchy portion.

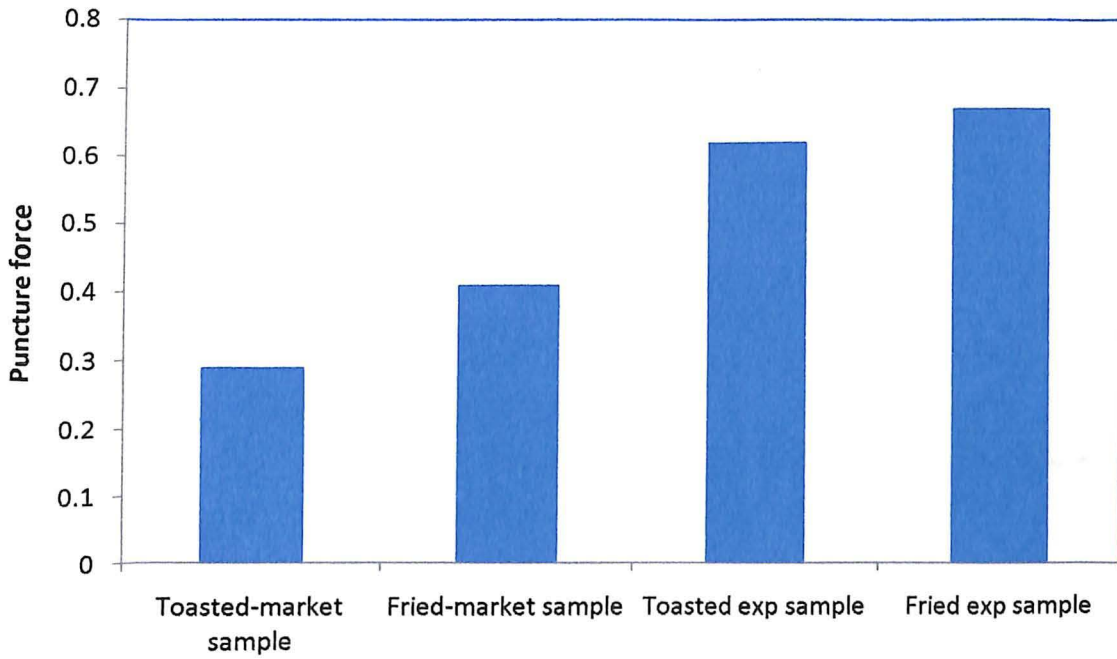


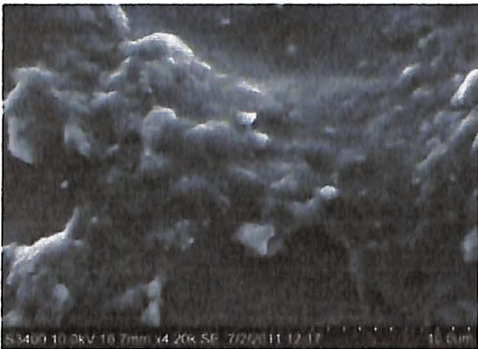
Table 4.9 Comparison of puncture force of corn flakes

4.4.4 Microstructure

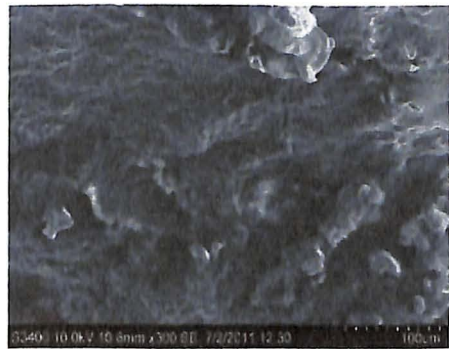
The expanded microstructure of fried and toasted, experimental and market sample of corn flake and extruded sample is shown in Fig 4. Extruded sample revealed large expanded bubbles. Conversely, the microstructure of cornflakes obtained from cooking process was observed to be less expanded and much more irregular. In the experimental fried cornflakes, some hard particles were observed which might be responsible for the more puncture force. The structure of experimental toasted sample is somewhat similar to the market sample, which is more uniform in shape. The variation observed for cellular structure of extruded and cooked cornflakes may be explained by the differences in heating or cooling kinetics (Chaunier et al., 2007).



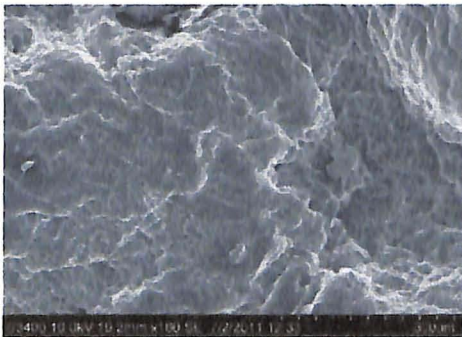
Fig. 4.2 Steam cooked cornflake and extruded product



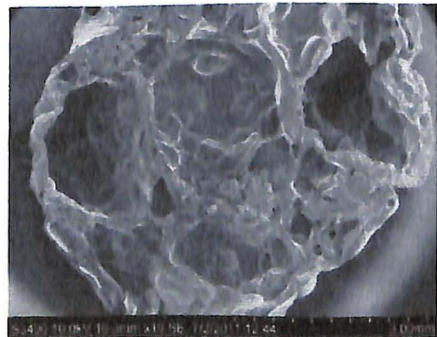
Fried product



Toasted product



Market sample



Extruded flake

Fig. 4.3 Scanning electron microscopy of corn flakes indicating microstructure

CHAPTER-V
SUMMARY AND
CONCLUSION

SUMMARY AND CONCLUSION

Corn flakes are possibly the most common form of breakfast cereals (Fast, 1990) prepared from maize. At present, corn flakes are popularly known as breakfast food in the world at large and generally taken with milk. Ready-to-eat (RTE) cereals are processed grain formulations suitable for human consumption without requiring further processing or cooking. The last decades have been marked by the rise in popularity of ready-to-eat breakfast cereal products, such as cornflakes. To investigate end-product features, the process must be carefully controlled.

The effective demand of corn flakes is relatively high, being 50 times the price of maize utilized to produce it. The demand for the product is likely to increase substantially if production takes place locally at a reasonable price by small entrepreneurs. This could increase the utilization of surplus maize for value addition to enhance the income and employment in rural sector. Despite numerous advances and improvements in cornflake processing, manufacturers still have some difficulties making consistent, high quality cornflakes. Though the cornflake processing is an already a commercially established process, the effect of important processing conditions on the characteristics of the products are not clearly known. Published data on changes due to cooking, drying and toasting of maize are scarce though such data are useful for process and product standardization, and for improvement in the product and processing conditions.

Hence, the objective of the present investigation is to determine the effects of important process variables like cooking, drying and toasting time on important product attributes. The study has been further elaborated with the determination of textural properties and cellular microstructure of the product for a detailed understanding of the process. For this purpose, conventional steam cooking process was adopted at the laboratory scale in order to obtain corn flakes and compared with extruded and commercial sample. Keeping this in view, the present work was undertaken with the following objectives.

Objectives

1. To standardize the cooking and drying process for flake preparation.
2. To analyse the quality of cornflakes and compare it with market sample.

Shelled maize grains were collected from the local market of Bhubaneswar. Then the lot was cleaned to remove the undesirable materials and damaged grains were sorted out manually. Maize grains collected from market were pearled in a carburandum coated roller mill to remove the germ and outer layer (pericarp) for better soaking and steaming. The pearled grains were cleaned and graded in a grader. The maize grains were soaked in cold and hot water. The increase in moisture content was determined. Both pearled and unpearled maize were also cooked in a household pressure cooker for gelatinization of starch. Samples were drawn from the cooker at 30 min intervals to analyse the moisture uptake and extent of gelatinization. The cooked maize samples were kept in polythene pouches for texture analysis and micro structure analysis. The cooked samples were dried in a mechanical tray dryer at 70°C drying air temperature. Samples were drawn at regular interval of 15 min for determination of moisture loss and texture analysis. The samples were partially dried to have a rubbery and non-sticky texture of the grains for proper flaking. The dried samples were pressed manually and between two hard surfaces to have maize flakes of 0.5 mm thickness. The maize flakes were dried in a fluidized bed dryer at 80°C to reduce the moisture content to 10% level. The flakes prepared from pearled grains were divided into two lots. One lot was toasted in a household microwave oven at 480 W power levels for 2 min and the other lot was fried in cooking oil at 180°C. The samples were cooled and stored in polyethylene pouches for quality analysis. Maize grain was milled in a hammer mill to obtain coarse flour. The maize flour was extruded in a twin screw extruder and the extruded products were cut to obtain thin slices of corn flake. The extruded flakes were compared with that obtained from steam cooking method and the market sample. From the above study the following conclusion were made moisture content increased up to 42.7% in pearled maize soaked in hot water for 5hr.

The moisture content, Hunter colour value, textural properties, microstructure, water and oil absorbance index of the samples were determined and analysed.

The quality of the corn flakes was compared with extruded products and market samples.

From the above study, the following conclusions were made.

- The moisture content of both unpearled and pearled maize grains increased with soaking time.
- It took 90 min for pearled and 120 min for unpearled maize grains to achieve 62% moisture content during steam cooking.
- The maximum compressive force decreased with cooking time for both unpearled and pearled grain as the moisture content increased.
- Steam cooking of pearled maize samples for 90 min completely gelatinized as indicated from the microstructure with moisture content of 62.9%.
- It was observed that starch are present separately as granules in raw maize. After 30 min cooking, expansion of granules by hydration was observed with distinct cell wall. The starch granules after 60 min cooking were found to be swelled by hydrothermal treatment but cell wall was observed to be intact. Cooking for 90 min resulted in a homogeneous mass with rupturing of cell wall indicating complete gelatinisation.
- The moisture content of samples decreased from an initial value of 62 to 47.2% and 41.1% after 60 min drying in hot air dryer at 70°C for unpearled and pearled samples, respectively.
- It was observed that pearled samples dried for 45 min in hot air dryer was not sticky and recorded maximum force of 39.5 kg at 44.7% moisture content (w.b.).
- The maximum colour change was observed in extruded flakes as indicated by the lower lightness and yellowness values probably due to high extrusion temperature.

- The WAI and OAI values of cornflakes obtained from pearled maize samples were observed to be higher than that of unpearled sample.
- The flakes obtained from unpearled sample were comparatively hard with two distinct layers of pericarp and inner starchy portion.
- The structure of experimental toasted sample is somewhat similar to the market sample, which is more uniform in shape.

From the above study, it could be concluded that pearled maize grains steam cooked for 90 min followed by 45 min drying in tray dryer at 70°C was suitable for cornflakes preparation.

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