Studies on the use of sucrose alternatives in traditional sweetmeats

Thesis

Submitted to

THE UNIVERSITY OF MYSORE



for the award of the degree of

DOCTOR OF PHILOSOPHY

In

FOOD SCIENCE

By

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Department of Lipid Science and Traditional Foods

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AUGUST 2004

August 6th, 2004

CERTIFICATE

I hereby certify that the thesis entitled “Studies on the use of sucrose alternatives in traditional sweetmeats” submitted by **Smt R. Chetana** for the award of the degree of **Doctor of Philosophy** in **Food Science** to the University of Mysore, India is the result of the research work carried out by her in the Department of Lipid Science and Traditional Foods, **Central Food Technological Research Institute,** Mysore, under my guidance during the period 1997 - 2004.

(**Dr S.Yella Reddy**)
(Research Guide)

DECLARATION

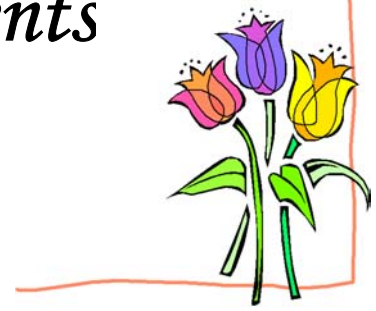
I hereby declare that the thesis entitled, “Studies on the use of sucrose alternatives in traditional sweetmeats” submitted to the University of Mysore, India for the award of the Degree of **Doctor of Philosophy** in **Food Science**, is the result of the research work carried out by me in the Department of Lipid Science and Traditional Foods, **Central Food Technological Research Institute**, Mysore under the Guidance of **Dr. S.Yella Reddy** during the period 1997– 2004.

I further declare that the results presented in this have not been submitted for the award of any other degree or fellowship.

August 6th , 2004. (**R. Chetana**)

Dedicated to

My Parents



Acknowledgements

I take great pleasure to put down my thoughts in words of gratitude to all those who have helped me in the making of this thesis.

I wish to express my sincere thanks and deep sense of gratitude to my guide Dr. S. Yella Reddy, Lipid science and traditional foods, CFTRI, Mysore, for his excellent guidance, invaluable suggestion and constant encouragement during the period of this investigation.

I am thankful to Dr. V. Prakash, Director, CFTRI, Mysore, for permitting me to carryout my research work in the institute and submit the thesis for award of doctorate degree.

I sincerely thank Dr. J.V.Prabhakar, Former Head, LSTF, and Dr. Shamanthaka Shastry, Former Head, PCT, for their constant support and encouragement.

I thank Dr. B.R. Lokesh, Head, Dr. A.G. Gopalakrishna, Dr. Nasirullah Dr. Sakina Khatoon, Mr. Sukumar Debnath, and Mr. Saramandel for their encouragement and help during the course of the study.

I thank my colleagues Dr. J.Hemavathy and Mrs. Jeyarani, for their invaluable suggestions, and help during the preparation of thesis.

… Mrs. Babylatha, Mrs. Asha Dinakar, Mrs. Shanthamma, Ms Nalinakshi, and Ms Poornima for their assistance and cooperation during this work.

I would like to thank Mr. Mukund, Mr. Umapathi and Mr. Krishnamurthy of CIFS dept., for help rendered during the analyses of samples and encouragement throughout the study.

… Mr Raviswamy, S&P, Mr Srinivasa, B&N, Dr. Baldev Raj Packaging dept. for their invaluable suggestions, timely help and encouragement.

I sincerely thank Dr Suvendu Bhattacharya, Food Engineering Dept., and Mr. K.K.Bhat, Dept of Sensory Science for their cooperation, support and pertinent suggestions in the preparation of this thesis.

I would like to thank Mr. B. Manohar, Food Engineering Dept., and Mr. R. Ravi Dept of Sensory Science for their excellent statistical analysis of my data.

I gratefully acknowledge Mrs. Rati Rao, Microbiology dept, and Mrs Leelavathi, FMBCT dept. for their timely help, valuable suggestions and encouragement.

My special thanks to Mrs. Sowbhagya, PPSFT dept., and all the ladies of FVT dept, for their encouragement and moral support.

I also express my sincere thanks to Mr. Dastur, Mr. Naganna, Mrs. Jayashree, Mr. Raghavan, Mr Raghuram, Mr. Kempegowda, Mrs. Savitha, Mrs. Sunitha, Ms. Chanchala and all the other staff of FOSTIS.

Words are not adequate to express my gratitude to my mother, brother, husband and daughter for their support, patience, understanding and encouragement throughout the study.

CONTENTS

ABBREVIATIONS

%	Percentage
°C	Degree centigrade
°B	Degree brix
g	gram
h	hours
mg	milligram
min	minutes
ml	milliliter
cm	centimeter
Mpas	millipascals
MD	Maltodextrin
S	Sorbitol
M	Mannitol
PD	Polydextrose
Kcal	Kilo calorie
w/w	Weight by weight
ERH	Equilibrium relative humidity
ppm	Parts per million
Kj/mol	Kilo Joules per mole
FDA	Federal drug administration
GRAS	Generally recognized as safe
CFU/g	Colony forming units per gram
PFA	Prevention of Food Adulteration Act
db	Dry basis
a_w	Water activity
RMSE	Root mean square error
TSS	Total soluble solids
Secs	Seconds
mm	Millimeter
N	Newton

<	Lesser than
>	Greater than
NIDDM	Non Insulin dependent diabetes mellitus
no.	Number
EC	European community
DKP	Diketopiperazine
ADI	Allowed daily intake
DE	Dextrose equivalent
HGS	Hydrogenated glucose syrup
VFA	Volatile fatty acids
CCRD	Central composite rotatable design
IMC	Initial moisture content
BET	Braunauer–Emmet-Teller
GAB	Guggenheim-Anderson-De Boer
BIS	Bureau of Indian Standard

Synopsis

Sugar is a natural food, which fulfills all the physiological functions of a carbohydrate food. It provides calories and combines with many valuable foods to enhance their taste appeal. It remains the major sweetener in foods especially traditional sweets. Sweetness is an attractive quality in foods. However, sugar has become a subject of controversy over its adverse effects in health and nutrition namely as a contribution to excessive calories, diabetes, hyperglycemia, hypertension and as a principal causative factor of dental carries.

Growing awareness of each of these issues has cast a negative influence on the consumer towards sucrose based foods and the demand for low or no sugar products is on the increase. Thus today there exists a need to provide low sugar or sugar free products, which have characteristics similar to those of sugar. However there are problems in replacing sugar with alternatives. This is because sugar in addition to sweetness, imparts many desirable characteristics to the product like body and texture. It is also a good preservative. Sucrose alternatives should naturally satisfy these requirements. Many types of sucrose alternatives are now available and with the help of these, tailor made foods can be prepared so that consumers are not penalized with excessive calories. The main aim of the present study was to replace sugar in Indian sweets with sucrose alternatives, without affecting the desirable quality attributes of these products. With this broad aim in view, the work was initiated on selected Indian sweets such as *jamun, burfi, laddu* and the results are presented in these studies.

Chapter 1 describes an introduction on sweetness, sweeteners, properties of sucrose and problems of sucrose replacements. In order to suit particular products or meet the requirements and demands for sugar free products an in depth knowledge of the existing sweeteners, their classification and properties have been discussed in detail. The Indian scenario for alterative sweeteners has also been touched upon.

Since the main aim was usage of sucrose alternatives in Indian sweets a broad classification of the types of Indian sweets has also been discussed. In the present study, sorbitol and mannitol are the two polyols used. Aspartame is the intense sweetener used along with bulking agents such as maltodextrin and polydextrose to prepare traditional Indian sweets and these sweeteners and bulking agents are discussed in detail.

Chapter 2 describes the detailed work carried out on preparation of *Gulab jamun* /*jamun* is a traditional khoa based sweet popular in India. It is round or oval in shape, dark brown in colour and served dry or immersed in sugar syrup. Sugar syrups play an important role in determining the quality of syrup based sweets. The concentration of syrups influence the texture and mouthfeel of many syrup based sweets and hence a study on the rheological behavior of sugar free syrups was studied in detail. The study investigates the rheological behaviour of dispersions containing sugar replacers such as sorbitol, polydextrose (PD) and mixtures of maltodextrin and polydextrose (MD+PD) while sucrose solution has been used for comparison. These rheological characteristics were studied to obtain desirable consistency to yield products with similar quality compared to that of sugar.

The results revealed that sugar and sorbitol solutions, behave like Newtonian fluids, while PD and MD+PD syrups exhibited a shear-thinning, non-Newtonian behavior with yield stress. Flow behavior of all the syrups studied could be well represented by the Herschel-Bulkley model. The yield stress, flow behavior index and consistency index were dependent on both temperature and concentration. The activation energy, as calculated by the Arrhenius equation, increased with increasing concentration of solids. To produce solutions/dispersions with the same viscosities as sugar solutions, the requirements of sugar substitutes (PD and MD+PD) were needed in smaller amounts than sugar alone, whereas for sorbitol it was similar to that of sugar. The colour of syrups showed that sorbitol syrup was brighter than the others and matches closely with sugar syrup.

Optimisation of any product or process requires an integrated approach, involving choice of the best set of conditions among specified

alternatives. Optimisation was designed for *jamun* to study the effect of processing parameters such as concentration of syrup, temperature of soaking and time of soaking the *jamun*s on the response functions such as texture and sensory overall quality.

The results indicated that the optimum conditions for *jamun* made with sugar or with sorbitol, were :- syrup strength 51 and 54°B; temperature of soaking, 54 and 65°C and time of soaking were 4 and 3 hrs respectively. Based on these conditions, *jamun* without sugar could be prepared without affecting the quality.

Instrumental texture, colour and proximate composition of *jamuns* were determined along with sensory analyses for *jamuns* prepared with sorbitol, mixture of MD+PD and PD. The stability of the added intense sweetener aspartame in these products were studied by HPLC. The microbiological profile of the products were also studied .

Colour measurements indicated that *jamun* prepared with sorbitol was lighter in colour, than *jamun* made with either a sugar syrup, or a syrup made with a mixture of maltodextrin and polydextrose (MD+PD), or a polydextrose (PD) syrup. The added intense sweetener aspartame, showed the least loss at refrigerated temperatures and highest loss at accelerated temperature. The microbial profile of *jamun* also indicated that *jamun*s with sugar syrup had a shelf life of 4 days, while *jamun*s made with MD+PD or PD syrups had a shelf life of 2 days. Interestingly *jamun* with sorbitol was found to be safe for the entire storage period of 8 days; moreover the lower calorific value of sorbitol *jamuns* is an added advantage. Thus *jamuns* could be prepared with sorbitol without affecting the overall quality compared to the traditional product prepared with sugar. Bulking agents like PD and mixtures of MD+PD along with added intense sweetener, aspartame also could be used for the preparation of *jamun*. But these showed a lowered overall acceptability compared to *jamun* with sugar and sorbitol.

Chapter 3 describes milk *burfi*, a popular sweet prepared from *khoa* (concentrated milk) and sugar. The effects of replacing sugar in these products were studied. It was observed that operational parameters such as total soluble solids (TSS) (ºB) at the end of cooking and days of storage influenced the quality of *burfi*. RSM was used to optimize the effect of these variables on the texture and overall quality of *burfi*.

The results revealed that the optimum conditions for *burfi* with sugar was 80°B of TSS and 2.34 days of storage, for obtaining a *burfi* with a breaking strength /snap of 13.3N and a sensory overall acceptability score of 9.5. In the case of *burfi* with sorbitol to obtain a product close to its sugar counterpart, 77.5°B and 5.5 days of storage was needed for obtaining a *burfi* with 12.9N with an overall acceptability score of 9.1. These parameters are well correlated with experimental conditions.

Studies on storage stability of *burfi* was carried out by instrumental texture and colour. The sensory analyses of sugar free *burfi* prepared with sorbitol, mixtures of sorbitol and mannitol (S+M) 80:20 and 90:10 and with PD and MD+PD were carried out in comparison with its sugar counterpart. The stability of added intense sweetener aspartame in these products and the microbial profile were also studied.

Colour measurements indicated that *burfi* prepared with sugar and mixtures of sorbitol and mannitol (80:20; 90:10) were similar and were lighter in colour, compared to sorbitol, polydextrose, mixture of polydextrose and maltodextrin. Stability of aspartame in these products showed least loss at refrigerated temperature and highest loss at accelerated temperature. The microbial profile of *burfi* indicated that *burfi* prepared with sugar had a shelf life of 10 days, *burfi* with sorbitol and mixtures of sorbitol and mannitol had a shelf life of 20 days, whereas products prepared using MD+PD and PD were found to be safe for consumption for 5-6 days only. The total reduction in calories was marginal in sugar free *burfi* as only 30% of sugar used was replaced by alternatives.

Moisture sorption isotherms give an insight into the moisture binding characteristics of foods. Hence sorption studies of *burfi* were taken up. The results revealed that moisture sorption isotherms of sugar and sugar free milk *burfi* showed sigmoidal pattern, similar to sugar rich products. The curves of *burfi* with sorbitol shifted towards left compared to that of sugar. Products with bulking agents like MD, PD or combination of these two were found to be similar to those of sugar counterpart. The GAB model showed a better fit compared to other models, as it is applicable to a wide range of water activity.

Milk *burfi* could be prepared with quality characteristics similar to those of *burfi* with sugar using sorbitol and mixture of sorbitol and mannitol (90:10).

Chapter 4 deals with the preparation of *laddu*, a legume based sweet. It is made from *boondi*, which is obtained by dropping batter of bengal gram flour through sieves into oil and deep fat fried. *Boondi* is bound together with sugar syrup and moulded into balls and are called *laddus*. Binding is very important in the preparation of *laddu*, which is imparted by the sugar syrup of optimum concentration. On storage, the sugar in *laddu* crystallizes partially, which is a desirable attribute. In order to obtain these desirable attributes, the effect of processing parameters on quality of *laddu* was studied. The stability of intense sweetener aspartame added along with the sucrose alternatives was studied by HPLC. The storage stability of *laddu* was studied along with instrumental texture and colour. The microbial profile and sorption studies of *laddu* were also studied.

Results indicated that *laddu* could be prepared using sorbitol and mixtures of sorbitol and mannitol (80:20; 90:10), whereas acceptable products could not be made with PD. *Laddu* with MD+PD gave rise to problems with moulding, as the spherical ball slowly disintegrated into individual *boondi.* Increasing the total soluble solids (°B) did not improve the moulding characteristics.

Colour measurements indicated that *laddu* prepared with sugar and mixtures of sorbitol and mannitol (80:20; 90:10) were lighter in colour. *Laddu* prepared with sorbitol or with MD+PD were moist throughout. Stability of

aspartame in these products showed marginal loss at refrigerated temperatures. Highest loss was observed at accelerated temperatures. The microbial profile of *laddu* indicated that *laddu* made with sorbitol or with mixtures of sorbitol and mannitol had a shelf life of 20 days whereas products prepared using MD+PD were found to be safe for consumption for 5 days only although sensorily the product scored least in overall quality.

Moisture sorption data is useful in choosing suitable packaging material having a desirable water vapour barrier property and also in addition to determining the stability of the product. Moisture sorption isotherms of sugar and sugar free *laddu* showed sigmoidal pattern, similar to sugar rich products. Addition of sugar replacers tended to shift the isotherm to the left. The GAB model showed a better fit compared to other models, as it is applicable to a wide range of water activity.

Chapter 5 describes the summary and the conclusions drawn from the study.

Chapter 6 lists bibliographic citations of the thesis.

Chapter 1

Introduction

Chapter I

1.0 Introduction

Sweetness is one of the four fundamental sensations perceived by the sense of taste (Nabors and Geraldi, 1991) and always gives a pleasure. Mankind has consumed sweet things ever since sweet ingredients have been available. It is thought that humans are born with a liking for sweetness (Birch, 1997).The following sections briefly review the role and applications of different sweet ingredients, sugar substitutes and Indian traditional sweets.

1.1Conventional sweet ingredients

A number of sweet ingredients are used in the preparation of different sweet tasting food products. Though the sources vary widely, they all contain sucrose as the major sweetening component. These sources are discussed in the subsequent sections.

1.1.1.Honey

The first recorded sweetener is honey. There are references to honey in many ancient manuscripts coming from ancient cultures, ranging from Greece to China. Honey is a supersaturated solution of sugars, mainly glucose, fructose and maltose with traces of sucrose, glucose oxidase, hydrogen peroxide, phenolics, flavonoids, terpenes etc. The sugars make honey hygroscopic (moisture absorbing) and viscous and the high sugar concentration along with other factors, such as low pH, hydrogen peroxide and also the flavonoids, phenolics and terpenes make honey an antimicrobial agent. The main use of honey is as a flavouring sweetener and energy source. The sweetness is from the sugars, particularly fructose and flavour is created by a wide variety of trace essences derived from plant esters, alcohols, aldehydes and other compounds. Other uses of honey are for the promotion of health and well being. Some of these include aiding healing of wounds, healing of serious skin burns and healing gastric ulcers (Schmidt, 1998).

1.1.2. Jaggery

Jaggery (Gur) is defined as the product obtained by concentrating the sweet juices of sugarcane, or of palm trees, to a solid or semi-solid state. It is in the form of balls or square blocks. It is a natural sweetener and has a sweet, winy fragrance and flavour. It has a heady aroma and a delicious flavour, somewhere between brown sugar and molasses. Jaggery contains proteins, minerals and vitamins. It is also a potent source of iron and has higher iron and copper contents than refined sugar. It is also a superior product among natural sweeteners with regards to the vitamin content. It is an energy food that is said to purify blood, regulate liver function and keep the body healthy. As a form of sugar, it forms an important item of the diet and is either consumed directly or as a sweetening agent for sweet preparations (Shahi, 1999). It also forms a base for the innumerable palatable dishes, which are famous in different countries. It has unique characteristics for which it is preferred by consumers over white sugar for preparation of certain sweet dishes (Manay and Shadaksharaswamy, 2001).

1.1.3. Sugar

Sugar, was originally extracted from sugar cane in the West Indies. However, due to the world wars, sugar derived from beetroot also played a significant role (Bright, 1999). Sucrose is the single most important ingredient in the manufacture of all types of confectionery from the simplest to the most sophisticated. Even with the advanced technologies available today for the synthesis of nearly any natural or synthetic compound, no suitable method of synthesizing sucrose has yet been found. There is nothing, as yet developed by nature or humans, which has the unique sweetening, bulking preference/liking and processing properties of this natural ingredient.

Part of the versatility of sucrose, as it imparts different properties to confectionery products lies in its solubility and the nicety of control that can be affected on solubility (Flanyak, 1991). Sugar has been and remains the major ingredient in most confections. It is the sweetness, flavour and functional properties of sucrose that to a great extent make a variety of confections so enormously popular throughout the world. Historically, sucrose has provided a readily available and relatively cheap source of food energy for mankind. It remains one of the most efficient food sources in terms of calories produced per acre of land (Ross, 1990). Some of the important properties of sucrose are listed below (Table 1.1).

Table 1.1 Some important properties of sucrose

• Sweetness	• Texturizer
• Flavour enhancement	• Gelling effects
• Caloric contribution	• Spoilage prevention
• Protein/ starch interactions	• Freeze point depression
• Tenderizer	• Gloss formation
• Aeration	• Recystallization
• Browning / caramellization	• Solubility
• Yeast nourishment / leavening	• Viscosity
• Whipping aid	• Moisture retention
• Surface tension	• Adhesion and binding
• Texture development	

At present it is difficult to imagine that just a few centuries earlier, sugar was a luxury commodity affordable only to the very rich and powerful. Sugar is used not only in the manufacture of candies and sweets, but also in savory dishes, baked products, as a preserving agent in foods, medicines and so on. The use of sugar in foods and medicines has changed only marginally in the last few centuries; but the numbers of its users, the quantities used and the symbolism attached to it have surely increased vastly (Sandra Mian, 2001).

1.1.3.1 Drawbacks of sugar consumption

The reason human beings prefer sweet taste is probably evolutionary i.e., to ensure that infants are attracted to the sweet taste of their mother's milk. However, what may have started off as evolutionary has today turned into a passion. It is hard to tell exactly how much sugar the average Indian consumes daily, but going by the number of sweetmeat (*mithai*) shops that are sprouting in every street corner and the sky rocketing sales of sweets, chocolates and candies, it is quite evident that Indians are a nation of sweet lovers (Anon, 2000).

Over the past few decades, however, the nutritional role of sucrose has become a subject of controversy, due to the changing dietary needs of the urbanized population. Medical, academic, government and industry associations have studied and debated the involvement of sucrose in ailments such as dental caries, obesity, diabetes, hypertension, hyperglycemia, heart diseases, behavioral problems etc. Each of these issues and the publicity about them has influenced consumers' attitudes towards sucrose based products.

Ten years ago, health authorities would have said that sugar posed no health risks other than tooth decay. Today, however, the soaring sugar intake in the population has led us to take a new look at the safety of sugar consumption. Virtually all researchers agree on one thing: viz, that sugar provides only empty calories and has no other nutritional value; thus, it can crowd important nutrients out of the diet. Whether sugar or other high glycemic foods increase the risk of developing diabetes or of having a heart attack in the insulin resistant minority is not clear. But even the possibility of this provides another reason for everyone to eat less sugar. So, one simple and healthful way to limit total carbohydrate consumption especially for persons who are diabetic or insulin resistant is to reduce or eliminate sugar consumption (Anon, 2000).

In recent years, the products of food industries have been subjected to criticism by health professionals particularly dietitians and dentists. The majority of the comments are of three types: -

1. That eating products of high sugar content makes the consumers more obese, thereby leading to increasing incidence of problems such as heart disease;
2. That high residual levels of sugar retained within the mouth are more likely to result in the early decay of teeth; and
3. Adverse effects of eating products made with sugar will occur amongst those consumers who have certain medical problems such as diabetes (Nabors and Gelardi, 1991).

Two main epidemics associated with excess sugar consumption and thus restrict the use of sugar containing products are: diabetes and obesity.

1.1.3.2 Dealing with diabetes

Diabetes is a fulminating epidemic. Type II, or non-insulin-dependent diabetes mellitus (NIDDM), is the major contributor to the meteoric rise in diabetes rates. According to World Health Organisation's predictions, diabetes incidence in the period from 1997 to 2025 will increase from 143 million to 333 million. Another alarming statistic around the world is the dramatic rate of rise of NIDDM amongst children and teenagers. Nutritional measures that help both to treat the disease and lessen its adverse effects, are essential.

According to the International Diabetes Federation, India currently ranks no. 1 in diabetics in the age group of 20 to 70 years. The country has a diabetic population of 32.7 million (Anon, 2002). Confections and sweets constitute a particularly conspicuous source of sugar and are consumed with meals. They represent an important risk factor in the etiology of diabetes and are likely to become one of the primary targets for elimination or reduction of sugar. This can be achieved in two ways:

a. reduction in confectionery consumption,
b. consumption of confections made from sugar substitutes.

The obese and diabetics are thus deprived of sweets. For such consumers' alternatives are required which will not raise the glycemic index.

1.1.3.3 Obesity

Obesity is a very serious health problem that can have severe implications and is reaching epidemic status in many parts of the world. Today more than 80% of diabetics are obese. Researchers regard obesity and diabetes as the twin epidemics, which threaten the health care system. Obesity is by far the greatest risk factor for type II diabetes. Obese people are more prone to type II diabetes. India has an obese population of 97 million (Nigam, 2004).

These health concerns about sugar have resulted in efforts to find alternative sweeteners that lessen the risk of these problems and also achieve a reduction in energy consumption.

1.2 Sucrose alternatives

To meet the requirements and demands for sugar free products, alternative sweeteners have come into use. Sugar replacers are used in a large variety of products on account of their very specific technological and sensory properties. The nutritional, physical and technological properties of sugar replacers make them good alternatives to sugar. They are the manufacturer's answer to a growing demand for "sugar free", "tooth friendly" and "calorie reduced" or "low-calorie" foods and they also increase the variety of products suitable for diabetics (Zieglader, 1982).

There has been a substantial growth rate in the sugar free market with the forecast saying that it will continue to increase. This growth rate has been and is being driven by two basic factors.

a. *Consumer:* First, the consumer with changing life style and an increased desire to eat a healthy diet is making more and more decisions based on what he or she sees on food labels. A manufacturer can offer new products based on various label statements. The important factor is that the individual should buy repeatedly to ensure a commercial success.

b. *Approval of intense sweetener:* The second reason for this category is the regulatory approval of intense sweeteners. Following, the approval of use of intense sweeteners, they have become available for use in confectionery; while the earlier sugar free products were acceptable, now new products that have sweetness equal to their sugar counterparts, can be easily produced. Additional new bulking agents are finding their way into confections (Raleigh, 1995).

Now with these bulking agents and intense sweeteners, many sugar confections can be made sugar-free. The need for product development towards "sugar free" or "low calorie" now is directed more towards cost issues, or calorie reduction, or food for diabetics. The low calorie sweetener business has evolved rapidly over the last twenty years. It is really possible to deliver products whose acceptability matches, or even exceeds, that of their sugar counterparts. In order to introduce sugar free products, which take advantage of the new processes and compounds, it is essential to understand the physical properties of sucrose alternatives and their interactions with other ingredients (Wright, 1990).

1.3 The ideal sweetener

Alternative sweeteners are used to:

a. Provide and expand food and beverage choices to control caloric, carbohydrate or specific sugar intake;
b. Assist in weight maintenance or reduction;
c. Aid in the management of diabetes;
d. Assist in the control of dental caries;
e. Enhance the usability of pharmaceuticals and cosmetics;
f. Provide sweetness when sugar is not available; and
g. Assist the cost effective use of limited resources.

An ideal sweetener does not exist. Even sucrose does not fulfill all sweetening needs. Alternative sweeteners are superior to sucrose in some products (pharmaceuticals and chewing gums). The ideal sweetener should be at least as sweet as sugar, colourless, odourless and non-cariogenic. It should have a clean pleasant untainted taste with immediate onset and without lingering aftertaste (Nabors and Gelardi, 1991).

A sweetener should be compatible with a wide range of food ingredients. The ideal sweetener should be water soluble and stable under both acidic and basic conditions and over a wide range of temperatures. Stability over a long period is also important and it is essential that an alternative sweetener be safe. The sweetener must be non toxic and be metabolized normally or excreted unchanged. A sweetener should be competitively priced with sucrose and other comparable permitted sweeteners, it should be easily produced, stored and transported (Nabors and Gelardi, 1991).

1.4 The multiple sweetener approach

Low calorie products were earlier dependent on saccharin, the oldest intense sweetener, but now, several other products have become available, so that a multiple sweetener approach can be adopted. Availability of a variety of sweeteners is important, as no single sweetener including sucrose is not perfect for all uses. Each sweetener can be used in the applications for which it is best suited. Limitations of individual sweeteners can be eliminated by

using them in blends (Nabors and Gelardi, 1991). Formulation of the optimum sugar free confection that provides the best product, in terms of taste, adequate stability and acceptable cost will, in many cases, require the use of multiple bulk sweeteners (Olinger, 1990).

Low calorie food products in combination with low amount of sugar are gaining increasing acceptance to the consumers. Thus, substitutes have drawn special importance to the researchers dealing with the development of such low calorie, low sugar products. The discovery of a large number of sweeteners over the past few decades has also led to the development of such type of products, particularly for weight watchers and among people with diabetes using a special diet or prone to obesity (Ozdemir et al, 1998). A product with reduced sugar can be adequately matched in sweetness using an intense sweetener such as aspartame, saccharin, etc. The challenge however, lies in how to match the other functions provided by sugar. Features and functional requirements of sucrose alternatives are shown in Tables 1.2 and 1.3.

1.5 Problems in sucrose replacement

Sugar does more than adding sweetness to a confectionery product. It provides bulk, lowers water activity and modifies the texture. High intensity sweeteners provide the sweet taste that is lost when sugar is removed, but they cannot perform other physical functions of sugar. For this reason, polyols (bulk sweeteners) and polymeric bulking agents (maltodextrin and polydextrose) are needed when producing sugar free sweets. Polyols alone or combined with other sweeteners can be used to produce sweets/confections that are safe for diabetics. These sugar replacers are physically, chemically and microbiologically stable (Bunting, 1994) and are discussed in detail later.

When searching for a replacement for sucrose, it is important that it should offer both the physical bulking effects and the clean sweetness characteristic of sucrose. Introduction of new sucrose replacers can involve long and expensive approval procedures that are aimed primarily at ensuring consumer safety. However, even sweeteners that enjoy good success show some defects when critically compared with sucrose.

Foods with high percentage of sucrose impart distinct textural and mouthfeel properties, which are due to the presence of sucrose. Unlike

artificial sweeteners, sucrose also possesses preservative action in foods in addition to providing body and sweet taste (Selby and Taggart, 1974). Therefore, it is difficult to obtain quality attributes in sugar free products similar to sucrose containing products, where high percentage of sucrose is used. The influence of textural properties on the perceived taste intensity of sugar replacers is a matter of interest from theoretical and practical points of view. The various types of sucrose alternatives are discussed below.

Table 1.2 Features of an ideal sugar alternative (Deis, 1994)

- Safe
- Stable
- Low calorie
- No gastrointestinal side effects
- Low cost
- No off flavours
- Highly soluble
- Low viscosity
- Crystalline
- Browning
- Protein/starch interactions
- Similar to sucrose

Table 1.3 Functional consideration of sweetener systems (Deis, 1994)

Appearance	▪ Gloss ▪ Crystallinity ▪ Colour development ▪ Clarity
Mouthfeel and texture	▪ Cooling ▪ Melting ▪ Crystallinity ▪ Viscosity ▪ Tackiness
Flavour	▪ Sweetness intensity ▪ After taste ▪ Flavour modulation ▪ Flavour masking ▪ Aroma
Marketing and regulatory Issues	▪ Label appeal ▪ Ingredient label position ▪ Regulatory restrictions ▪ Potential health implication ▪ Caloric content ▪ Digestive effects ▪ Serum glucose value ▪ Cariogenicity consumer clean up
Storage and handling	▪ Crystallization ▪ Hygroscopicity ▪ Bulking properties ▪ Flowability ▪ Pumpabililty ▪ Dusting potential ▪ Electrostatic potential ▪ Foaming properties
Process and preparation	▪ Solubility ▪ Dispersibility ▪ Freeze point depression ▪ Boiling point elevation ▪ Water activity ▪ Dielectric properties ▪ Preservative qualities ▪ Enzymatic properties
Reactivity	▪ Heat stability ▪ pH stability ▪ Inversion ▪ Microbial stability ▪ Fermentability ▪ Colour stability

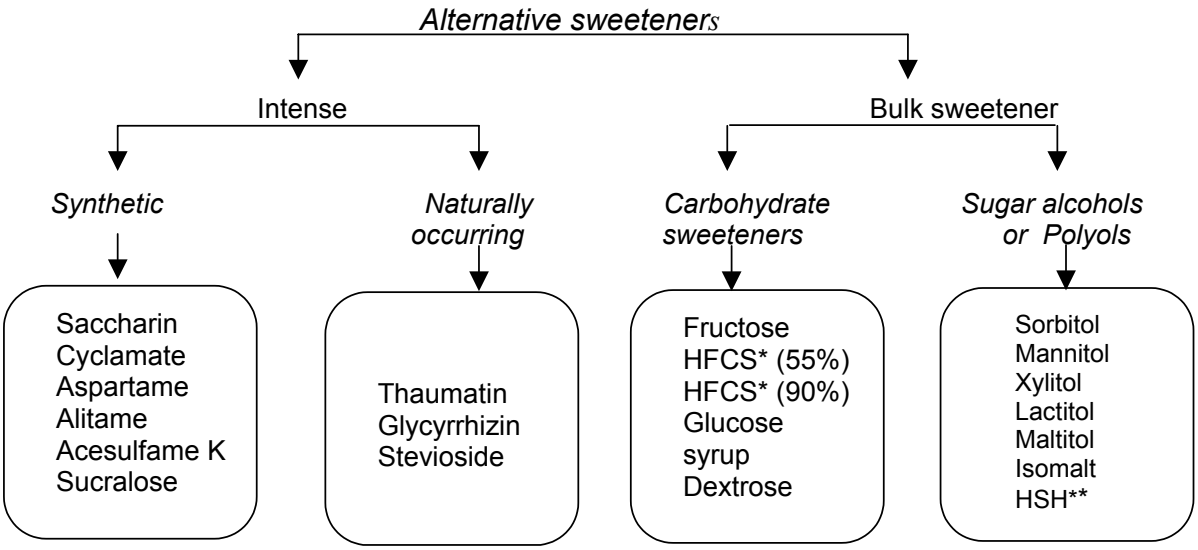
1.6 Classification of alternative sweeteners

There are several approved and unapproved, nutritive and non-nutritive, alternative sweeteners. Some are synthetic, a few are found in nature, isolated and purified for use in the food industry. Alternative sweeteners can be categorized in several ways:

a. Chemical nature (synthetic vs. naturally occurring)
b. Applicability (i.e. whether they are heat stable, pH stable etc.)
c. Level of intensity (compared to the sweetening power of sucrose)
d. Date of approval (whether earlier or later than 20 years ago).
e. Type of applications (e.g. low-calorie foods)
f. Acceptability (approved vs. unapproved)

This classification helps in selecting the appropriate sweetener to be incorporated in the particular food of interest. Broad, general classification of sucrose alternatives are shown in Fig. 1.1.

Fig. 1.1 Classification of alternative sweeteners (Pepper, 1987**).**



New generation sweeteners

Neotame
Tagatose
Erythritol

* Hydrogenated fructose corn syrup

** Hydrogenated starch hydrolysate

1.7 Intense sweeteners

Historically, intense sweeteners have formed the basis for the development of low calorie foods and beverages. Saccharin was first developed in the late 1800's and by 1917 it was a common table top sweetener; cyclamates were discovered in 1973 (Mitchell and Pearson, 1991). These substances are many times sweeter than sucrose; it and that is the reason, why their solubility is of lesser importance, as only a very low concentration is needed to achieve the desired sweetness. The considerations more important, than intensity of sweetness are the taste profile and stability to degradation. Intense sweeteners cannot deliver the bulking properties of bulk sweeteners. Hence, these sweeteners can be used with the bulking agents that are much less sweeter than sucrose. They are also characterized by a strong non-linear concentration-response relationship, which must be considered, when formulating sucrose-replaced formulations. Many of the intense sweeteners may exhibit a range of unattractive, non-sweet flavours. For example, acesulflame K and cyclamate have bitter and burnt flavours, while neohisperidine dihydrochalcone (NHDC) has a strong liquorice flavour. The impact of these flavours depends on the food matrix and it is a common practice to use blends of intense sweeteners to optimize the sweetener's profile.

Several sweeteners are now available, but their use is often limited on account of their regulatory status and/or physical properties. Intense sweeteners are broadly classified into synthetic and naturally occurring sweeteners. Some of those, which are currently in use and some that may be used in the near future are as follows.

1.7.1 Synthetic intense sweeteners

1.7.1.1 Saccharin

The name saccharin is derived from the Latin word for sugar. Discovered in 1879, saccharin is a cyclized derivative of orthosulfamoylbenzoic acid. It is slightly soluble in water. It is available in the form of acid saccharin, calcium saccharin and as its sodium salt. Table 1.4 shows the properties of different saccharin forms. It is known to have a bitter, metallic after taste and is usually blended with other sweeteners, such as cyclamates, aspartame, or sucralose.

Table 1.4 Properties of saccharin forms

	Acid saccharin	Sodium saccharin	Calcium saccharin
Molecular formula	$C_7H_5NO_3S$	$C_7H_4NO_3SNA_2H_2O$	$[C_7H_4NO_3S]_2$ $Ca.2H_2O$
Molecular weight	183.18	241.20	440.48
Melting point (°C)	228.23	>300	>300

At pH < 2.0 when subjected to extremely high temperatures, hydrolytic decomposition to 2-sulfobenzoic acid and 2-sulfamoyl benzoic acid can occur and neither of these compounds exhibit sweet taste. Saccharin is stable when heated at normal food processing temperatures, but when heated to decomposition (380°C), all three saccharin forms exhibits toxic fumes of nitrogen oxides and sulphur oxides. Although, saccharin does not decompose under the conditions encountered during typical food processing, some degree of hydrolysis does occur on prolonged exposure to extreme conditions of temperature or pH.

Saccharin is 300 times sweeter than sugar and is used mainly as a table top sweetener, in tablet, powder, or liquid form, as well as in soft drinks and other beverages, in many processed fruits, chewing gum confections, gelatin desserts, juices, jams, toppings etc. Currently saccharin is sold in the market under the trade name Nutra-sweet (Newsome, 1993; Mitchell and Pearson, 1991).

1.7.1.2 Cyclamate

Cyclamate is a non caloric sweetener, 30 times sweeter than sugar (Table 1.5). It was discovered accidentally by Michael Sveda in 1937 and gained popularity in the 1950's and 1960's. It was used primarily in a blend with saccharin. Cyclamates, whether in the form of sodium or calcium salts, are stable and soluble in water; they were first marketed as dietetic aids by Abbot Laboratories in the early 1950's. Cyclamates are now used as table top sweeteners and also in beverages and other low calorie foods. In addition, cyclamates are useful as flavour enhancers (Bopp and Price, 1991).

Table 1.5 Relative sweetness of various sweeteners compared to sucrose (Source: Nabors and Gelardi, 1991)

Carbohydrate, sweeteners	
Fructose	1.3-1.8
High fructose corn syrup (55%)	1.0
High fructose	>1.0
Glucose syrups	0.3-0.5
Dextrose	0.6
Sugar alcohols	
Xylitol	1.0
Isomalt	0.45-0.64
Lactitol	0.3-0.4
Maltitol	0.7-0.9
Mannitol	0.7
Sorbitol	0.54-0.7
Intense sweeteners	
Acesulfame K	200
Aspartame	180
Alitame	2000
Cyclamate	30
Monellin	1500-2000
Saccharin	300
Stevioside	300
Sucralose	600
Thaumatin	2000-3000
Glycyrrhizin	50-100

Relative sweetness (Sucrose=1)

Cyclamates are approved for use in more than 50 countries, the notable exception being the United States of America. The Food and Drug Administration (FDA) of the USA once listed cyclamates as GRAS substances and they were used most often in combination with saccharin. But the scientific studies (Neil, 1987), showed that cyclamates were the causative agents of malignant bladder tumors. So, the FDA removed them from the GRAS list for foods, beverages and pharmaceuticals (Newsome, 1993). However, subsequent studies on cyclamates, along with the extensive data now available on their pharmacokinetics and metabolism in humans and animals, combined with epidemiological evidence, have demonstrated the safety of cyclamates when used by human beings (Newsome, 1993).

1.7.1.3 Aspartame

Aspartame is probably the most well known intense sweetener and has enjoyed a great success. Aspartame, which was discovered in 1965, is a dipeptide of phenylalanine and aspartic acid and also contains a methyl ester. It is a clean tasting synthetic sweetener that leaves no bitter or metallic after taste (Newsome, 1993). The relative sweetness of aspartame is 180-200 times greater than sugar (Table 1.5).

Aspartame is highly stable in the dry state, but in solution its stability is a function of pH and temperature. Aspartame is stable in the range of pH 3-5 and is most stable at pH 4.3. It loses its stability at pH values greater than 5 and also when heated. In aqueous systems at certain temperatures and pH levels, aspartame hydrolyses to form the end products like methanol and the dipeptide aspartyl phenylalanine. These end products exhibit no sweetness. Further, in its dry state, or under aqueous conditions, aspartame can form the compound diketopiperazine (DKP). This reaction becomes most prominent at neutral and basic pH levels and when subjected to heating. Once this reaction occurs, the sweetness is lost. DKP decreases the sweetness of aspartame, even if the reaction is not complete and aspartame is still present. If aspartame decomposes and forms methanol and aspartyl phenylalanine, the dipeptide can also form DKP (Nabors and Gelardi, 1991).

Aspartame is digested just like any other protein, upon digestion; aspartame breaks down in the blood and does not accumulate in the body. Aspartame enhances fruit flavours and works well in acidic, fruit-based systems. In its dry state, aspartame decomposes at temperatures > 150°C and has a melting point of 246-247°C. Aspartame has been reviewed and

approved for use by the Joint Expert Committee of Food Additives of the FAO/WHO and the scientific committee for food of the European Community (EC) (Altschul, 1993). Aspartame is now considered as safe for the general public and diabetics. The allowed daily intake (ADI) for aspartame has been set at 50mg/kg of body weight (Holmer et al, 1991).

1.7.1.4 Acesulfame pottasium

Discovered in 1967 and marketed under the brand name “Sunnette” and “Sweet one”, it is approximately 200 times sweeter than sucrose. The sweetness intensity of acesulfame K is perceived quickly but often fades away rapidly. It is quite stable at elevated temperatures and at a pH range of 3 to 7. At high concentrations, bitterness or a chemical synthetic note may be detected. It forms synergistic blends with aspartame and with the nutritive sweeteners such as fructose and sugar alcohols. Acesulfame K is not metabolised in the body and thus it is a non caloric item. The sweetener is excreted by the kidneys (Hanger, 1995).

1.7.1.5 Alitame

Developed by Pfizer, it is approximately 2000 times sweeter than sucrose. This high sweetness enables its use at very low level, probably in the 20-200 ppm range. Like aspartame, it is a dipeptide sweetener containing two amino acids; aspartic acid, alanine and an amide group. The melting point of alitame is 136-147°C. The amide group is in part responsible for alitame’s intense sweetness and noteworthy stability characteristics compared with those of aspartame. It is soluble in water and forms clear solutions. The dipeptide bond of alitame can be hydrolyzed to form the two products, aspartic acid and the alanine amide. These end products do not exhibit sweetness. Alitame is stable in carbonated beverages and can withstand the pH levels typical of soft drinks. At neutral pH and under aqueous conditions, it is stable for more than a year.

Because it is stable during heating, alitame can be used in processed foods such as baked goods. Alitame participates in the maillard browning reaction by providing the -NH group. At pH <4, off- flavours may be formed in the presence of sodium bisulphite, ascorbic acid and some caramel colours.

1.7.1.6 Sucralose

Sucralose was developed by Tate and Lyle (London, England). The manufacturing process is patented. The process results in intense sweeteners having low stability unless stored under appropriate conditions. A stable liquid form was also developed. It has a sweet taste and a flavour profile similar to that of sucrose. It is 600 times sweeter than sugar (Table 1.5).

Due to its three substituted sites (at which chlorine replaces a hydroxyl group on the sucrose molecule), the reactivity of sucralose is much lower than that of sucrose. Under acidic conditions, sucrose hydrolyses to its component like sugars, glucose and fructose. Sucralose gets hydrolysed only under highly acidic conditions and the extent of hydrolysis increases with increasing temperatures. However, the rate of hydrolysis is much lower than that of sucrose. Since, the primary reaction sites are substituted, sucralose is also less chemically reactive than sucrose. Sucralose does not interact with other food molecules in food systems. In aqueous systems, it is stable over a wide range of pH. Some hydrolysis occurs at pH 3 or lower, but only to a small extent, at pH 4 -7.5; virtually no sucralose is lost when stored at 30°C for a year. An ADI of 15 mg/kg was set by FAO/WHO expert committee on food additives (Miller, 1991).

1.7.2 Naturally occurring intense sweeteners

1.7.2 .1 Thaumatin

In 1855, the fruit of *Thaumatococcus daniellii*, a plant found in West Africa, Uganda and Sudan, was noted to have very sweet taste. In 1979, two proteins named thaumatin I and II were characterized as the cause of sweet taste. The British firm Tate and Lyle markets the proteins as “Talin”. It is cream coloured and is available in the aluminium cation form, which is intensely sweet. It is stable in powder form and blends synergistically with acesulfame K, stevoiside and saccharin. Thaumatin is well known for its flavour enhancing capabilities. It is known to enhance the flavours of peppermint, spearmint, coffee and ginger. The sweetness of thaumatin develops slowly and has a characteristic aftertaste that can linger.

Thaumatin is very soluble in water and is also soluble in ethanol, propanol, glycerol and propylene gycol. It is insoluble in acetone and ether. It is 2000 to 3000 times sweeter than sugar (Table 1.5). Solutions of thaumatin

in water can be heated without loss of sweetness. However the aqueous stability of thaumatin does depend on the concentration of the solution, amount of oxygen present, presence of certain salts and polyelectrolytes and on pH. Solutions of thaumatin at room temperature are stable at pH 2-10; its aqueous solutions have maximum stability at pH 2.8-3.0.

Solutions can be pasteurized without loss of sweetness at pH 2.8-3.5 and can be heated at 100^0C for few hours. The thermal stability of an aqueous solution depends on several factors that influence the thermal denaturation of the protein molecule. Once the protein denatures the molecular configuration responsible for the sweetness changes and the sweetness is lost. Thaumatins may also change their molecular configuration and again sweetness would be lost. Alteration of the disulfide bonds can occur as a result of heat denaturation as well as of chemical cleavage (Nabors and Gelardi, 1991).

1.7.2.2 Glycyrrhizin

First isolated in 1970, glycyrrhizin is a compound that is extracted from the roots of the liquorice plant, *glycyrrhiza*. Licorice has been known as a healing herb and medicinal plant since ancient times. Its healing properties are being explored even today in areas such as AIDS research and studies of immunological function. Ammoniated glycyrrhizin, a form that is readily soluble in water, is most often used in food applications. Glycyrrhizin is a triterpenoid and is approximately 50-100 times sweeter than sucrose; it has a long lasting after taste. In Japan, glycyrrhizin is widely used as a sweetening agent in many food and beverage applications. It is used in many countries, for its medicinal properties as well as in food applications. Ammoniated glycyrrhizin is on the GRAS list of food additives for natural food flavourings in the US, but it is not approved as a sweetening agent. Ingestion of a large amount of glycyrrhizin may result in edema, headaches, hypertension and fatigue. The Ministry of Health in Japan has cautioned that the levels used in drug formulation should not exceed 100 mg/day (Nelson, 1997).

1.7.2.3 Stevioside

Stevia rebaudiana, a South American plant, is the source of this sweetener. Stevioside is classified as a diterpenoid compound and is one of the eight sweet compounds present in the plant. In its pure form stevoiside is a white, crystalline powder, with a melting point of 196-198°C. However, stevioside is not generally used as a sweetener in pure form, but rather as

S*tevia rebaudiana* extracts of various degrees of purity such as 10, 50 and 90% w/w. Stevioside is stable in dry form and when maintained in solution in the pH range 3-9; it decomposes rapidly at pH levels of greater than 10. Stevioside is soluble in water; it combines synergistically with glycyrrhizin and is available commercially in a blend with this natural sweetener. It forms synergistic blends with aspartame, cyclamate and acesulfame K, but not with saccharin.

The leaves of the stevia plant are about 30 times sweeter than sucrose and purified stevioside is 200–300 times sweeter than sugar. It is known for its sweetness, slight bitterness and liquorice flavour in powder form. Once it is dissolved in liquid, the bitterness and liquorice notes are less apparent. Stevioside is widely used as a sweetening agent and flavour enhancer in Japan. It is also used in many other countries such as China, Taiwan, Paraguay, Chile etc. Studies have shown that both stevia and stevioside are safe. Stevia leaves have been used for their proposed medicinal properties, which include combating fatigue, facilitating digestion, regulating blood glucose levels, sustaining feelings of vitality and well being and caring for the skin. Stevioside is not an approved food additive in the United States and does not have the GRAS status. In countries other than US, it is used in products such as table top sweetener, soft drinks, juices, confectionery, jams, yoghurts, baked goods and chewing gum (Nelson, 1997; Kinghorn and Soejarto, 1991).

1.8 Bulk Sweeteners

1.8.1 Carbohydrate sweeteners

1.8.1.1 Glucose

Glucose is usually manufactured by enzymatic hydrolysis of starch or by inversion of sucrose to its constituent's glucose and fructose, followed by separation. It is less sweet, less viscous and less soluble than sucrose. However, it has better humectant and better preservative properties, owing to its lower water activity. It is mainly used to form fondants and in cream pastes where it's cooling effect is considered appealing (Pepper, 1990).

1.8.1.2 Fructose

Fructose is one of the major naturally occurring carbohydrate sweeteners. It is manufactured by the inversion of sucrose by enzymatic or acid hydrolysis. Fructose is the major constituent (about 40%) in honey. It is present in many fruits like apple, pear, berry etc. (Moskowitz, 1991).

In the crystalline state, only ß-D-fructopyranose anomer exists, but upon dissolution in water, rapid mutarotation occurs, resulting in the formation of three and possibly four fructose tautomers (Hyvonen et al., 1977). The temperature, pH and concentration of the solution are the most important environmental conditions that influence the magnitude of sweetness of freshly prepared solutions of fructose in water.

The tasting medium also has an effect on the relative sweetness of fructose. A slight acidity of cold fructose solutions, enhances the sweetness of fructose, whereas high acidity depresses the sweetness. Experience has shown that citrus flavoured beverage bases sweetened with pure crystalline fructose and containing the usual amounts of acidulants, can help to reduce the usual sweetener calories up to 50%. Conversely, one of the least efficient uses of fructose is in hot coffee, in which the mutarotation to the furanose forms diminishes the sweetness to the point where it is iso-sweet with sucrose. The temperature also determines the equilibrium state of the anomers at the time of consumption. Thus, cakes made with pure crystalline fructose will taste sweeter after they have been allowed to cool than when tasted just out of the oven.

As compared to sucrose, fructose reacts more favorably with many starches, resulting in a more rapid development of viscosity and greater final gel strength. It was observed that fructose increased the rate of viscosity over the sucrose system, requiring 20 minutes to attain the same viscosity compared to 60 minutes needed for sucrose. Since the water binding capacity of fructose is greater than that of the other sugars, it can be used as a humectant in baked goods and intermediate moisture foods (IMF) such as jams, jellies, pet foods and certain other confections (Osberger, 1991).

1.8.2 Polyols

The polyhydric alcohols or polyols or sugar alcohols are the other type of naturally occurring carbohydrate sweeteners. Sugar-free confectionery has been a success story in recent years, partly due to renewed consumer interest, but mainly due to development of new and better ingredients. Sugar alcohols can provide the functionality and flexibility needed to develop extremely good sugar-free products. Further developments could be made by a better understanding of the chemical, physical and functional differences (Table 1.3) of alternative sweeteners (Deis, 2000).

In general, commercial polyols can be divided into three broad groups: monosaccharides, disaccharides and polymeric mixtures. The monosaccharides are sorbitol, mannitol, xylitol and erythritol; the disaccharides are maltitol, lactitol and isomalt; which the polymeric polyols are maltitol syrup and hydrogenated starch hydrolysate (HSH). The monosaccharide alcohols have been available for a long time, whereas the disaccharide alcohols (2^{nd} generation sugar replacers) have only been available for the last few years. Since sugar alcohols have a very specific technological and taste conferring properties, the quality of sugar-free products can often be optimized by combining sugar replacers. Table 1.6 shows the relevant properties of sugar alcohols compared with those of sucrose.

Table 1.6 Properties of sugar alcohols

	Solubility at 25°C	Heat of soln (KJ/Kg)	a_w value at 25ºC	Melting point ºC	Sweetening power	Sweetening characteristic
Sucrose	67	-18.2	0.85	188	1.0	S
Xylitol(M)	63	-153	NA	93-94	1.0	G
Sorbitol(M)	70	-111	0.32	93-97	0.6	G
Mannitol(M)	18	-121	NA	166-169	0.6	G
Maltitol (D)	62	-79.2	NA	146-147	0.8	S
Lactitol(D)	55	-53.2	NA	120	0.35	S
Isomalt (D)	25	-40	0.85	145-156	0.45	S

*M=Monosaccharide alcohol; D= Disaccharide alcohol; S= like sucrose; G=like glucose; Solubility is expressed as g/100g ; NA: Data not available ; a_w: Water activity

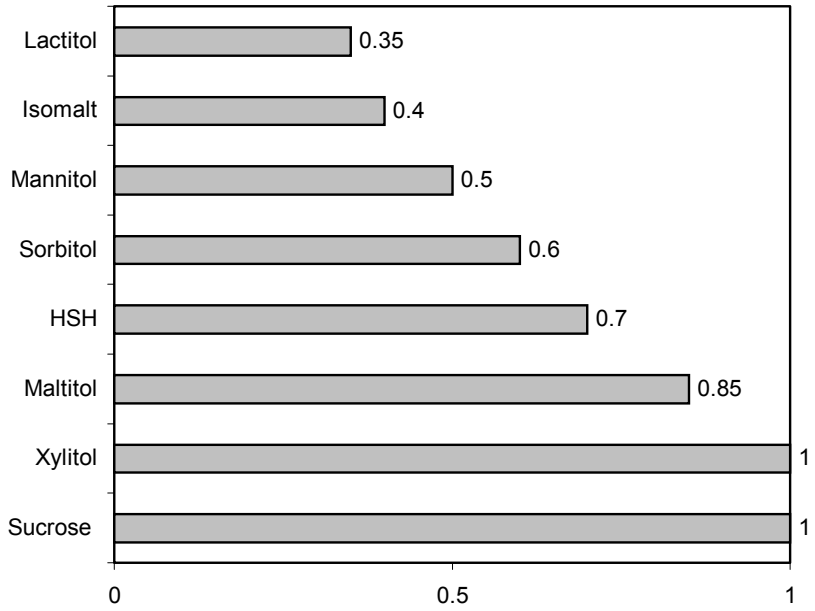
1.8.2.1 General properties of bulk alternative sweeteners

Proper selection of the bulk alternative sweetener and combination of different sweeteners are the critical factors in the successful development of a sugar free confection. The range of bulk sweeteners permitted as sucrose substitutes are characterized by a linear concentration response function, but are less sweet than sucrose and polyols such as sorbitol and xylitol give a cooling effect, which can limit applications. Bulk sweeteners, which are either in use or have the approval for use as sugar free sweeteners, are sorbitol, mannitol, xylitol, maltitol and polysaccharide syrup. Among the properties which can be critical when selecting a bulk sweetener are:

a. *Bulk sweetener cariogenicity*: The cariogenicity of a bulk sweetener is dependent upon the sweetener's susceptibility to fermentation by *Streptococcus mutans* and other oral microorganisms. Fermentable sweeteners such as sucrose, glucose, starch, corn syrup and others are cariogenic or caries causing. Polyols are generally not fermented to any significant degree, thus formation of cavity causing fermentation plaque acids is minimal. Polyols such as xylitol, soribitol, mannitol, maltitol and polydextrose are classed as non-cariogenic or not caries causing.

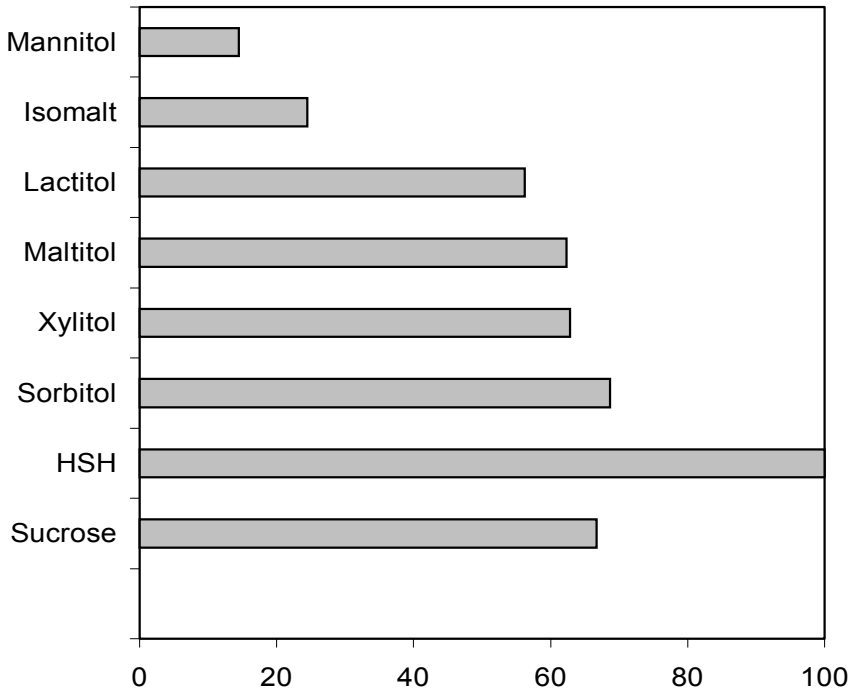
b. *Sweetness of polyols*: A major factor in the appeal of a confection is sweetness and the quality of that sweetness. Xylitol is the sweetest with sweetness equivalent of 1 indicating its iso-sweet characteristics, compared to sucrose (Fig.1.2). The relative sweetness of all the sweeteners are shown in Table 1.5.

Fig. 1.2 Relative sweetness of sugar alcohols or polyols



c. *Solubility and viscosity*: The solubility of bulk sweeteners is greatly influenced by the mouthfeel and texture of the final product. Solubility can also affect the perception of sweetener's onset. The solubility of alternative bulk sweeteners like xylitol, maltitol, sorbitol and polydextrose exhibits solubilities equal to or greater than sucrose, (Fig. 1.3). The low solubility of mannitol can be particularly noted by the chalky mouthfeel it imparts in certain sugar free products

Fig. 1. 3 Solubility of polyols

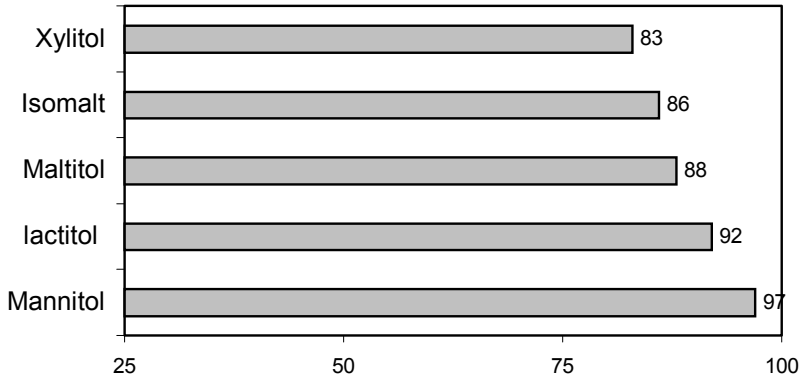


d. *Negative heat of solution*: Cooling effect of polyols is due to the negative heats of solution. When their crystalline forms are dissolved in the mouth, it creates a pleasant cooling sensation. Many confections use this property to enhance the consumer's enjoyment of the product.

e. *Hygroscopicity*: The hygroscopicity of an alternative sweetener can adversely affect the shelf life (stability) of sugar free products. It can also affect the manufacturing characteristics. Mannitol is generally considered to be non hygroscopic, while sorbitol is highly hygroscopic (Fig.1.4).

f. *Chemical stability*: As non-reducing sugars, they do not exhibit browning through maillard type reactions. They tend to resist discolouration even at high temperatures for extended periods and are stable to acids.

Fig. 1.4 Hygroscopicity of polyols



g. *Gastrointestinal tract metabolism*: Sugar alcohols/polyols are slowly absorbed from the intestine and enter the liver, without the need for insulin, where they are converted into fructose. Ingestion of sugar alcohols can result in slower and lower plasma glucose and insulin responses than sucrose or glucose ingestion, except in the insulin deficient person. So, sugar alcohols are recommended for diabetics (Olliger, 1990).

h. Caloric *value*: Despite their slow absorption rate, sugar alcohols are defined by FDA to be metabolized to yield 4 Kcal/g, which is same as that of sugar and other carbohydrates. Outside the USA, however, sugar alcohols are considered to give half of the total calories i.e. 2 Kcal/g due to slow rate of absorption and ingestion.

i. *Laxative effect*: The incomplete digestion and slow absorption of sugar alcohols can cause osmotic diarrhoea effect. This usually occurs after ingestion of excessive amounts in single dose but in some cases, it can have a cumulative effect. The extent of this laxative effect varies depending on the type of sugar alcohol, tolerance of the person and conditions at the time of consumption. In addition to these common characteristics, each sugar alcohol has specific properties that make it more or less suitable for a particular product (Ross. 1990; Ollinger, 1990)

In the present study, sorbitol and mannitol are the two polyols used. Aspartame is the intense sweetener used along with bulking agents such as maltodextrin and polydextrose to prepare the traditional Indian sweets and these are discussed in detail in the subsequent sections.

1.8.2.1 Sorbitol

Sorbitol (synonyms D-glucitol, sorbite) is one of the most wide spread sugar alcohols in nature occurring in many fruits such as apple, pear, cherry, berry, etc. In the mammalian system, sorbitol is present in the foetal blood and plasmas where it is undoubtedly a normal metabolite. Sorbitol is best known for its use in diabetic foods.

Sorbitol ($C_6H_{14}0_6$) is commercially manufactured by reduction of dextrose or is obtained as a by-product of mannitol production from fructose. Sucrose, glucose and starch are the preferred raw materials for the production of sorbitol. The physicochemical characteristics of sorbitol are given in Table 1.7. Manufacturers who use sucrose as a raw material often produce a sorbitol (75%) and mannitol (25%) simultaneously by the hydrogenation of invert sugar (Sicard, 1982 and Dwivedi, 1991).

Table 1.7 Physicochemical properties of sorbitol

Chemical formula	$C_6H_{14}O_6$
Mol. weight.	82.17
Melting point °C	86-97
Heat of solution at 25°C (Cal/g)	-28
Solubility in water at 25°C(g/100g of Water)	235
Caloric value/g (Kcal/g)	4
Sweetness (Sucrose=1)	0.5-0.6
Taste	Cool, Sweet
Resistance to high temperature	Stable
Hygroscopicity	medium

Source: Sicard and Lerory, 1983.

Sorbitol is commercially available as a 70% solution and as a crystalline powder. Liquid sorbitol has humectant and plasticizing properties, which are desirable in soft candies. Crystalline sorbitol has three isomeric forms: namely, the alpha (amorphous), beta (unstable) and gamma (stable) forms. The unstable form is much more hygroscopic than the others and hence, it is advantageous to use stable sorbitol to avoid problems of product shelf life and lumping of the powder during storage. Processing conditions in

operations such as hard pan coating, boiling of candy and tableting must be controlled so as to ensure that the crystals are in a stable state (Ross, 1990). At 20ºC the solubility of sorbitol is 69%, which is slightly higher than that of sucrose; at 50ºC it increases to 83%, compared to 72% for sucrose. The viscosity of sorbitol also increases with temperature, in contrast to that of sugar. Sorbitol's high solubility combined with its low heat of solution (-28 cal/g) in its stable crystalline form creates a cooling effect in the mouth (Wright, 1990). Sorbitol has a sweetness level of approximately 60% that of sucrose (Table 1.5); it has a calorie value of 4 Kcal/g and is non-cariogenic (Whitemore, 1985 and Caliari, 1983). However due to slow absorption in the intestinal gut the caloric value has been calculated as 2.6 Kcal.

Sorbitol has been used as a sweetening agent for diabetics ever since it was reported (in the late 1920's) that moderate amounts of sorbitol taken by normal or diabetic subjects caused only a small and insignificant rise in blood sugar concentration. It is more slowly absorbed in the intestine than the other sugar alcohols; to avoid laxation the recommended limit for consumption of sorbitol (50g/day) is higher than that for mannitol (Ross, 1990). "*Excess consumption may have a laxative effect*".

Some health professionals have discouraged the use of sorbitol by diabetics on the ground that sorbitol is capable of being converted to glucose and eventually requires insulin for its metabolism; but this objection is now disregarded. The intracellular accumulation of sorbitol is directly related to hyperglycemia produced due to lack of insulin. Because sorbitol ingestion results in lower blood sugar levels, sorbitol is expected to reduce the severity of diabetic complications (Dwivedi, 1978 and 1991). Intensive studies have been made of its suitability for diabetics.

Crystalline sorbitol lowers the water activity in some products, such as chocolates; so it can be used to extend shelf life and maintain freshness (Ross, 1990). It improves the shelf life of confections based on sugars. It finds application in many confections - such as fondant, fudge, icings and toppings, chewing gum, hard candy, cookies, etc., as a partial or total alternative to sucrose. It is possible to obtain a hard and smooth sorbitol coating, which is not hygroscopic and should be used below 40ºC. The specific advantage of using sorbitol is its low cariogenicity. The explanation offered for this is that it cannot be metabolized as easily by the oral microflora to produce acids that attack the teeth in the caries process (Grenby, 1983).

FDA has classified sorbitol as Generally Recognized As Safe (GRAS) additive; it may be used in foods at levels not in excess of Good Manufacturers' Practices (GMP). It may be used at levels not to exceeding 99% in hard candies and cough drops, 98% in soft candies, 75% in chewing gums, 30% in jams and jellies, 30% in baked goods and mixes, 17% in frozen dairy desserts and mixes and 12% in other foods (Ross, 1990).

1.8.2.2 Mannitol

Mannitol is found plentifully in the sweet exudates of trees and in certain varieties of mushrooms and marine algae (Ross, 1990). It was originally obtained from seaweeds as a by product in the production of alginates (Sicard, 1982). It is an isomer of sorbitol and may be prepared by hydrogenation of fructose, a process that yields 3 parts of sorbitol and one part of mannitol. Mannitol, being less soluble, crystallizes from solution and mother liquor containing predominantly sorbitol.

Mannitol can also be obtained from starch (Dwivedi, 1978). Dextrose is purified by crystallization and it is then epimerised before hydrogenation to D-mannose (25-30%) in presence of ammonium molybdate followed by enzymic isomerisation using glucose isomerase to give a mixture of 44% fructose, 50% glucose and 6% polysaccharide, which is roughly equivalent to invert sugar and catalytically hydrogenated. The low hygroscopicity and excellent flow characteristics of mannitol makes it suitable for use in tableted powders, chocolates, dusting powders for chewing gums, lubricants and release aids for mould and equipment. The physico-chemical characteristics of mannitol are shown in Table 1.8.

Table 1.8 Physico-chemical properties of mannitol

Chemical formula	$C_6H_{14}O_6$
Mol. weight	182.17
Solubility (g/100g water) at 30ºC	25
Melting point (ºC)	165-168^{0}C
Heat of solution	-29 cal / g
Hygroscopicity	Moderate

Mannitol has about 50-65% of the sweetening power of sucrose and has the lowest caloric value (2 Kcal/g) among the approved polyols. The main use of mannitol has been in chewing gum, not as the sole sweetening and bulking

agent but blended with sorbitol (Wright, 1990). Mannitol is slowly fermented by mixed plaque organisms in vitro and is less cariogenic than sucrose. The FDA has recommended a maximum daily intake level of 20g (Ross, 1990). In the United States, mannitol has interim food additive status and may be used at levels not exceeding the following limits:- pressed mints 98%; hard candies 5% cough drops 5%; chewing gum 31%; soft candies 40%; confections and frosting 80%; non standardized jams and jellies 15% and others 2.5% (Dwivedi, 1991).

1.8.2.3 Xylitol

Xylitol is a pentitol, which occurs widely in berries and vegetables such as raspberry, strawberry, plum, carrot, cauliflower, spinach, lettuce etc. Xylitol is found as a normal intermediate in the human body during glucose metabolism; it is produced in the liver at a rate of 5-15 g/day (Pepper and Olinger, 1988). Since it is largely insulin independent, it is used as a sweetener in the diabetic foods and as an energy source in parenteral nutrition. Xylitol has been used as a sweetening agent since 1960.

Xylitol is the sweetest of the sugar alcohols and has the greatest cooling effect when used in dry applications, such as hard candy and chewing gums. It has approximately the same sweetening power as sucrose, being twice as sweet as sorbitol and thrice as sweet as mannitol. The viscosity of xylitol is lower than that of sucrose or other sugar alcohols, thereby yielding a poor bodying effect, unless compensated by use of other ingredients such as polydextrose or mannitol. The calorie content of xylitol is same as sucrose i.e., 4 Kcal/g. Xylitol, being a nutritive sweetener, will not change the caloric value of a formulation.

Dental health researchers generally recognize xylitol to be the best of all the nutritive sweeteners in preventing caries. Clinical studies demonstrate that xylitol has cariostatic property, which gives it advantage over other sugar alcohols. Some evidence suggests xylitol may even be anticariogenic. Xylitol must be present at a total sweetness level of at least 50%, if one desires to claim dental benefits (Ross, 1990). In 1988, the FDA cleared xylitol for use in foods for special dietary uses. When eaten in solid or crystalline form, it gives a pleasant cooling fresh sensation because of its high negative heat of solution (-146.16 j/g), the lowest of the polyols. The solubility of xylitol in water at 30^0C is same as that of sucrose (63g/100g solution). Below that

temperature it is less, above it, more soluble than sucrose. Since the melt is stable under certain conditions, any degree of supersaturation is possible. These unique characteristics make xylitol particularly well suited for breath mints and chewing gums that are promoted as a means to help prevent cavities. Because it is so sweet, it can be used alone in chocolate, caramels and gummy candies as a one replacement for sucrose. (Sandra Mian 2001).

The joint FAO/WHO expert committee on food additives has not specified an acceptable daily intake for xylitol. This means that, on the basis of available data, the potential daily intakes do not represent a hazard to health. The regulatory status of xylitol varies from country to country. In Scandinavia, xylitol is permitted in chewing gums, pastilles and in chocolates. In Denmark, xylitol is permitted only in chewing gum. In the UK, the Food Additives and Contaminants Committee recommended that xylitol be approved as a sugar substitute. In the USA, xylitol is allowed in special dietary foods (Bar, 1991).

1.8.2.4 Lactitol

Lactitol under the trade name “lacty” is a bulk sweetener, is a disaccharide sugar alcohol, derived by hydrogenation of the glucose portion of lactose. It exists in an anhydrous form, as also in 2 crystalline forms, monohydrate and dihydrate. Lactitol has a clean, sweet taste, with a very low cooling effect. The sweetness of lactitol is approximately 40% that of sugar. It is possible to increase the sweetness by using an intense sweetener along with it. Lactitol has been used alone as well as in combination with polydextrose to prepare chocolates and hard candy. Chocolates sweetened with lactitol exhibit a pleasing mouth-feel. The acceptable mouth-feel is facilitated by its solubility. It is a versatile bulk sweetener, which, in combination with other polyols, polydextrose and intense sweeteners can achieve different objectives in the field of sugar free product development. It is a superb bulk sweetener for soft candy, chewing gums and panned products (Mesters, 1995). It is not hydrolyzed by the enzyme lactase. Lactitol has very low hygroscopicity, lower than that of sucrose.

The FDA has given a caloric value of 2.0 Kcal/gm for lactitol. Thus, it is among the sugar alcohols having with the lowest caloric value. It is suitable for diabetics. Several clinical trials have shown that its consumption does not increase blood glucose or insulin levels. Lactitol is non-cariogenic as it is not

fermented by the oral micro-flora; so, its consumption does not lead to the formation of acids that demineralize tooth enamel (Mesters, 1995; Velthuijsen and Blankers, 1991).

1.8.2.5 Maltitol

Maltitol, or α, (1-4) glucosyl sorbitol, is a crystalline polyhydric alcohol obtained by the hydrogenation of maltose, a disaccharide consisting of two glucose units linked via an α (1-4) bond. Maltitol syrup is defined as one that contains more than 50% maltitol and also low levels of sorbitol. Maltitol and higher hydrogenated oligosaccharides, crystalline maltitol powders with maltitol contents as high as 99% are also available.

Maltitol exhibits a negligible cooling effect in the mouth given its negative heat of solution (-23 Kj/Kg) which is much less than that of other polyols. Like other polyols, maltitol has no reducing groups and will not undergo Maillard reactions. It exhibits very low hygroscopicity. It is stable at pH 5-7, but at lower pH levels and especially at higher temperatures, maltitol can hydrolyse. Enzymes can also cleave it. Maltitol is very soluble in water (66g/100g at 25°C) and is more soluble than sucrose at temperatures > 40°C.

Maltitol based confections include chocolates, hard boiled candy, pressed tablets, caramels, jellies, gums and pastilles. By substituting maltitol for sucrose one can make sugarless chocolates of high quality. As is the case for many polyols, excessive consumption of maltitol may have a laxative effect. Because hydrolysis of maltitol is slower than that of sucrose in humans, it is suitable in diabetic diets. Studies have shown that ingestion of maltitol does not produce a marked elevation in blood glucose levels in diabetic individuals (Moskowitz, 1991).

1.8.2.6 Isomalt

Isomalt is a sweet bulking agent, which has been developed to replace sugar in many food applications, particularly in confectionery industry. Isomalt has the clean, pure taste typical of sugar, without any after taste. The calorie value of isomalt is one half that of sugar.

Isomalt does not promote tooth decay and is suitable for use by diabetics. It is non hygroscopic and thereby extends the shelf life of many products. In Europe, isomalt is currently being used in the production of

confectionery, chocolate, chewing gum, baked goods and ice cream (Irwin, 1990). Due to these similarities with sugar is that in most products, isomalt can be substituted for sugar in the formulas and the products can be produced in existing facilities without making significant changes in the process or equipment (Irwin, 1990).

Under practical conditions, isomalt can be considered non-hygroscopic and does not absorb any water at 25ºC and at 85% RH, at 60ºC and 80ºC the RH must be 75% or 65% respectively. The solubility of isomalt in water though not as good as that of sucrose (approx. 25% at room temperature), increases significantly with temperature and is very adequate for most food applications. The viscosity of isomalt solutions is comparable to those of sucrose solutions having the same concentration.

Clinical studies have shown that isomalt is non-cariogenic because it is not a suitable substrate for plaque formation or acid formation; and its influence on oral microflora is minimal. Diabetics easily tolerate isomalt because its ingestion results in slower and smaller changes in serum glucose and insulin blood levels (Irwin, 1990).

Unlike many other sugar alcohols, isomalt (Palatinit) has a low negative heat of solution (-7.37 Kj/mol as against –6.2 Kj/mol for sucrose) therefore, like sucrose, it does not produce a cooling effect. The microbiological stability of isomalt is a result of its 1, 6 disaccharide linkages, as against the 1, 2 linkage in sucrose. These 1, 6 linkages are resistant to attack by human digestive enzymes, as well as by the majority of food spoilage microorganisms. Its chemical-thermal stability is also due to the 1, 6 linkage (Strater and Irwin, 1991).

1.9 Polymeric sucrose replacers

In addition to the polyols, there are several polymeric sucrose replacers to add bulk in the absence of sugar. These include maltodextrin (MD) and polydextrose (PD). Both have been used in the present study, to prepare sugar free products especially with intense sweetener aspartame and are discussed below:

1.9.1 Polydextrose

Polydextrose is a randomly bonded melt polymer of dextrose. A melt condensation polymer is created from a mixture of dextrose, sorbitol and citric acid in a 89: 10: 1 ratio. Polydextrose was created by Pfizer Inc in the year 1970 as a low calorie bulking agent with FDA approval granted in 1981. Polydextrose contains only 1 Kcal/gm because human enzymes do not recognize most of the complex polymers. It is not sweet but does provide many of the physical characteristics found in sucrose making it easy to incorporate into many confections. Because it can be used in such high concentrations, polydextrose solutions are very viscous making them excellent bodying agents. Solutions of polydextrose are slightly more viscous than sugar solutions, which play an important role in partial or full replacements in food systems. Unlike the polyols, polydextrose participates in the Maillard browning reaction and the caramelized flavour produced is very desirable. The hygroscopicity of polydextrose makes it an excellent humectant, but products that do not benefit from moisture retention should be well packaged.

On usage in products, polydextrose reduces calories while maintaining the body and texture of full sugar foods. Due to its fat like characteristics, it is also considered as a fat mimetic in 45 countries (including China). Polydextrose is extremely stable to processing and is not carcinogenic (Deis, 1994 and Bunting 1994). Many formulations using polydextrose under the brand name Litesse has been reported (Kopchik, 1990 and 1995).

Hard candy, toffee, caramels, coatings etc have been formulated satisfying calorie reduction and fat reduction could be achieved by using polydextrose. Usage of polydextrose in hard candy, gum drops, peanut brittle, caramel and toffee have been reported (Moppet, 1991).

Most of the polydextrose ingested passes through the body unabsorbed. The principle utilization pathway for the reminder involves metabolism by intestinal microorganisms to form carbon dioxide and volatile fatty acids (VFA). These acids can be absorbed and utilized as an energy source. A laxative effect can occur at high levels of ingestion because the unabsorbed portion of the polydextrose and the microbial metabolites create an osmotic load in the lower intestines. In a study with adults the mean laxative threshold was 90 gms/day for polydextrose (ranging from 50-130

gms) compared to 70 gms / day for sorbitol (ranging from 40–110gms). Polydextrose has been labeled “safe for teeth “as it does not support the growth of *S. mutans* (Moppet, 1991).

1.9.2 Maltodextrin

Maltodextrin (MD) is simply dried corn starch hydrolysate. It has a DE of less than 20 and is therefore not sweet. They represent a mixture of saccharides with a broad molecular weight distribution between polysaccharides and oligosaccharides and are available mostly as white powders or concentrated solutions. In contrast to native starches, maltodextrins are soluble in water. Maltodextrin is hygroscopic and non crystalline. Some of their important functional properties include: bulking, gelling, crystallization prevention, promotion of dispersibility, freezing control and binding (Chronakis, 1998). Maltodextrin is commonly used to replace sugar bulk, although their caloric contribution is equal to that of sugar. They have the advantage of low cost. Maltodextrins are non-sweet nutritive saccharide polymers consisting of D-glucose units and are produced by the acid and enzyme hydrolysis of corn starch. Other uses include increasing viscosity, building soluble solids, inhibiting sugar crystallization and controlling freezing point. Maltodextrin when used in combination with an alternative sweetener is a full caloric sucrose replacer that provides desirable texture to many food products (Bunting, 1994 and Deis, 1994).

1.10 Indian Scenario

India is the largest producer and consumer of sucrose (197 lakh tonnes during 2003) in the world. There is a stringent regulatory status for synthetic /natural alternatives.

Sorbitol, maltitol and hydrogenated glucose syrup (HGS)

In India sorbitol is permitted for use as an emulsifier and stabilizer and as a sweetening agent in certain confections (PFA, 1955). Some of the other polyhydric alcohols occur in fruit and vegetables, which form part of our daily diet, thus the question of their safety is easily answered. Also some of the polyhydric alcohols have been used in foods in the USA and elsewhere for several decades. Because polyols are functional food ingredients, their use is of interest in the design of lower sugar or reduced calorie foods, which are tooth friendly. Such sugar free confections are common in the USA, European

markets; Denmark, Norway and Finland, for e.g. sugar free gums represent over 90% of the polyol market (Dias and Mehta, 1998).

Saccharin is allowed as a table top sweetener since 1952, aspartame since 1980's. Recently, both aspartame and acesulfame K have been allowed for use in a few food products up to a maximum level of 700 ppm (GOI, 1999). Sucralose is still awaiting approval.

It is imperative to look into the pros and cons of these sweetener applications in Indian sweets. Most of the Indian sweets comprise of as high as 50% sucrose. Hence, the incorporation of alternate sweeteners in Indian sweets offers a great challenge. There are market opportunities in India for such reduced sugar/calorie, tooth friendly products targeted at the growing number of health conscious individuals.

1.11 Indian traditional sweets

India with divergent food habits is having a number of traditional foods. A large proportion of these foods are milk based, mostly lactic fermented and consumed as such or as a sweetmeat. The changing food scenario has led to the commercialization of these traditional foods at the same time; the growing awareness among consumers to obtain safe and healthy foods has laid emphasis on microbial food safety.

Many kinds of traditional sweet products are manufactured in India. No authentic data is available to indicate the exact volume of trade because the industries manufacturing these types of preparations are not well organized (Dwarkanath and Srikanta, 1977; Punjarth and Patel, 1991; Venkatasubbiah and Dwarkanath, 1985). Depending on the raw materials used in the preparation of traditional sweetmeats they can be broadly grouped into:

Flour-based sweets

***Bengal gram* flour based:**

1. *Mysore pak*: A porous structured sweet prepared by heat processing a mixture of *Bengal gram* flour, hydrogenated fat and sugar.
2. *Sohan papdi*: Laminated structured sweet prepared by heat processing a mixture of *Bengal gram* flour / refined wheat flour and hydrogenated fat. Fibrous structure is formed due to crystallization of sugar during

processing. The product is generally topped with broken cashew kernels and raisins.

3. Sweet *boondi*: Droplets of Bengal gram batter fried in oil and soaked in sugar syrup.
4. *Laddu*: Prepared from sweet *boondi*: balls are formed with dry grapes and nuts.

Refined wheat flour based:

1 Badam *puri*: A fried product made out of refined wheat flour and hydrogenated fat. The final product is allowed to soak in sugar syrup.

2 *Jelabi*: Fat fried product prepared out of refined wheat flour with a small proportion of *bengal gram* flour, fermented. The final product is allowed to soak in sugar syrup.

Milk based

A. Heat desiccated products

Khoa : (*Khoa* is concentrated semi solid milk) is the intermediary product, which serves as base for a large number of traditional sweets such as *Milk Burfi, Peda, Gulab Jamun, Kalakand* etc.

1. *Burfi: khoa* based sweet prepared by heating *khoa* on medium heat with sugar and with or without nuts and added flavourings.
2. *Peda*: Similar to *Burfi* but comparatively harder with better keeping quality, with flattened top and bottom, prepared from *khoa* topped with nuts.
3. *Kalakand*: Prepared by heating a mixture of *khoa* and sugar with continuous stirring until characteristic grainy texture and caramelized flavour develops.
4. *Gulab Jamun*: Balls prepared by kneading *khoa* with refined wheat flour, semolina and baking powder or using an instant mix consisting of milk powder, refined wheat flour, fat and other additives. Deep fried in oil or ghee and dipped in sugar syrup.
5. *Rabri*: prepared from buffalo milk consisting of clotted particles in a viscous mass. Popular in the north and central regions of India.

6. *Kurchan*: Heat clotted layers of milk obtained by simmering milk in an open shallow vessel.
7. *Pyodi*: Concentrated buffalo milk with sugar and aromatic spices, popular in the western and southern regions of India.

B. Heat / acid coagulated products

Channa based sweets (*channa* – coagulated casein/ milk solids)

1. *Rasagolla* : Balls made by kneading *channa* with wheat semolina and cooking in sugar syrup
2. *Sandesh* : Small cubes of *channa* cooked in sugar syrup and added aromatic spices
3. *Rasmalai*: *Channa* balls cooked and served in thickened milk, sweetened and added aromatic spices and nuts

C. Fermented / Cultured products

1. *Mishti Doi*: prepared by fermentation of concentrated sweetened milk using lactic acid bacteria.
2. *Srikhand*: prepared by sweetening *chakka* (drained *dahi* / yoghurt) and added sugar, aromatic spices, nuts and at times fruits.
3. *Lassi*: prepared by stirring *dahi* / yoghurt with added sugar and salt.

D. Frozen products

Kulfi / kulfa: It is a frozen dessert prepared from concentrated milk / *khoa* and sugar; it has a typical icy texture and caramel flavour.

E. Cereal based products

1. Liquid type of traditional Indian sweets

I Pulse based

a. Green gram based type: Consists of dehulled split green gram, coconut gratings, jaggery, ghee and cardamom.
b. *Bengal gram* based consists of dehulled split *bengal gram*, coconut gratings, jaggery and cardamom.

II Cereal based sweet preparations

a. Wheat semolina based consists of wheat semolina, milk, dehydrated coconut gratings, sugar and cardamom.

b. Sago based type - contains sago granules, sugar, milk and cardamom.

c. Vermicelli (wheat macaroni) contains vermicelli, sugar, milk, cashew nuts and cardamom.

III Milk based

a. Kheer: Rice cooked in milk and thickened by slow simmering, sweetened and served hot or chilled with a dash of nuts and aromatic spices.

b. Basundi : contains concentrated milk cream, sugar and flavourings.

c. Badam milk: consists of *badam* (almonds), milk, food colour and flavourings.

IV. Other preparation

a. Poppy seed based sweets: consists of poppy seeds, jaggery, coconut gratings, rice and cardamom.

F. Nut based

Other category of sweets made from coconuts, cashew nuts, almonds, pista etc either as rolls with sugar or jaggery, also as *burfi* when *khoa* is added.

G. Miscellaneous

a. Jahanghir or Jangree: Prepared by grinding together black gram dhal and bengal gram dhal. The batter is deep fat fried and finally soaked in sugar syrup.

(Dwarkanath and Srikanta, 1977; Punjarth and Patel, 1991; Venkatasubbiah and Dwarkanath, 1985)

Scope of the present investigation

Sugar has been and remains the major sweetener in foods especially Indian traditional sweets. However, sugar has become a subject of controversy over its adverse effects in health and nutrition, namely as a contributor to excessive calories, diabetes, hyperglycemia, hypertension and as a principal causative factor to dental caries.

Growing awareness of each of these issues has cast a negative influence on the consumer towards sucrose based foods and the demand for such health-based foods is on the increase. As consumer demands have initiated a desire to lower the amount of sugar in food products, low and reduced calorie food products containing sugar alternatives have gained special importance and consumer attention. The discovery of a large number of new sweeteners over the past decade has also led to the development of various new sugar free products.

Such studies on using sugar alternatives are likely to find beneficial usage in traditional sweets. A survey of the literature has indicated that not much work has been carried out on the usage of sucrose alternatives in Indian sweets. A fundamental understanding of the process could eventually facilitate this type of work. In order to introduce sugar free products, which take advantage of the unique qualities of new processes and compounds, it is essential to understand their physical properties and their interactions with other ingredients in the system.

Many kinds of traditional sweet products manufactured in India, have great social, religious, cultural and economic importance. Because of the changes in traditional family structure and hurried life style, which have changed the food choices of modern consumers, ready mixes of a variety of traditional products have become popular. One such example is the *Jamun* mix.

Sugar does more than adding sweetness to a confectionery product or sweet. It provides bulk, lowers water activity and modifies the texture. High intensity sweeteners provide the sweet taste that is lost when sugar is removed, but they cannot perform other physical functions of sugar. For this reason, polyols and or polymeric bulking agents are needed when producing sugar free sweets. Polyols alone or combined with other sweeteners can be

used to produce sweets/confections that are safe for diabetics. These sugar replacers are physically, chemically and microbiologically stable.

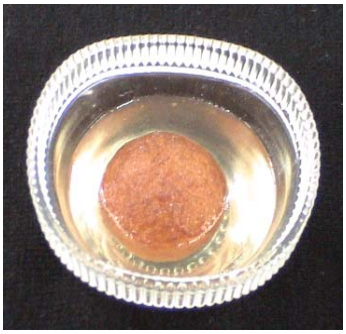
Based on the current knowledge of sucrose alternatives the need to study the sensory and textural aspects with specific emphasis on Indian panel and Indian sweets was necessary as the sweetness threshold is quite high. Due to continued and higher usage levels of sucrose in Indian sweets there lies the tendency to compare any sweet to that of its sugar counterpart. The compatibility of sweetness in Indian sweets is also a major problem.

In an attempt to find out the functional suitability of polyols either alone and or in combination with intense sweeteners and other bulking agents such as polydextrose and maltodextrin, three selected Indian sweets are: namely *Gulab jamun, Milk burfi* and *laddu.* The effect of processing parameters on the quality of these products is studied.

The main objectives of the present investigation are:

1. Selection of appropriate sugar alternatives based on their properties for use in traditional sweets.
2. Process optimization for preparation of sugar free traditional sweets such as *jamun, burfi* and *laddu.*
2. Studies on rheological characteristics of sugar free syrups for use in *jamun.*
3. Studies on textural measurements, sensory and colour characteristics of sugar free products as compared to sucrose based products.
4. Examination of the stability of the products as judged by HPLC and microbiological studies.
5. Studies relating to storage characteristics of these products.

Chapter 2



Jamun

Chapter II

Jamun

2.1 Introduction

Gulab jamun/jamun is a traditional, *khoa*-based sweet, popular in India (*Khoa* is a semi-solid mass obtained by concentration of milk). Preparation of *jamun* is still an art that is traditionally followed by sweet makers or *halwais* (Rangi et al, 1989). It is round or oval in shape and dark brown in colour, it may be served dry, or immersed in sugar syrup (Fig. 2.12 pg no. 88). The increased interest in commercial production of *jamun* along modern processing lines is ascribed not only to its growing demand within the country, but also to its potential for export (Patel et al, 1992).

Because of the changes in traditional family structure and the current hurried life style, which have changed the food choices of modern consumers, ready mixes of a variety of traditional products have become popular. *Jamun* is one such product. It is commercially available under a few brand names (Rao et al, 2002). All manufacturers of instant mixes follow more or less similar formulations and the products prepared from different brands do not differ significantly in texture or mouthfeel. Hence, in this study a commercial mix was taken for preparation of *jamun.*

Jamun is one of the syrup based sweets and other such sweets include *rasagolla, champakali* etc., in which syrups play an important role in determining the quality of the sweets. The concentration, or strength, of the syrups influences the texture and mouthfeel of many of these syrup based sweets. Hence, it is important to study on the rheological behaviour of these syrups.

Rheological properties are considered to be important, not only in the design of food processing equipment and handling systems, but also in quality control and sensory evaluation of many foods (Saravacos, 1970). The flow behaviour characteristics of various food products, particularly jams, jellies, spreads and syrups, which contain high or moderate levels of sugar and or very small amounts of gelling agents, have been widely studied by many investigators (Collins and Dincer, 1973; Chirife and Bruera, 1997; Ozdemir, et al, 1998). These studies indicate that the rheological properties, as well as or

sensory attributes of the final product, are affected by the amount and type of bulking agent used and by the temperature of processing (Ozdemir, et al, 1998). In addition to consistency (rheology) or syrup strength, the other processing parameters affecting the quality of *jamun* are temperature of soaking syrup and time of soaking.

To replace sugar, without significantly affecting the desirable characteristics of a product, the formulation and processing parameters need to be optimized and for this purpose response surface methodology (RSM) must choosen. Preliminary studies on the preparation of *jamun* have indicated that there are 5 main independent variables: i.e., the 2 ingredients (sugar and sugar replacer, sorbitol) and the 3 processing variables. The independent processing variables are; temperature of soaking syrup, concentration of syrup and time of soaking the *jamun*.

RSM has been reported to be an effective tool for last three decades for optimising a process when the independent variables have a combined effect on the desired response (Hunter, 1959). Several workers have used it for optimisation of cake formulations (Kissel and Marshall, 1967; Macdonald & Bly, 1966), peanut – sweet potato cookie formulation (Palomar et al, 1994), *tandoori roti* (Saxena and Rao, 1996), *puri* (Vatsala et al, 2001) and south Indian *parotta* (Indrani and Rao, 2001). Experiments were performed using different combinations of the experimental variables, at different levels, or factors according to a pre-determined design such as central composite rotatable design (CCRD), orthogonal design, etc. In the present study, the effects of syrups made of sugar and a bulk sweetener, sorbitol on the consumers response to factors like texture and overall sensory quality of *jamun* have been studied.

The objectives of this study are :

(1) To investigate the rheological behaviour of dispersions containing commonly used sugar replacers such as sorbitol, polydextrose (PD) and mixtures of polydextrose (PD) and maltodextrin (MD+PD) along with added aspartame as compared with that of sucrose solution. Such results could be useful during development of sugar free products.

(2) To study the rheological characteristics of sorbitol and other sugar free syrups to obtain a desirable consistency that would yield products having similar quality compared to that obtained with sugar.

(3) To establish the relationships that exist between the factors affecting the quality of *jamun* such as concentration of syrup, temperature and time of soaking.

(4) To determine instrumental colour, texture and desirable sensory attributes of the sugar free products in comparision with sugar counterpart.

(5) To determine optimum processing conditions for obtaining *jamun* with sugar and using an alternative bulk sweetener, sorbitol.

(6) Microbiological stability of sugar free *jamun,* in comparison with its sugar counterpart.

2.2 Materials and Methods

2.2.1 Materials

Cane sugar (sucrose) and *jamun* mix were procured locally. *Jamun* mix had the following proximate composition: 7.7% moisture, 15% fat, 14.2% protein and 6% total sugars. The composition had been standardized by the manufacturers and hence did not have significant variations. Sorbitol syrup (68% solids) was obtained from Maize Products, Ahmedabad, Gujarat, India. Polydextrose (Littesse II) was procured from Cultor Food Science, Xyrofin GmbH, Hamburg, Germany. Maltodextrin was procured from Sukhjit Starch and Chemicals Ltd, Phagwara, Punjab. Aspartame used in the study was obtained from Ajinomoto Co. Inc, Tokyo, Japan.

2.2.2 Preparation of syrup

Sugar syrup was prepared by dissolving 100 g of sugar in 50 ml of water and then boiled for 5 mins on medium heat. The syrup thus obtained was adjusted to the required concentration (°B), measured using a hand refractometer (Erma, Japan), which has been calibrated with known concentration of sugar syrup. Commercially available sorbitol syrup has a concentration of 68% solids (°B) and thus, it was diluted to the required concentration by adding water. Polydextrose (PD) (100g) was dispersed in 35 ml water and heated till a clear solution was obtained. The mixture of maltodextrin and polydextrose syrup (MD+PD) was prepared by dispersing equal proportions of these two ingredients in 35 ml water, followed by heating and then adjustment to the required concentration (°B). All the solutions prepared were rested for 1 hour after preparation, before conducting further analysis. An intense sweetener, aspartame was added (0.25g/100ml in sorbitol syrup and 0.7g/100ml for MD+PD and PD syrups) to obtain a syrup having a sweetness level equivalent to that of sugar syrup at the same concentration, prior to soaking of *jamun* in it. Equi-sweetness level was calculated based on relative sweetness of aspartame vs sugar and also based on results from preliminary sensory evaluation of products with and without sugar.

2.2.3 Rheological properties

A universal controlled stress rheometer (Model #SR5, Rheometric Scientific, New Jersey, USA.) with a coaxial cylinder having an external

diameter of rotating bob: 28.8mm, inner diameter of stationary cup: 30.0mm was used for the rheological measurements. Fixed volume of samples (30 ml) was used while maintaining the temperature of measurement at 25, 40, 60 and 80°C employing a circulatory water bath. Syrups of 35, 45, 55 and 65% solids were subjected to increasing shear rates from 10 to 100 s^{-1} in 100s to obtain data sets comprising shear rate, shear stress and viscosity/apparent viscosity values. All rheological measurements were conducted on triplicate samples. The software supplied by the equipment manufacturer was used to examine the suitability of common rheological models and viscosity at a shear rate of 25 s^{-1} as a significant difference was observed at this shear rate. The parameters of Herschel Bulkley model (Eq.1), such as yield stress, consistency index and flow behaviour index were obtained from shear stress versus shear rate data. The extent of fitting to models was judged by finding the coefficient of determination (r^2) and checking its statistical significance at the probability (P) level of 0.01.

$$\sigma = \sigma_0 + KY^n \text{ --- (1)}$$

where σ is shear stress, σ_0 is yield stress , K is consistency index, Y is shear rate and n is flow behaviour index. A 'n' value of 1 indicates Newtonian behaviour, while values deviating from 1 indicate the non Newtonian behaviour.

2.2.4. Preparation of *jamun*

The traditional method of preparing *jamun* involves blending of *khoa*, refined wheat flour and baking powder, along with small amounts of water, to a homogenous mass, so as to obtain a smooth dough. The balls of the dough are deep fat fried in *ghee* (heated butter oil), or in refined vegetable oil, to a golden brown colour and subsequently transferred to the sugar syrup. *Jamuns* of uniform and acceptable quality could be prepared from these mixes by both housewives and confectioners. As mentioned earlier, convinient mixes are prepared for *jamun* and being marketed. Commercially available instant mix of *jamun* was used in this study (Dharampal, 2000).100g of instant *jamun* mix was weighed into a container to which 48 ml of water was gradually added and a dough was made by gentle mixing. The dough was allowed to stand for about 2 mins and then shaped into small balls approximately 30mm in diameter. These balls were deep fat fried at 165°C, for 6 mins, until the outer crust became brown in colour; they were then transferred to the syrup. The

frying of dough balls was conducted in batches where dough to oil ratio was maintained at 1:10. The time of frying, concentration of syrup and time of soaking were varied as per the experimental design discussed later.

Thus the*, jamun* ball after soaking has a typical coat and core structure (Patel et al, 1992). The texture and quality of *jamun*, according to the preliminary study, were found to depend on the concentration of syrup, temperature and time of soaking of the *jamun*.

2.2.4 Uptake of syrup by *jamun*

The absorption of syrup by *jamun* was determined from the difference of mass of *jamun* ball before and after putting into syrup. The number of replications were four and the values were expressed as gram of syrup absorbed per gram of *jamun.*

2.2.5 Texture measurement of *jamun*

The hardness/shear of *jamun* was determined with a Universal Texture Testing Machine (Model LR 5K, Llyods Instruments, UK). The product was sheared using a load cell of 5 kg fitted with a Warner Bratzler shear attachment at a crosshead speed of 50 mm/min. The maximum force required for complete shearing of *jamun* into two pieces was reported. The test was repeated four times and arithmetic mean 1 $\pm$ 0.28 standard deviation (SD) values were reported as the texture of the product.

2.2.6 Sensory analysis

Jamun has a thin but distinct crust overlaying a soft porous inner layer (Patel et al, 1992); the crust is caused by frying and the soft inner layer results from a slow but uniform penetration of syrup throughout the spherical ball. Soaked *jamun* is soft, but should not collapse, or get distorted in shape. Also, it should not be pasty on the palate. Considering these desirable characteristics of *jamun*, sensory evaluation was carried out with the help of a panel of 12 trained judges, using a 10-point linear rating scale ranging from 0 (lowest intensity on left end) to 10 (highest intensity on right end) (Amerine et al, 1965). The judges were asked to rate the perceived attributes - such as appearance, colour, softness, uniformity of core and overall quality - by

drawing a vertical line on the scale and writing the code numbers for the products. *Jamun* samples were served to the judges in bowls with codes, one at a time.

2.2.7 Experimental design and data analysis

Three level factorial experiments (-1, 0 and +1) in coded level variables), central composite designs and Box-Behnken designs were employed to fit a full quadratic response surface model and approximate the factor levels that provide the optimal response. The design was chosen for its relatively few combinations of variables which are adequate to estimate complex response functions.

The Box Behnken design (Montgomery, 1997), selected in this study and its experimental variables chosen are shown in Table 2.1. Three duplicates are included at the centre of the design. The total number of test runs needed for this design was 15 which is less than 17 that is required for central composite design with the same number of duplicates and 27 required for a 3^3 factorial design without duplicates. Based on prior studies, the various processing parameters involved in the optimization of *jamun* are concentration of syrup (X_1), temperature of syrup for soaking (X_2) and duration of soaking in hours (X_3) and the three levels (low, medium and high denoted as -1, 0 and +1, respectively). The actual design of experiments is presented in the Table 2.8. *Jamun* was prepared according to experimental design and analysed for sensory overall quality and texture (shear) by instrumental methods.

A 2^{nd} order polynomial was employed to fit the experimental results and to predict the overall quality of *jamun* prepared with sugar and sorbitol and are in the form shown below.

$$Y = A_O + A_1 X_1 + A_2X_2 + A_3X_3 + A_4X_1^2 + A_5X_2^2 + A_6X_3^2 + A_7X_1X_2 + A_8X_2X_3 + A_9X_3X_1 + \in$$

where Ao = constant

X_1, X_2 and X_3 are independent variables (coded levels)

A_1, A_2, A_3 = linear coefficients

A_4, A_5, A_6 = quadratic coefficients

A_7, A_8, A_9 = cross product coefficients

$\in$ = error

and Y = predicted overall quality or response functions

The coefficients of the response function, their statistical significance and process conditions for obtaining maximum sensory overall quality were evaluated by means of the Microsoft Excel software (using generalized, reduced gradient nonlinear optimization). Response surfaces with contour lines were created by keeping the third variable constant with Kyplot software (Version 2.0, 2000).

Table 2.1 Levels of variables chosen as per the experimental design

	Variables	+1	0	-1
X_1	Concentration (°B)	65	55	45
X_2	Temperature (°C)	80	60	40
X_3	Time of soaking (h)	4	3	2

2.2.8 Colour measurement

Colour of syrups was measured using the CIELAB illuminant D_{65} and 10° standard observer condition (Perez – Magarino and Gonzalez-Sanjose, 1999). The parameters L*, a*, b* and the total colour difference (ΔE*) were measured in triplicate with a colour meter (Model Labscan XE, USA) using the principle of reflectance of light in the wavelength range 400 and 700 nm. The CIELAB parameter L* indicates the lightness (or brightness), a* indicates redness with positive values and greenness with negative values and b* indicates yellowness with positive values and blueness with negative values.

The parameter ΔE^* indicates the total difference of colour with respect to a standard white. Colour of *jamuns* was also measured in triplicate.

2.2.9.1 Statistics

Duncan's Multiple Range Test (DMRT) was applied to differentiate among the means of different samples at a probability (P) of 0.05. In the present section, DMRT was employed to differentiate among the colour values of dispersions containing sugar, or a few selected sugar substitutes and also for *jamun* prepared with and without sugar.

2.2.10 HPLC analysis

HPLC analysis of aspartame was performed using Shimadzu LC – 10AT pump (Shimadzu Corporation, Tokyo, Japan) attached to a Shimadzu SPD-10AVP UV – visible detector controlled by class LC –10 workstation. The RP–HPLC column Exsil ODS stainless steel column (250X4.6 mm, 10μm) procured from SGE Australia was used. The mobile phase used is a mixture of 0.17% KH_2PO_4 (pH adjusted to 3.5 using 5% *o*-phosphoric acid) and acetonitrile (85:15 and 0.0125 M) at 1.0 ml/min (Prodolliet and Bruelhar, 1993). Good separation was achieved at 214 nm within 15 min. HPLC analysis was carried out for samples stored under accelerated (36±1°C), ambient (27±1°C) and refrigerated conditions (8±1°C).

The sweetener was identified by comparing the retention time of the standard and the concentration was determined from the area of the peak. The concentration of the sweetener was calculated as follows

$$\text{Concentration of sweetener} = \frac{\text{Concentration of standard}}{\text{Peak area of the standard}} \times \text{peak area of sweetener}$$

The percentage recovery of aspartame was calculated from the difference of the initial amount added and the amount recovered from the product.

2.2.10.1 Sample preparation for HPLC

The *jamuns* were drawn from storage and brought to room temperature. 20g of sample were weighed into a beaker and any traces of oil were removed with petroleum ether. After decanting the petroleum ether, triple distilled water 20-30 ml was added to the sample and stirred. The

solution was filtered through cotton into a 250 ml standard measuring flask. The extraction was repeated Carrez solutions A (solution of zinc acetate and glacial acetic acid) of and B (solution of potassium ferrocyanide) were added (2ml each to precipitate any protein present in the sample) and made upto volume. After resting for 20 mins the flask was shaken gently and filtered through a Whatman No. 1 filter paper. An aliquot was drawn, passed through a 0.45μm filter membrane, (Millipore) and collected into a vial for analysis.

2.2.11 Microbiological studies

All glasswares and other materials used in the present study were sterilized by steam, at 121°C for 20 minutes in an autoclave. All the media used in this study were procured from Hi Media Lab Private Limited, Mumbai. The media were prepared according to manufacturers instructions.

A. Plate count agar

The compositions of the agar medium (g/l) was as follows

Casein enzyme hydrolysate	5.0
Yeast extract	2.5
Dextrose	1.0
Agar	15.0

The requisite quantity of dehydrated medium was dissolved in water by boiling, then dispensed in appropriate amounts in erlenmeyer flasks and autoclaved.

B. Potato dextrose agar

The composition of the agar medium (g/l) was as follows

Potato effusion	200
Dextrose	20
Agar	15

The requisite quantity of dehydrated medium was stirred in water and warmed till the medium was completely dissolved. Appropriate amounts were

then dispersed in erlenmeyer flasks and autoclaved at 15lbs pressure (121°C) for 15 minutes.

C. Baird Parker agar base

The composition of the agar medium (g/l) was as follows:

Casein enzyme hydrolysate	10.0
Beef extract	5.0
Yeast extract	1.0
Glycine	12.0
Sodium pyruvate	10.0
Lithium chloride	5.0
Agar	20.0

The requisite quantity of dehydrated medium was dissolved in water by boiling, followed by dispensing in erlenmeyer flasks and autoclaved. Prior to pouring into the plates, 5ml of egg yolk and 0.3ml of 3.5% potassium tellurite were added to 95 ml of molten medium and mixed well. Prepared plates were used within 48 hrs of pouring.

D. McConkey agar

The composition of the agar medium (g/l) was as follows:

Peptic digest of animal tissue	20.0
Lactose	10.0
Bile salt mixture	1.5
Sodium chloride	5.0
Neutral red	0.03
Crystal violet	0.001
4 methyl umbelliferyl	0.10
B-D glucoronide agar	15.0

The above medium was supplemented with 1% glucose for use in the enumeration of total *Enterobacteriaceae* count. The requisite quantity of dehydrated medium was dissolved in water by boiling, followed by dispensing in appropriate amounts in erlenmeyer flasks and finally autoclaved.

Results and Discussion

2.3.1. Preparation of *jamun*

Prior to the actual experimentation, a few preliminary studies were conducted to find out the approximate processing conditions required to obtain *jamun* with desirable quality attributes. Sensory analyses of *jamun* with varying concentrations of sugar and sorbitol syrups were conducted to find out their effect on important quality aspects, such as colour, extent of sweetness and textural attributes like chewiness, mealiness, juiciness, softness etc. The desirable sensory attributes of *jamun* such as softness, juiciness and overall quality, were assessed by trained panelists and also by instrumental texture measurement. The results of the sensory evaluation showed that *jamuns* soaked in 45°B syrup were soft and soaked in 55°B syrup were highly acceptable, whereas those soaked in 65°B had a hard core in the center (Fig. 2.1). Thus 55°B syrup was considered to be an ideal syrup for preparation of *jamun* and hence used in further studies.

Similar trials were carried out for *jamuns* in sorbitol syrup in comparison with sugar syrup (Fig. 2.2). The results indicated that *jamuns* prepared using 45°B syrup were soft (0.9N) and those prepared with 55°B was highly acceptable (1.8N), whereas those prepared using 65°B syrup were chewy and had a hard core in the center (3.6N).

Fig. 2.1 Sensory attributes of *jamun* made with sugar syrup of different concentrations (45, 55 and 65°B).

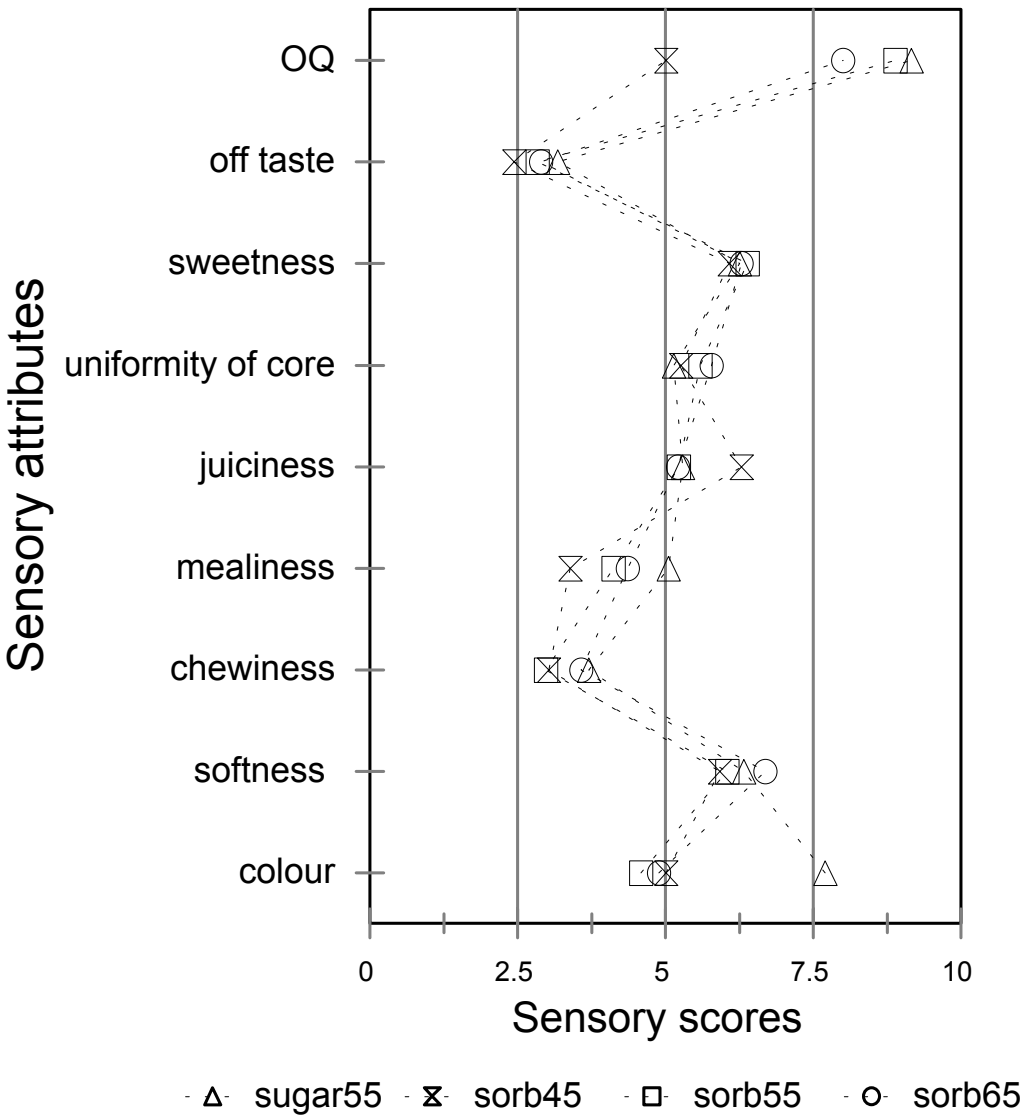
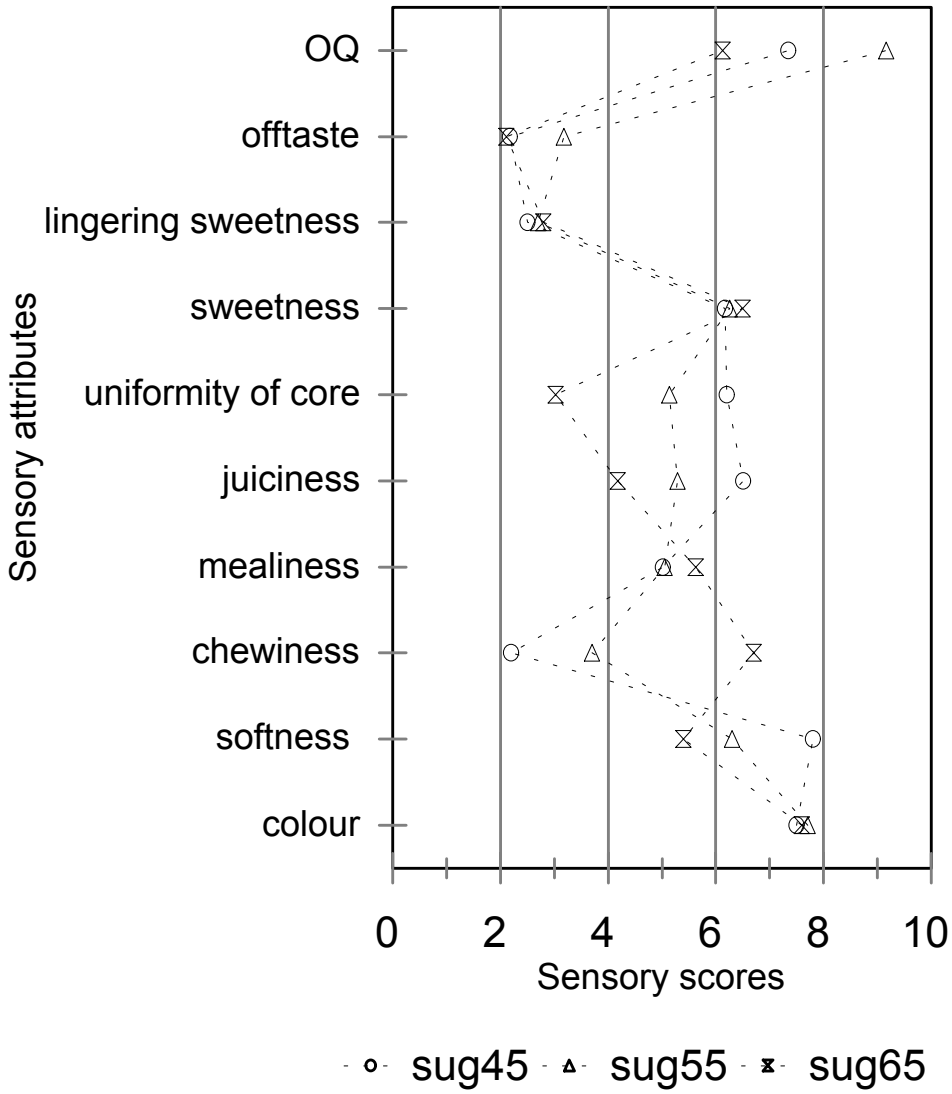


Fig. 2.2 Sensory attributes of *jamun* prepared with sorbitol syrups of different concentrations (45, 55 and 65°B) and sugar syrup (55 °B)



Instrumental texture measurements indicated that hardness of the product increased with an increase in concentration of syrup.It has been reported that higher sugar syrup concentration resulted in a decrease in volume expansion and harder *jamun* (Rao et al, 2002). The correlation between sensory scores and instrumental texture for softness was 0.87, juiciness –0.94, while the overall quality showed a significant correlation of 0.84. Softness and overall quality showed positive correlation, while juiciness showed negative correlation i.e., as juiciness increased the shear value decreased. If *jamun* contains a hard core, it registers high shear force and if it is very soft with insufficient body, a low shear value is obtained and both these attributes are not desirable. Based on these preliminary studies, rheological characteristics and process optimisation of selected syrup, sorbitol in comparison with sugar syrups were conducted.

2.3.2 Rheological behaviour of syrups

The rheological behaviour of different syrups was studied over the concentration range of 35 to 65% solids at different temperatures of 25, 40, 60 and 80°C. The rheograms comprising shear stress and shear rate for different samples indicate Newtonian shear thinning behaviour for sorbitol and sucrose solutions (Fig. 2.3) and non Newtonian shear thinning for syrups made with polydextrose or with mixtures of polydextrose and maltodextrin (MD+PD) (Fig. 2.4). Figures are shown only for syrups which yield products with desirable characteristics. Between Power law and Herschel Bulkley models, the latter provided a more suitable ($r^2 > 0.994$) fit for shear stress/shear rate for PD as well as MD+PD syrups. Similar observations were made with gum dispersions, which showed pseudoplastic behaviour, i.e., they became thinner as the shear rate increased (Collins and Dincer, 1973). The results in Table 2.2 showed that the apparent viscosity (η) of the dispersions increased with an increase in the concentration of the syrup from 35 to 65% solid, while it decreased with an increase in temperature. Apparent viscosity increased from 8.8 to 129 mPas for sugar, 7.3 to 83.0 for sorbitol, 4.75 to 287.5 for PD and 12.8 to 248 for syrups respectively over the concentration range from 35 to 65%. Similar trends were observed in the case of blackcurrant and mango juice concentrates (Ibarz et al, 1992; Gunjal and Waghmare, 1987).

The consistency index increased with increase in solid concentration but decreased with temperature (Fig. 2.5). For example, at 25°C the

consistency index of 65% polydextrose syrup showed the maximum value of 253.1 mPas-s^n followed by the mixture of syrup with 226.4 mPas-s^n. Similar trends were observed in both sugar and sorbitol syrups.

The yield stress which represents the minimum stress that is needed to initiate flow (Holdworth, 1971) ranged from 199.4 to 85.2 for polydextrose samples and from 164 to 40.4 mPa for the mixture of MD + PD. These are the values for the entire range of temperature (25 to 80°C) and concentrations (35 to 65%) (Fig. 2.6). Polydextrose syrup manifested the maximum yield stress. Similar results were reported for mango concentrates (Rao and Cooley, 1983).

Fig. 2.3 Sample rheogram for sorbitol (Δ) and sucrose (▲) solutions at a concentration of 55%

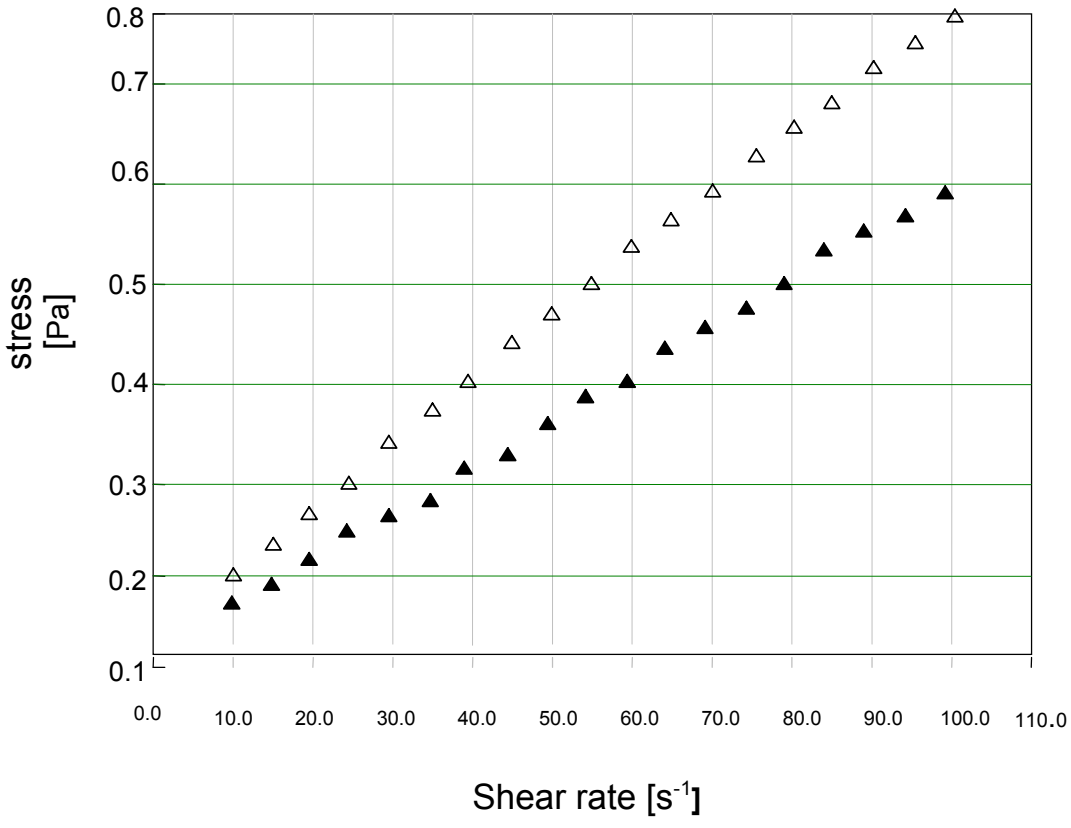
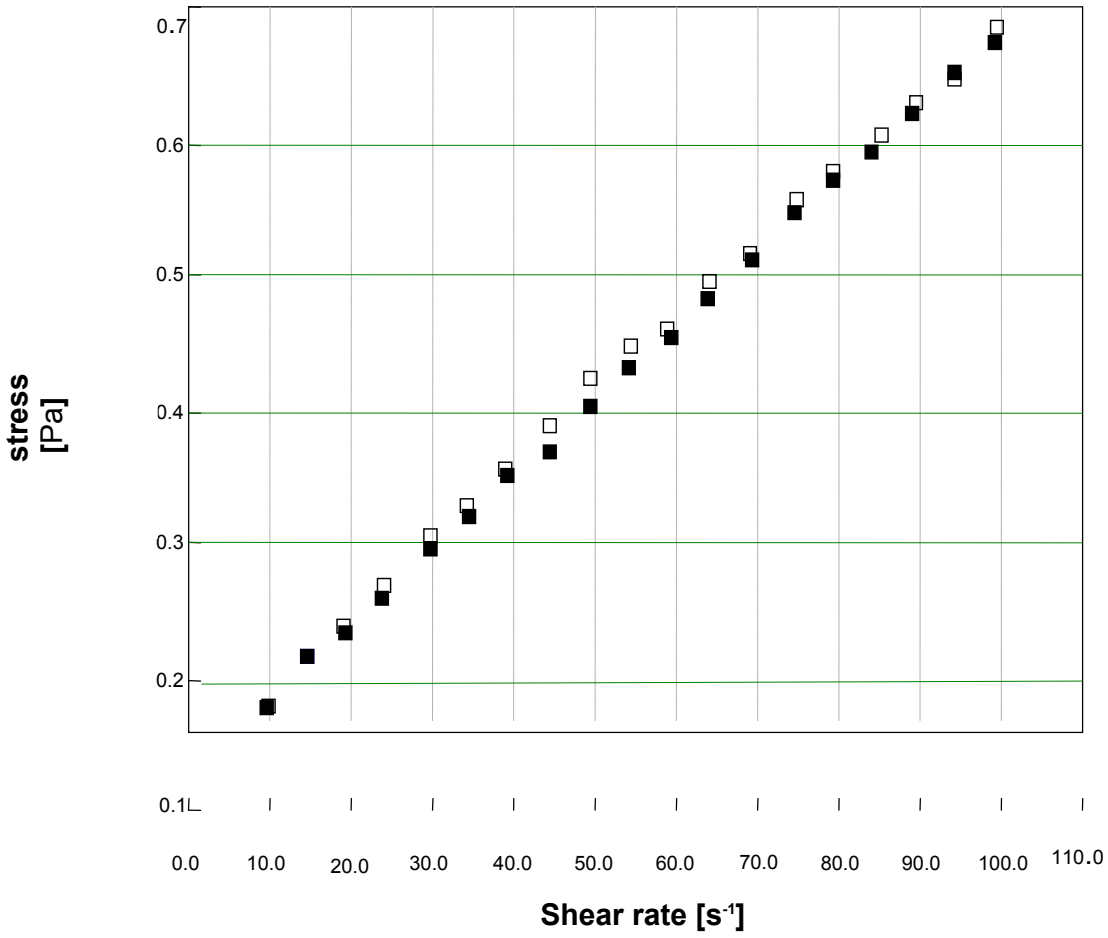


Fig. 2.4 Sample rheogram for maltodextrin (□) and polydextrose (■) (50:50) dispersions at a concentration of 45%



The flow behaviour index (n) of syrups was less than one for polydextrose syrups and for syrups made with MD+PD mixtures, which indicates their pseudoplastic, shear thinning nature (Fig. 2.7) and was equal to one in the case of sugar and sorbitol syrups. Similar results were observed in studies carried out for salad dressings (Parades et al, 1989). The ‘n’ values decreased markedly when solid concentration is increased indicating enhanced non Newtonian behaviour while the effect of temperature is opposite in nature.

The effect of temperature on apparent viscosity of syrups could be explained by the Arrhenius equation to determine activation energy (Eq. 2).

$$\eta = \eta_o e^{-(Ea/RT)} \quad \text{--- (2)}$$

Where η is apparent viscosity (at a shear rate 25 s^{-1}), η_o is Arrhenius constant, E_a is activation energy, R is universal gas constant and T is absolute temperature.

The Arrhenius equation has been successfully used to predict temperature dependence of sugar rich foods such as tamarind juice concentrates (Manohar et al, 1991), clarified banana juice (Bhandari et al, 1999) and processed honeys (Mossel et al, 2000). All the syrups in the present study showed high coefficient of determination (r^2) values (0.93 to 0.99). Activation energies of the syrups increased with an increase in the concentration of syrups (Table 2.3). These results were in accordance with those observed in the case of blackcurrant and other clarified juices (Rao et al, 1984; Khalil et al, 1989).

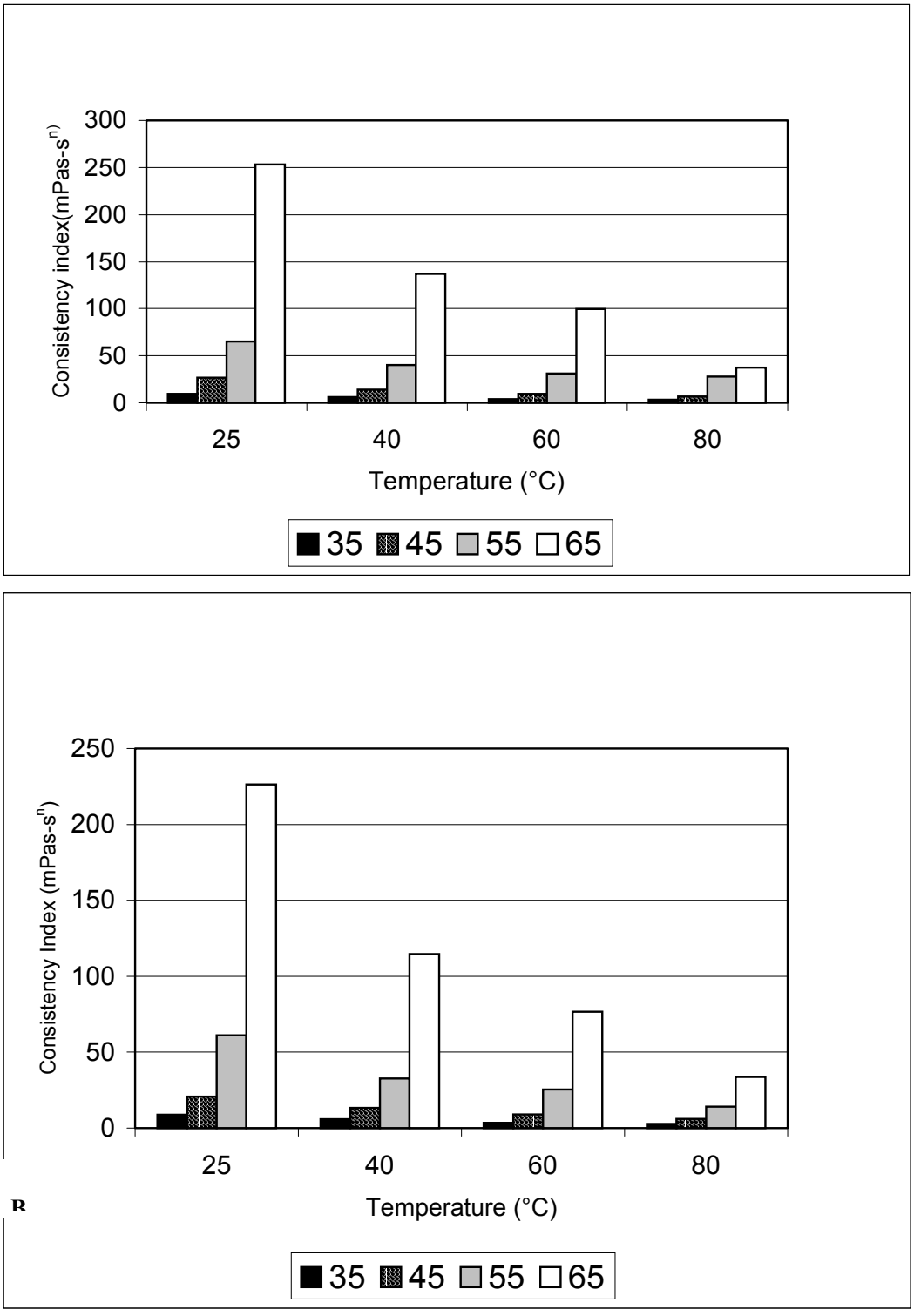
In general, activation energy increased with an increase in syrup strength. The syrups suitable for preparation of *jamun*, namely sugar, 55˚B; sorbitol 55˚B and PD 45˚B showed similar activation energies. The polydextrose syrup of 65% solids showed higher activation energy when compared to other syrups at the same concentration. A sugar solution having 55% solid concentration is often used for the preparation of several traditional sweets such as *jamun*, *rasagolla* etc. The viscosity of such a solution is 14.7 mPas at 60°C (Table 2.2). To achieve the same viscosity in other systems, the required solid concentrations are 59% for sorbitol, 44% for polydextrose and 45% for matodextrin + polydextrose (1:1, w/w). These results indicate that syrups containing PD and mixture of MD+PD with lower concentration of solids showed a viscosity similar to that of sugar syrup with 55% solids and hence their use saves on processing costs. On the other hand, the syrup containing sorbitol requires slightly higher solids (59%) to achieve the same viscosity as that of sugar with 55% solids.

Table 2.2 Apparent viscosity (mPas) of solutions / dispersions at a shear rate 25 s^{-1}

Type of syrup	Concentration	Temperature			
		25°C	40°C	60°C	80°C
Sugar	35	8.80±1.2	7.51±1.5	6.41±2.0	6.12±1.2
	45	10.14±1.5	9.94±1.8	8.32±1.5	6.78±1.5
	55	23.98±1.8	19.01±2.0	14.67±1.6	9.51±1.8
	65	129.24±2.8	41.00±3.0	26.0±1.8	16.50±1.6
Sorbitol	35	7.32±1.0	6.45±1.2	6.09±0.5	5.40±1.0
	45	9.50±1.2	9.20±1.0	8.00±0.6	7.20±1.2
	55	20.90±1.5	15.90±1.5	10.50±0.8	10.00±0.5
	65	83.00±1.8	38.00±1.6	20.50±1.0	12.80±0.8
PD	35	14.75± 1.2	11.90± 1.0	9.93± 1.0	9.46± 1.2
	45	28.80± 1.5	23.30± 1.7	15.10± 2.1	11.63± 1.7
	55	92.66± 1.8	68.54± 1.8	37.43± 1.0	31.00± 1.6
	65	287.50± 1.0	158.45± 1.0	92.68± 1.5	38.77± 1.2
MD+PD	35	12.80± 1.0	10.10± 1.2	9.30± 0.7	8.31± 1.2
	45	23.20± 2.0	17.40± 1.4	14.80± 0.6	10.80± 1.0
	55	70.80± 1.5	43.20± 1.0	31.53± 0.9	22.10± 2.0
	65	248.00 ± 1.6	127.40 ± 2.1	85.71± 1.2	36.26± 1.5

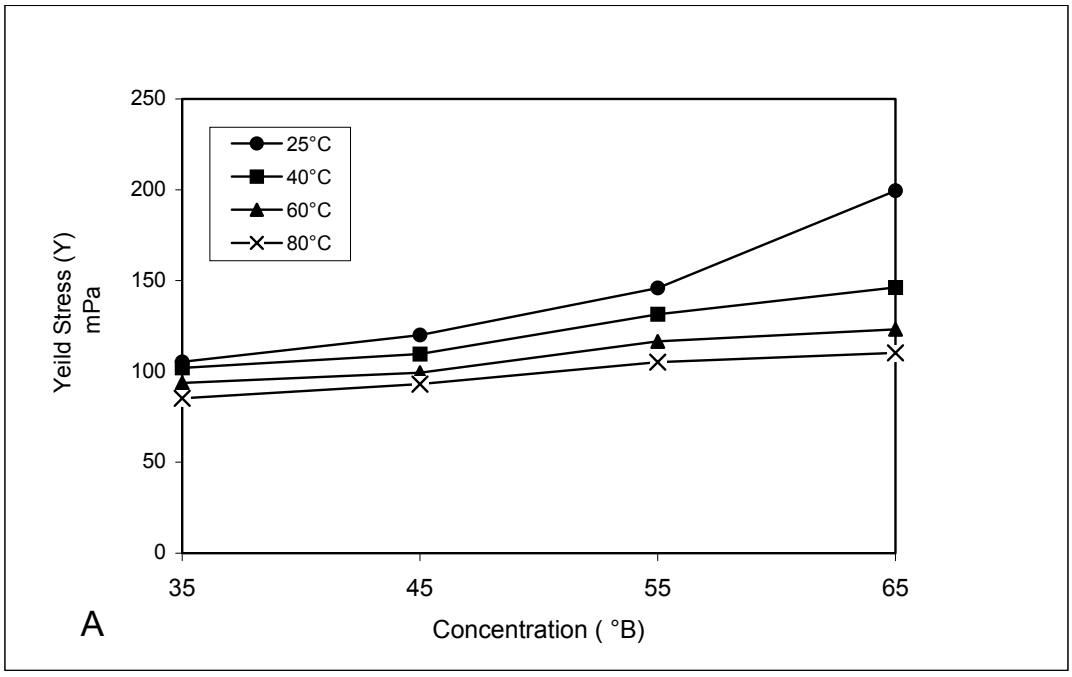
MD=Maltodextrin; PD=Polydextrose

Fig. 2.5 Consistency index (κ) for PD (A) and MD+PD (B) (50:50) syrups at different concentrations and temperatures



B

Fig. 2.6 Yield stress for PD syrup (A) and MD+PD syrup (B) at different temperatures and concentrations



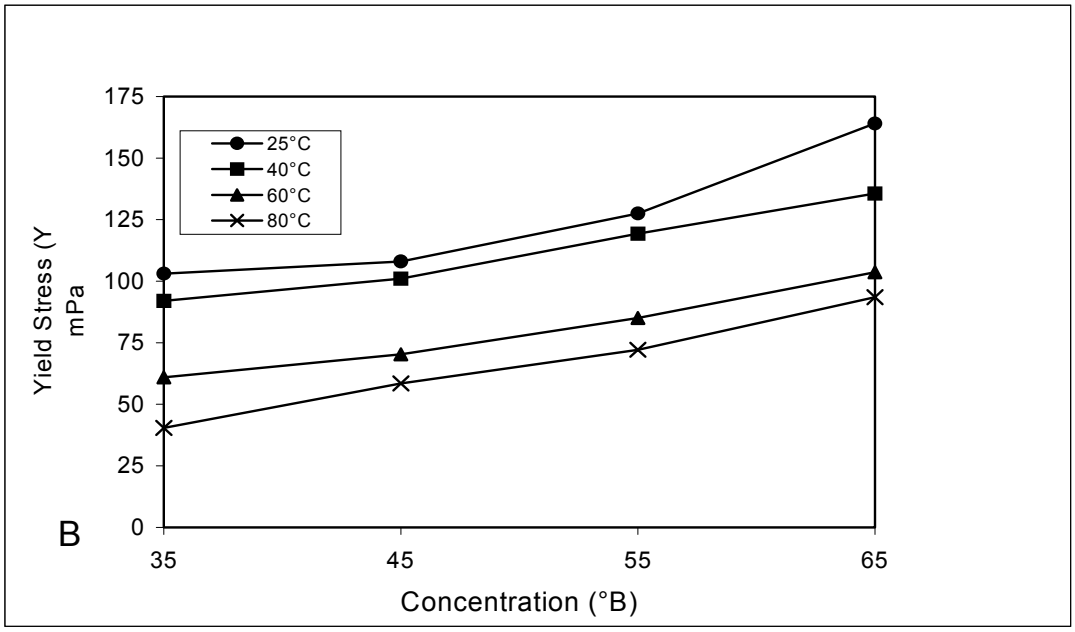
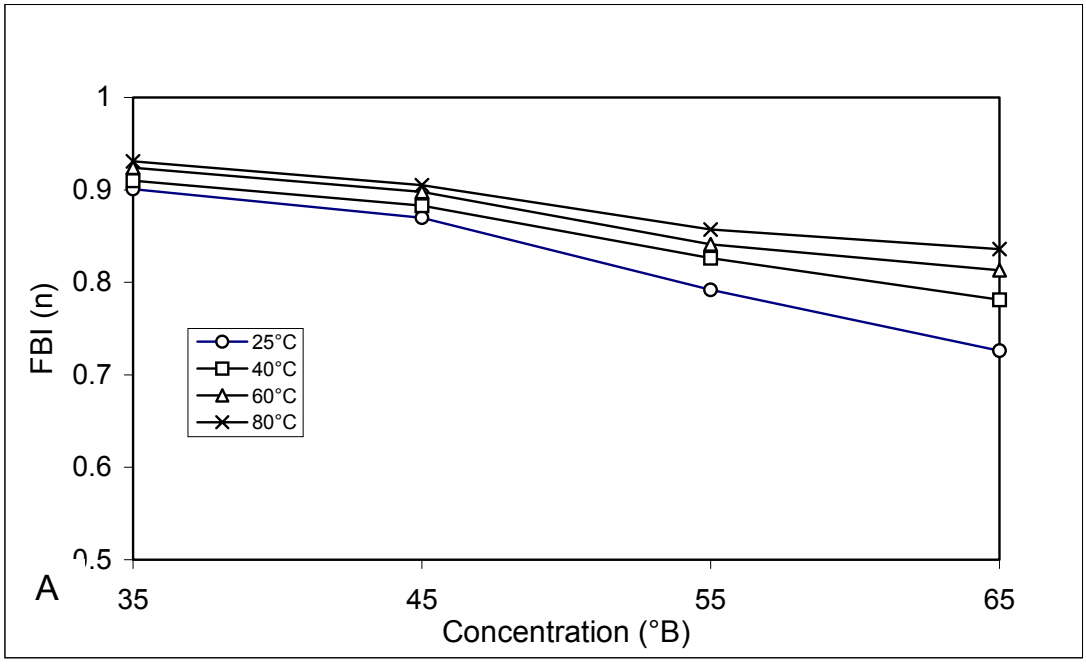


Fig .2.7 Flow behaviour index for PD (A) syrup and MD+PD syrup (B) at different temperatures and concentration



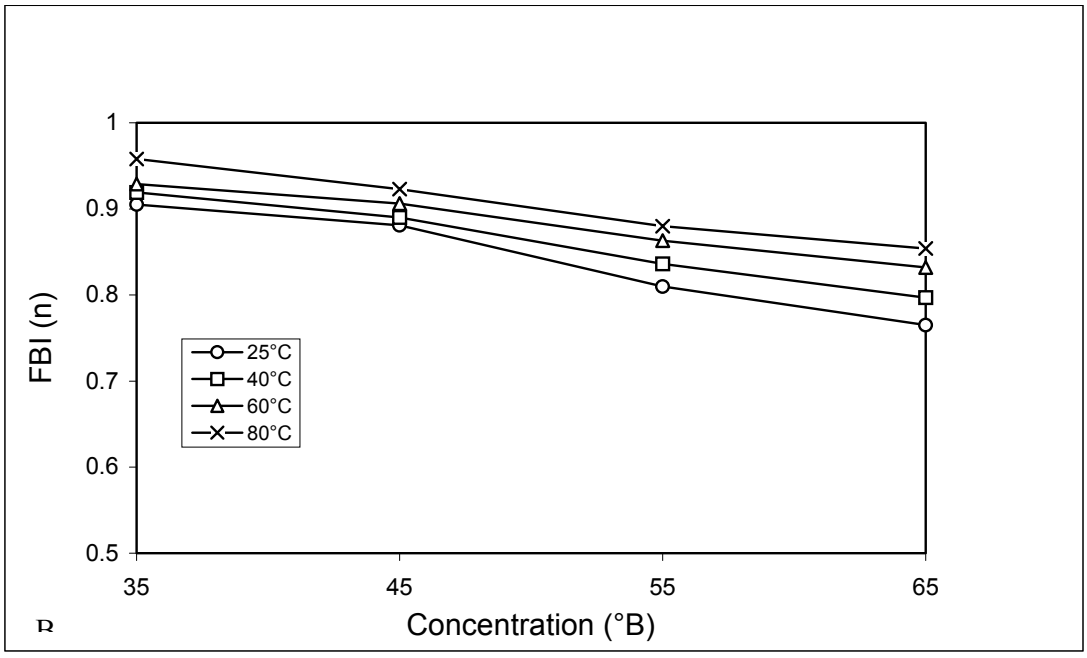


Table 2.3. Activation energies of samples at different concentrations

Type of syrup	Concentration	Activation energy E_a (kJ/ mole)
Sugar	35	5.88 ± 1.2
	45	6.58 ± 1.5
	55	14.32 ± 0.8
	65	30.09 ± 1.7
Sorbitol	35	4.56 ± 0.8
	45	5.46 ± 1.0
	55	12.43 ± 1.1
	65	29.32 ± 1.2
PD	35	7.149 ± 1.1
	45	14.94 ± 1.7
	55	18.45 ± 1.2
	65	30.90 ± 1.0
MD+PD	35	6.41 ± 1.2
	45	11.56± 1.5
	55	17.89± 1.8
	65	29.02± 1.9

MD=Maltodextrin; PD=Polydextrose

2.3.3. Optimisation of process parameters of *jamun* with sugar and sorbitol

The preliminary studies showed that the process parameters such as syrup strength, temperature and time of soaking influenced the syrup absorption and in turn the texture and quality of *jamun.* In order to obtain optimum process parameters for *jamun* with sugar and sorbitol syrup, the Box Benkhen design was employed to reduce the number of experiments and time of experimentation. The products prepared with MD+PD and PD were not taken up for the study due to lower overall quality scores.

The response surface equation for *jamun* prepared with sugar fitted the experimental data well with $R^2 \leq 0.95$ with $P < 0.01$ (Table 2.4). The average

absolute deviation is 3.59%. Figs. 2.8, 2.9 and 2.10 show the effects of variables on overall quality prepared using sugar substitute and sugar.

The regression coefficient along with their significance, t-values and coefficient (R^2) of determination for the full quadratic response surface models are presented in Tables 2.4 to 2.7. These models were tested for adequacy by the analyses of variance. The experimental data fits the response equation at a high degree of significance.

The maximum overall quality of 7.73 was obtained for *jamun* prepared with sugar syrup of 51°Brix strength, 54°C temperature and a duration of soaking of 4 h. The response surface equation for *jamun* with sugar substitute fitted the experimental data well with $R^2 \leq 0.94$ ($P < 0.05$) (Table 2.5). The average absolute deviation is 4.88%. The maximum overall quality of 8.0 could be obtained at process conditions of 54°Brix syrup, temperature and soaking time of 65°C and 3 h, respectively. These results indicate that the optimum process conditions especially the syrup concentration, soaking temperature and time of soaking for *jamun* with sugar and sugar substitute lie at the mid points of the range of variables involved (Figs. 2.8 to 2.10).

Table 2.4 Anova for overall sensory response function of *jamun* prepared with sugar

	Degrees of freedom	Sum of squares	Mean sum of squares	F	Significance F
Regression	9	18.00	2.00	10.01	0.01
Residual	5	1.00	0.20		
Total	14	19.00			

Variables	Coefficients	Estimate	Standard Error	t Stat	P-value
Intercept	A_0	7.43	0.26	28.80	0.00**
Conc. (C)	A_1	-0.24	0.16	-1.50	0.19
Temp. (T)	A_2	-0.46	0.16	-2.93	0.03**
Time (t)	A_3	0.03	0.16	0.16	0.88
CC	A_4	-1.64	0.23	-7.06	0.00**
TT	A_5	-1.04	0.23	-4.48	0.01**
Tt	A_6	0.03	0.23	0.14	0.89
CT	A_7	0.20	0.22	0.89	0.41
Tt	A_8	-0.08	0.22	-0.34	0.75
tC	A_9	-0.78	0.22	-3.47	0.02**

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

Table 2.5 Anova for overall sensory response function of sugar free (sorbitol) *jamun*

	Degrees of freedom	Sum of squares	Mean sum of squares	F	Significance F
Regression	9	24.45	2.72	9.12	0.05
Residual	5	1.49	0.30		
Total	14	25.94			

Variables	Coefficients	Estimate	Standard Error	t-Stat	P-value
Intercept	A_0	7.93	0.32	25.18	0.00**
Conc. (C)	A_1	-0.35	0.19	-1.81	0.12
Temp. (T)	A_2	0.46	0.19	2.40	0.06
Time (t)	A_3	-0.01	0.19	-0.06	0.95
CC	A_4	-2.18	0.28	-7.67	0.00**
TT	A_5	-0.90	0.28	-3.18	0.02**
tt	A_6	-0.75	0.28	-2.66	0.04**
CT	A_7	0.30	0.27	1.10	0.32
Tt	A_8	-0.33	0.27	-1.19	0.28
tC	A_9	-0.30	0.27	-1.10	0.32

* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

Table 2.6 Anova for texture response function of *jamun* prepared with sugar

	Degrees of freedom	Sum of squares	Mean sum of squares	F	Significance F
Regression	9	24.83	2.76	5.95	0.03
Residual	5	2.32	0.46		
Total	14	27.15			

Variables	Coefficients	Estimate	Standard Error	t-Stat	P-value
Intercept	A_0	1.77	0.4	4.52	0.00**
Conc. (C)	A_1	1.38	0.24	5.74	0.00**
Temp. (T)	A_2	-0.94	0.24	-2.05	0.95
Time (t)	A_3	-0.33	0.24	-1.38	0.22
CC	A_4	1.209	0.35	3.41	0.01**
TT	A_5	-0.24	0.35	-0.68	0.52
Tt	A_6	0.40	0.35	1.13	0.30
CT	A_7	0.32	0.34	0.96	0.38
Tt	A_8	-0.01	0.34	-0.04	0.96
TC	A_9	-0.09	0.34	-0.28	0.78

* $p< 0.05$

** $p< 0.01$

*** $p< 0.001$

Table 2.7 Anova for texture response function of sugar free (sorbitol) *jamun*

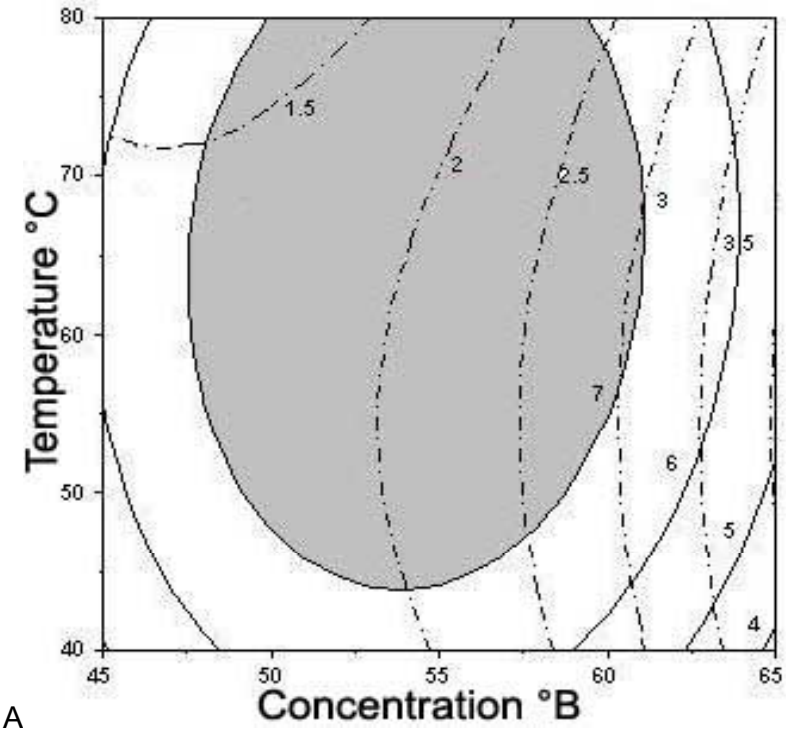
	Degrees of freedom	Sum of squares	Mean sum of squares	F	Significance F
Regression	9	15.44	1.72	67.06	0.00
Residual	5	0.13	0.03		
Total	14	15.57			

Variables	Coefficients	Estimate	Standard Error	t-Stat	P-value
Intercept	A_0	2.16	0.09	23.42	0.00***
Conc. (C)	A_1	1.14	0.05	20.26	0.00***
Temp. (T)	A_2	-0.16	0.05	-2.87	0.03**
Time (t)	A_3	-0.47	0.05	-8.42	0.00**
CC	A_4	0.70	0.08	8.43	0.00**
TT	A_5	-0.29	0.08	-3.54	0.01*
Tt	A_6	0.16	0.08	1.94	0.10
CT	A_7	-0.0	0.07	0.0	0.95
Tt	A_8	0.26	0.07	3.25	0.02
TC	A_9	0.27	0.07	3.40	0.01

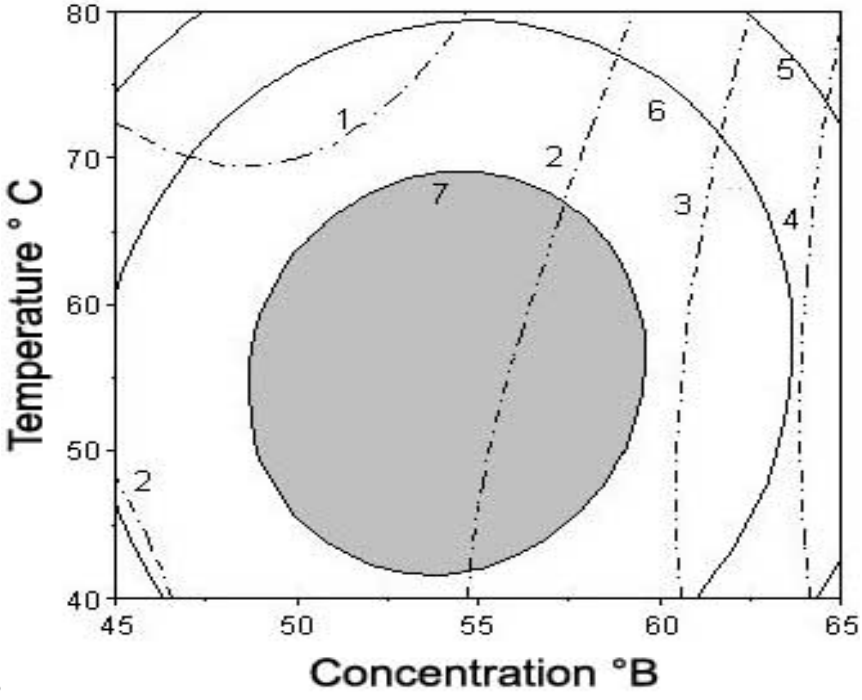
* $p < 0.05$

** $p < 0.01$

*** $p < 0.001$

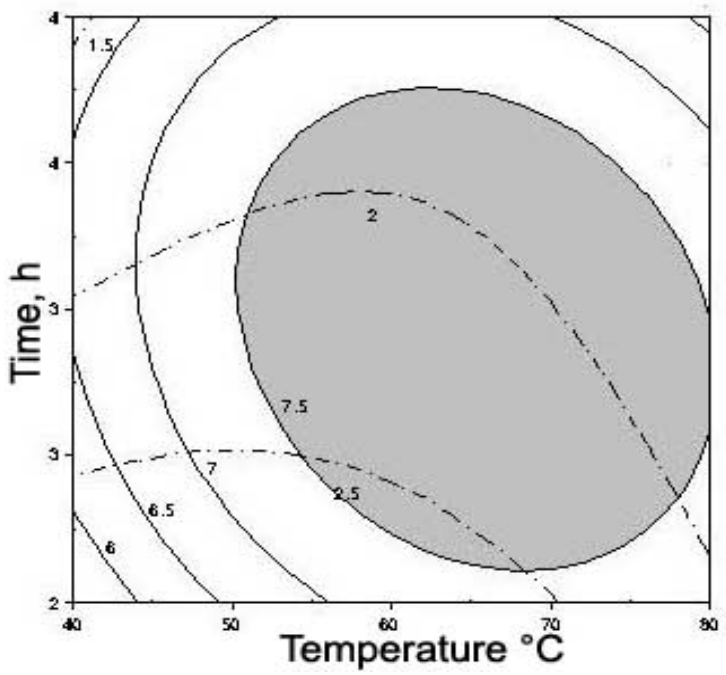


A



B

Fig. 2.8 A,B: Contour plots showing the influence of syrup concentration and temperature of soaking on sensory overall quality score and texture of *Jamun* prepared with sorbitol and sugar respectively. (——— Sensory ; ------ Texture)



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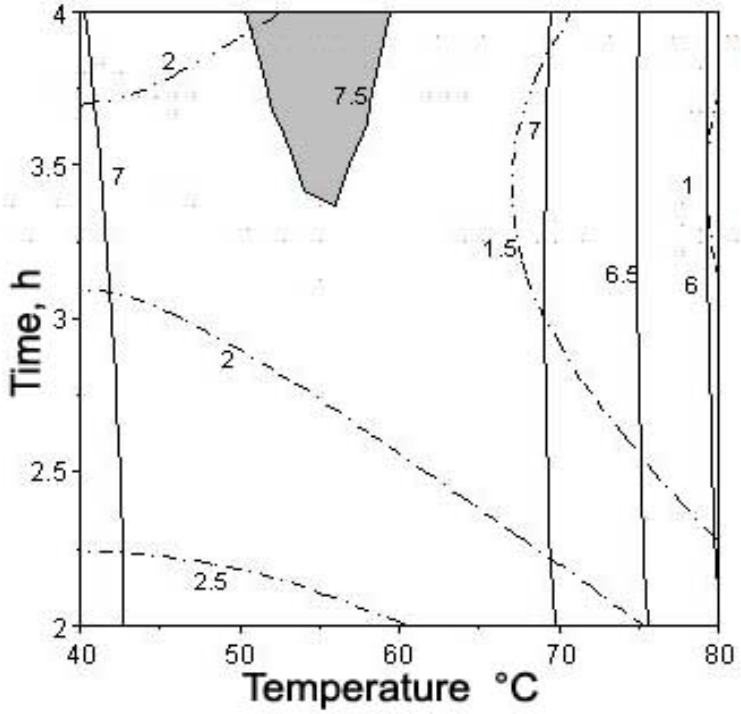
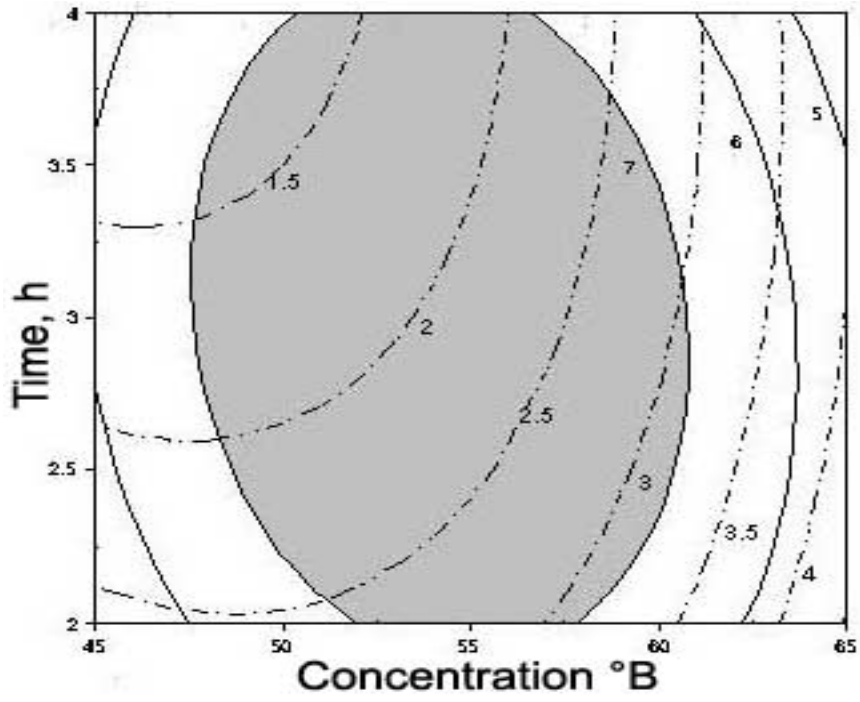
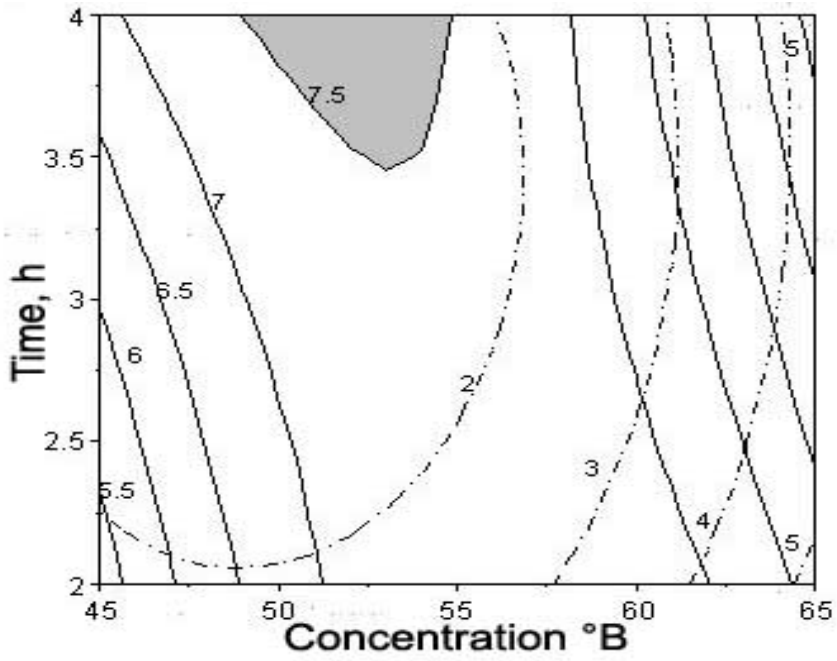


B

Fig. 2.9 A,B: Contour plots showing the influence of temperature and time of soaking on sensory overall quality score and texture of *jamun* prepared with sorbitol and sugar respectivley (——— Sensory ; ------ Texture).



A



B

Fig.2.10 A, B: Contour plots showing the influence of syrup concentration and time of soaking on sensory overall quality score and texture of *jamun* prepared with sorbitol and sugar respectivley (——— Sensory ; ------ Texture).

The experimental and predicted sensory scores for overall quality of both sugar and sorbitol containing *jamun* (Table 2.8) were found to have a correlation coefficient of 0.97, at P = 0.01. Similarly, the instrumental texture of these products had a correlation coefficient of 0.97 at P=0.01. Thus, these results showed very good correlation between experimental and predicted values for sensory score and texture values.

With respect to temperature and time, Fig. 2.9 (A) shows that, in the case of *jamun* made with a sugar substitute, the overall quality increased with temperature upto about 65°C and 3 hrs time and then decreased. Increase in time of soaking decreases texture values. In the case of *jamun* with sugar (Fig. 2.9 B), the effect of temperature and time on the overall quality showed similar trend. But with respect to time, the overall quality is nearly independent of time of soaking and the optimum sensory score was about 7.5. It was observed that the overall quality increased up to 55°B, after which it showed a decreasing trend in Fig. 2.10 (B). With respect to time, the best overall quality for *jamun* with sugar was about 3.5 h (Figs. 2.9B, 2.10B).

Figure 2.8 shows that the overall quality improved upto a syrup concentration of 55-60°B and soaking temperature of 60-70°C; below and above these ranges, it decreased for both sugar and sorbitol syrups. This can be attributed to the fact that at higher concentrations, there is a decrease in penetration of syrup into the *jamun,* resulting in a product with a hard core. The more viscous the syrup, the less the absorption even at higher temperatures, so that the overall acceptability of the product decreases. The apparent viscosity increased with increase in concentration of both sugar and or sorbitol syrups (Chetana et al, 2004). *Jamun* with sorbitol had the maximum sensory score in the region of 55°B and with 3h soaking and the syrup absorption in the range of 2.8-2.9 g/g. Similar results were reported with sugar where high syrup concentration decreased the volume expansion and increased the hardness of *jamun* (Rao et al, 2000)

The absorption of syrup (sugar or sorbitol) by *jamun* is shown in Table 2.9. Absorption is marginally higher in the case of sugar syrup (1.54 - 3.61g/g) compared to that of sorbitol (1.8 - 3.62 g/g) and is a function of the three variables studied. The higher the concentration of the syrup (65°B), the lower is the syrup absorption, and so an increased shear value (Table 2.8). This can be attributed to the fact that due to poor syrup absorption, a hard core is

formed thereby giving increased hardness to the *jamun*. In this situation, the high viscosity of syrup limits its ingress to the outer surface of the product, giving it heterogeneous texture, with soft outer layer and a hard inner core. Obviously, such products are not liked by the judges as reflected by the poor sensory scores shown in Figs. 2.8 and 2.9. At lower concentrations of the syrup (45°B), there is an increased syrup penetration due to the lower viscosity of the syrup and the resulting product is softer. The higher the temperature, the greater will be the amount of syrup absorbed, resulting in a soft and pasty *jamun* which was ranked low by the judges. From Table 2.8, it can be observed that a sensory score of about 7.9 can be achieved when the texture (shear) values were between 1.7 and 2.2N for *jamun* made with either sugar or sorbitol. However, all samples showing these texture values are not suitable as they showed3 low overall quality scores due to other sensory attributes.

The accuracy of the model chosen is shown by an error value of 3.60 between experimental and predicted values for *jamun* with sugar and an error value of 4.8 for *jamun* without sugar. Hence, the model for optimization of syrups and processing conditions for preparation of *jamun* with and without sugar appears to be satisfactory.

Table 2.8 Mean overall quality sensory scores and instrumental texture (shear) values of *jamun* prepared with sugar and sorbitol

Process parameters			Overall Quality		Texture (N)	
Concentration (°B)	**Temperature (°C)**	**Time (h)**	***Jamun* with sugar**	***Jamun* with sorbitol**	***Jamun* with sugar**	***Jamun* with sorbitol**
1 (65)	1 (80)	0 (3)	4.4	5.3	3.8	3.6
1 (65)	-1 (40)	0 (3)	4.8	4.1	3.6	3.7
-1 (45)	1 (80)	0 (3)	4.3	5.0	1.2	1.4
-1 (45)	-1 (40)	0 (3)	5.5	5.0	2.3	1.5
1 (65)	0 (60)	1 (4)	4.5	3.8	4.5	3.9
1 (65)	0 (60)	-1 (2)	6.5	5.1	5.8	4.4
-1 (45)	0 (60)	1 (4)	6.7	5.5	1.1	1.1
-1 (45)	0 (60)	-1 (2)	5.6	5.6	2.0	2.7
0 (55)	1 (80)	1 (4)	6.1	6.9	1.0	1.6
0 (55)	1 (80)	-1 (2)	5.7	6.9	1.3	1.9
0 (55)	-1 (40)	1 (4)	7.3	6.3	2.6	1.6
0 (55)	-1 (40)	-1 (2)	6.6	5.0	2.8	2.9
0 (55)	0 (60)	0 (3)	7.9	7.9	1.8	2.2
0 (55)	0 (60)	0 (3)	7.4	8.1	1.7	2.1
0 (55)	0 (60)	0 (3)	7.0	7.8	1.8	2.1

* Figures in parenthesis are actual experimental process parameters

Table 2.9 Syrup absorption of *jamun* in sugar and sorbitol syrups

Process parameters in coded level			Syrup absorption (g/g)	
Concentration (°B)	Temperature (°C)	Time (h)	Sugar	Sorbitol
1	1	0	1.83	1.18
1	-1	0	1.77	1.58
-1	1	0	2.96	2.92
-1	-1	0	2.28	2.62
1	0	1	1.67	2.08
1	0	-1	1.54	1.73
-1	0	1	3.61	3.25
-1	0	-1	2.53	2.81
0	1	1	2.96	3.62
0	1	-1	2.03	3.43
0	-1	1	2.18	2.63
0	-1	-1	2.03	2.24
0	0	0	2.28	2.93
0	0	0	2.31	2.94
0	0	0	2.32	2.81

2.3.4 Checking optimum parameters on quality of *jamun* by sensory analysis

Sugar syrups of 55°B were found to be suitable for preparation of *jamun.* The viscosity of such syrups was 14.7 mPas at 60°C (Table 2.2) and the syrup having similar viscosity is 59°B of sorbitol, 44°B of PD and 49°B of MD+PD. The results of the optimization studies also revealed that the suitable syrups for preparation of *jamun* are 55 °B of sugar and 54 °B of sorbitol.

Jamuns were prepared with these syrups to confirm the analyses. The sensory analyses of these products are shown in Table 2.10 *jamuns* with sorbitol had the highest overall score of 8 followed by sugar with 7.8 indicating that the *jamun* prepared with sorbitol could be comparable to *jamun* prepared with sugar. Since the sorbitol syrup of 55°B was slightly less viscous, than 55°B of sugar syrup, the *jamuns* made with sorbitol syrup were softer than those made with sugar. The *jamun*s prepared with sorbitol were lighter in colour when compared with other samples; but this was found to be a desirable attribute and so the product made with sorbitol scored higher for overall quality (Table 2.10). *Jamun*s made with bulking agents in combination with the intense sweetener aspartame, showed a slightly lower acceptability. This could be attributed to the fact that these syrups showed a slightly higher off taste, especially of polydextrose syrup, even though they matched the other sensory and textural attributes of *jamun* made with sugar.

Table 2.10 Sensory analysis of *jamun* prepared with and without sugar

Sensory Attributes	Sugar	Sorbitol	MD +PD	PD
Colour	7.66	5.84	7.25	7.5
Softness	5.67	5.0	5.77	5.65
Chewiness	6.34	6.01	5.36	6.0
Mealiness	7.41	5.47	5.9	6.75
Juiciness	4.91	6.3	4.93	4.81
Uniformity of core	6.41	6.41	6.89	6.17
Sweetness	5.53	5.66	6.34	6.48
Juice sweetness	6.51	5.84	5.1	5.75
Off taste	1.3	1.3	3.8	4.2
Overall quality	7.8	8.0	6.19	5.9
Instrumental Texture Shear (N)	2.0	1.8	2.5	2.3

MD=Maltodextrin; PD=Polydextrose

2.3.5 Colour of syrups

Colour plays an important role in the appearance of food materials. Colour acts as an indicator of quality, which dramatically influences the surface, subsurface properties, the taste perception and finally, the acceptance of food. L*, a* and b* system allows instrumental readings to match closely the perception of human observers. The colours of various sugar free syrups and that of *jamuns* were determined and the results are shown in Table 2.11 and 2.12.

L*, the lightness of the sample was highest and significantly different for sorbitol syrup, whereas no significant differences were observed among the other syrups (Sugar, MD+PD and PD). The negative values of a* show that the samples possess a slight blue tint but it can be neglected due to their low magnitudes. The b* values are high for MD+PD and PD syrups indicating a slight yellow tint. The ΔE* gives the total colour difference with respect to a standard white colour. PD syrup has a low ΔE* value showing marginal dullness. Thus, it is concluded that sorbitol syrup is not different significantly ($P \leq 0.05$) from sugar syrup considering ΔE* values. In addition, MD+PD also match closely with sugar syrup while PD offers a dull appearance. Sorbitol syrup is lighter in colour compared to sugar syrup (Fig. 2.13 pp 88).

Table 2.11 Colour of dispersions containing sugar and sugar substitutes

Type of Syrup	L*	a*	b*	ΔE*
Sugar	54.64^{a}	-2.10^{b}	13.19^{b}	48.27^{c}
Sorbitol	58.85^{b}	-1.55^{a}	3.64^{a}	46.56^{bc}
PD	$52..21^{a}$	-2.30^{b}	26.05^{c}	38.93^{a}
MD+PD	54.59^{a}	-3.37^{c}	28.12^{c}	44.08^{b}

MD=Maltodextrin; PD=Polydextrose

* Values in the same column with different superscripts differ significantly (P< 0.05 according to Duncan's Multiple Range Test (DMRT)

2.3.6. Colour of *jamun*

The appearance of *jamun* is normally brown in colour (Fig. 2.12 to 2.15 pp 88 and 89). The effect of alternative syrups on surface appearance of *jamun* were determined and are given in Table 2.12, as colour is one of the important quality attributes of a desirable *jamun*.

Lightness (L*) value was highest for *jamun*s with sorbitol, indicating lighter coloured *jamuns*. It was significantly different from those of *jamuns* made with other syrups (Fig. 2.12), although the balls were fried together for the same time and at the same temperature. This could be attributed to the lightness of the sorbitol syrup (Table 2.11), which results in a light coloured product. A slightly deeper red coloured product (according to a* values) was obtained with MD+PD syrups; other syrups did not produce a significantly ($p<0.05$) different colour. Minimum yellowness (b*) was observed for samples made with sugar syrup. The total colour difference (ΔE^*) was highest for *jamun* with sugar syrup and lowest for *jamun* prepared with sorbitol. No significant difference was found for L* values and ΔE^* between MD+PD and PD samples. Thus, to a common consumer, *jamuns* made with sorbitol syrup would appear as marginally lighter or brighter than *jamuns* made with sugar or MD+PD, or PD syrup; *jamun*s made with these last three syrups did not show any significant difference in colour.

Table 2.12 Colour of *jamun* (outer surface), made with different syrups

Type of *jamun*	L*	a*	b*	ΔE^*
Sugar	19.50 ± 0.28^{a}	14.77 ± 0.09^{a}	24.81 ± 0.48^{a}	75.02 ± 0.22^{c}
Sorbitol	28.21 ± 0.19^{c}	14.11 ± 0.14^{a}	33.43 ± 0.31^{b}	69.23 ± 0.19^{a}
MD+PD	25.49 ± 0.35^{b}	19.13 ± 0.06^{b}	31.16 ± 0.51^{b}	72.42 ± 0.26^{b}
PD	25.23 ± 0.33^{b}	14.84 ± 0.04^{a}	30.11 ± 0.62^{b}	71.26 ± 0.25^{b}

MD=Maltodextrin; PD=Polydextrose
Values in the same column with different superscripts differ significantly ($P<0.05$, according to Duncan's Multiple Range Test (DMRT)

2.3.6 Stability of aspartame during storage

The stability of aspartame during storage is important considering the maintenance of sweetness in the finished product. Products prepared with aspartame in combination with sugar substitutes were subjected to three different storage conditions such as ambient, refrigerated and accelerated. Aspartame was recovered from the samples withdrawn at regular intervals and analysed by HPLC. Chromotograms obtained for standard aspartame and that extracted from the sample are shown in the Fig. 2.11. The stability of aspartame was least under the accelerated condition, with the lowest recovery of aspartame (68.5%) at the end of 4 days. Under ambient storage conditions, the lowest recovery was 74.5% after 8 days. There was marginal difference in the percent loss at the refrigerated conditions (81.6%) at the end of 12 days. Aspartame was incorporated in all types of syrups at the end of product preparation i.e. at 65°C to avoid loss of aspartame due to processing. It was necessary to add the sweetener just before the *jamuns* were added to syrup to ensure thorough mixing throughout the product.

Results of the study showed a low recovery pattern of aspartame. Samples stored at refrigerated temperature showed the least loss, while those kept in accelerated temperature showed the highest loss.

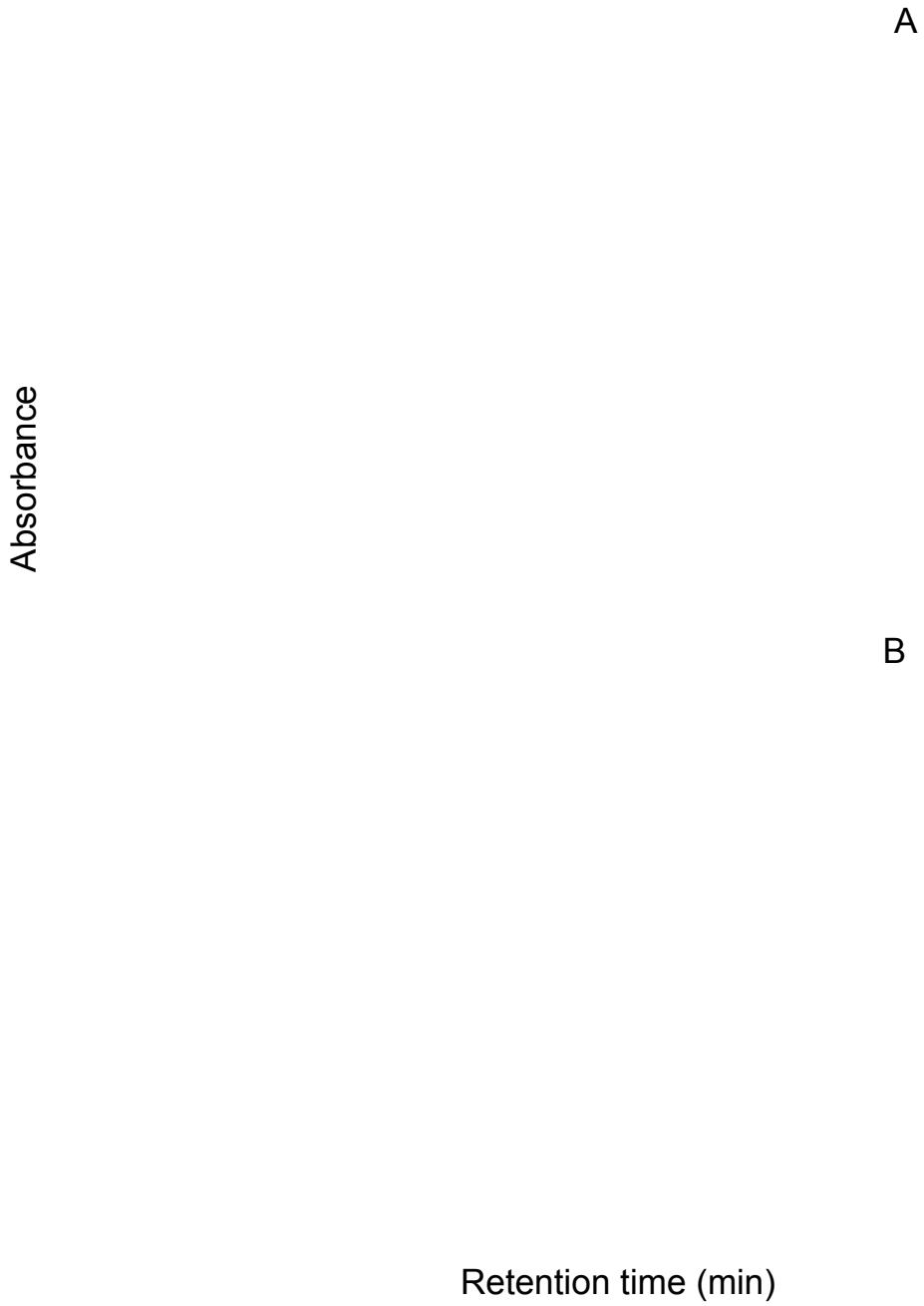
Table 2.13 Recovery of aspartame in *jamun* samples stored under ambient, accelerated and refrigerated conditions

Type of *jamun*	Withdrawals*	Percentage recovery of aspartame in sugar free *jamun*		
		Refrigerated	Ambient	Accelerated
Sorbitol +Aspartame	0	96.4	95.5	94.8
	1	95.6	89.7	88.5
	2	95.0	87.8	84.4
	3	94.6	85.5	80.8
	4	94.4	82.1	72.1
PD+ Aspartame	0	95.5	94.9	93.4
	1	91.6	89.9	86.1
	2	86.3	81.5	78.9
	3	84.4	75.8	73.7
	4	80.0	69.0	70.3
MD+PD+ Aspartame	0	93.4	94.4	93.2
	1	88.5	89.0	78.3
	2	86.8	84.6	81.2
	3	86.0	78.8	76.3
	4	81.6	74.5	68.5

MD=Maltodextrin; PD=Polydextrose

* Withdrawal days– Accelerated: 0, 1, 2, 3, 4; Ambient: 0,2,4,6,8 and Refrigerated 0,3,6,9,12 days

Fig. 2.11. HPLC chromatogram of standard aspartame (A) and the sweetener extracted from *Jamun* (B)



2.3.8 Microbiological profile of *jamun*

The microbial profile of *jamun* after preparation and during storage is important from the point of safety of consumption. The microbial profile of the *jamuns* prepared with and without sugar and stored for up to 8 days is shown in Table 2.14. Proliferation of the microbial population was observed in the MD+PD and PD samples, whereas it occurred to a lesser extent in sugar and sorbitol samples.

The microbial quality of various commercial Indian sweets has been studied with emphasis on sweets steeped in liquid (Dwarkanath and Venkatasubbiah, 1985). They reported high values of total bacterial count; apparently, coliforms were absent, but yeasts and moulds were present in milk based preparations. The occurrence of micro flora in commercial samples was found to be much higher than those observed in this study.

Table 2.14 Microbiological profile of *jamun* prepared with and without sugar

Type of *jamun*	Storage period (Days)	Mesophllic aerobes Log $_{10}$CFU/g	Yeasts and molds Log $_{10}$CFU/g	Staphylococcus Log $_{10}$CFU/g
Sugar	0	3	<2.0	<3.0
	2	3	<2.0	<3.0
	4	<3	<2.0	6.4
	6	5.38	<2.0	>7.3
	8	6.38	<2.0	>8.3
Sorbitol+ Aspartame	0	<2.0	<2.0	<3.0
	2	<2.0	<2.0	<3.0
	4	<2.0	<2.0	<3.0
	6	<2.0	<2.0	>6.6
	8	<2.0	<2.0	>7.3
MD+PD+Aspartame	0	3.6	<2.0	<3.0
	2	5.17	<2.0	<3.0
	4	6.3	<2.0	6.75
	6	6.69	<2.0	>7.3
	8	6.89	2.6	>8.3
PD+Aspartame	0	3.0	<2.0	<3.0
	2	3.77	<2.0	<3.0
	4	6.38	<2.0	6.77
	6	6.69	<2.0	>7.3
	8	7.04	2.8	>7.3

MD=Maltodextrin; PD=Polydextrose

Proliferation of the microbial population was much greater in the MD+PD and PD samples than in the sugar and sorbitol samples. The microbial count remained static at $< 10^2$ log $_{10}$ CFU/g throughout the storage period of 8 days for *jamuns* made with sorbitol. The safety parameters for these samples included *Eschericia coli*, which is the sanitary index level and *Staphylococcus aureus*. Both were absent in all the samples studied during the entire storage period. Though the microbial safety of these samples has been established, it must be noted that proliferation of *staphylococci* did not occur in all the samples. Interestingly this trend was observed in all the sweet samples studied.

Staphylococcal contamination in food is normally attributed to the food handlers. Such a situation could be explained during the preparation of *jamun* where excessive handling and intimate contact with the skin takes place especially while rolling balls for *jamun*. However, the mere presence of *staphylococcus* will not render these products unfit for consumption, since organisms such as *B. cereus*, or toxic metabolites of *S*. *aureus* must be present in sufficient numbers to cause infection. The presence or absence of *E*. *coli* and *S*. *aureus* indicates the sanitary status and safety of these products. The other pathogenic organisms such as *Salmonella, Bacillus cereus and Enterococci* were absent in the preliminary studies. Moreover, observance of strict hygienic practices (by following GMP) ensured the safety of the product.

There are no specifications for microbiological quality of *jamun*s in terms of total plate count ; for other sweets, like *burfi,* (IS 5550 1975) stipulates a maximum plate count of 30,000/g and yeast and mold count of 10/g. Keeping this standard in view, it was found that *jamun* made with sugar had a shelf life of 4 days, samples made with MD+PD or PD samples had a shelf life of only 2 days, whereas *jamun made* with sorbitol were found to be safe for the entire storage period of 8 days. The polyalcohols are also more resistant to microbial degradation than sugar (Dwivedi, 1991), for example sorbitol produces a better preservative effect than sugar. Thus these results revealed that sorbitol has better preservative properties compared to sugar.

2.3.9 Proximate composition

The proximate composition of *jamuns* with and without sugar was estimated (Table 2.15). The moisture content of all the *jamun*s ranged from 25 to 31%, protein content from 6.1 to 6.9%, total ash from 0.6 to 0.98% and fat from 6.4 to 10.3 %. The calorific value of polydextrose (PD) was taken as equal to 1 Kcal (Bunting, 1994; Moppet, 1991); of sorbitol 2.4 Kcal and of maltodextrin and sugar 4 Kcal. (Nabors and Gelardi, 1991; Deis, 2000). Thus, the calorific value of *jamuns* prepared with PD was the lowest. The calorie calculations were based on composition of the prepared sweets and colorific value of individual components. Some calorie reduction was observed in the sugar free *jamuns*.

Table 2.15 Proximate composition of sugar and sugar free *jamun*s

Type of *jamun*	Moisture (%)	Protein (%)	Total Ash (%)	Fat (%)	KCal/100g
Sugar	25.63±0.46	6.94±1.16	0.94±0.03	28.68±1.18	361±1.05
Sorbitol	31.83±0.22	6.3±0.41	0.60±0.01	25.41±0.41	254±1.82
PD	34.66±0.16	6.18±0.22	0.83±0.03	23.56±0.22	201±0.98
MD+PD	28.27±0.15	6.91±0.03	0.98±0.04	23.33±0.31	282±1.11

MD=Maltodextrin; PD=Polydextrose

Conclusions

Sugar and sorbitol solutions behave like Newtonian fluids, while other syrups (MD and PD) studied exhibited a shear thinning, non Newtonian behaviour with yield stress. Flow behaviour of all the syrups studied could be well represented by the Herschel-Bulkley model. The yield stress, flow behaviour index and consistency index were dependent on both temperature and concentration. The activation energy, as calculated by the Arrhenius equation, increased with increasing concentration of solids. The requirements of sugar substitutes (MD+PD and PD) were needed in smaller amounts than sugar alone, whereas for sorbitol it was similar to that of sugar to produce solutions/dispersions with the same viscosities as sugar solutions. The colour of syrups showed that sorbitol syrup was brighter than the others and matches closely with sugar syrup.

It was observed that the processing conditions, such as syrup strength, temperature and duration of soaking, influenced the texture and overall acceptability of the product. To prepare *jamun* without sugar, these parameters need to be optimised to get a product having a texture and quality similar to that obtained by using sugar syrup. Response surface methodology (RSM) was found to be an useful tool for optimisation of these parameters. The results indicated that the optimum conditions for *jamun* made with sugar or with sorbitol, were: syrup strength 51 and 54°B; temperature of soaking 54 and 65°C and time of soaking were 4 and 3 hrs respectively. Based on these conditions,sugar free *jamun* could be prepared without affecting the quality.

Colour measurements indicated that *jamun* prepared with sorbitol was lighter in colour than *jamun* made with either a sugar syrup, or a syrup made with a mixture of maltodextrin and polydextrose (MD+PD), or a polydextrose (PD) syrup. The added intense sweetener aspartame, showed the least loss at refrigerated temperatures and highest loss at accelerated temperature. The microbial profile of *jamun* also indicated that *jamun*s with sugar syrup had a shelf life of 4 days, while *jamun*s made with MD+PD or PD syrups had a shelf life of 2 days. Interestingly, sorbitol was found to be safe for the entire storage period of 8 days; moreover the lower calorific value of sorbitol *jamuns* is an added advantage.

It can be concluded from these results that *jamun* could be prepared using sorbitol without affecting the overall quality compared to the traditional

product prepared with sugar. Syrups prepared with bulking agents MD+PD and PD along with the intense sweetener aspartame also could be used for preparation of *jamun.* However, these products showed lower overall acceptability scores compared to *jamuns* with sorbitol and sugar.

Fig. 2.12 *Jamun* in sugar syrup

Fig. 2.13 *Jamun* in sorbitol syrup

Fig. 2.14 *Jamun* in maltodextrin+ polydextrose syrup

Fig. 2.15 *Jamun* in polydextrose syrup

Chapter 3

Burfi

Chapter III

Milk Burfi

3.1 Introduction

Milk *burfi/burfi* is one of the most popular milk based sweet in India. It has great social, religious, cultural and economic importance. Several varieties of *burfi* are available in the market such as plain or *mawa/khoa burfi*, fruit and nut, chocolate, saffron and *rava burfi*. *Burfi* sold commercially varies widely in colour, body, texture, sweetness and flavour characteristics (Sarkar et al, 2002).

Burfi is prepared by heating a mixture of concentrated milk solids (*Khoa*) and sugar to a near homogenous consistency followed by cooling and cutting into small cuboids. Beating and whipping operations prior to cooling are sometimes practiced to obtain a product with smooth texture and closely knit body.

Wide variation could be observed in physical attributes of *burfi*. The variations in ingredients, their proportions and processing conditions affect the quality of *burfi.* Lack of knowledge in these aspects is a serious limitation for the process standardization and quality control. It is thus desirable to know the effect of these variables on the quality attributes of the finished product.

Although the Bureau of Indian standards has developed a standard for chemical and microbiological quality of milk *burfi*, IS 5550 (1970), no legal standards have been fixed under the Prevention of Food Adulteration (PFA) act. There is a need for generating data on the processing and quality aspects of milk *burfi*. Although *burfi* has long been a popular sweet of India, adequate research attention has not been provided for optimizing the product in relation to quality and storage stability.

In addition, as mentioned earlier, to meet the requirements and demands of the health conscious consumers, formulations and process for preparation of low sugar milk *burfi* are studied.

The need and importance of replacing sugar in traditional sweets have been discussed in detail earlier (chapter 2, *jamun*). To replace sugar, apart from

texture and sensory attributes, the stability and packaging aspects of the products need to be considered. Information on moisture sorption behaviour of products is a pre-requisite for selection of packaging material and prediction of shelf life (Hariharakrishnan, 1979) and such data reveals deteriorative changes in food. It also provides an easy way to evaluate parameters for the determination of stability of foods (Labuza et al, 1970; Mizrahi and Karel, 1977). Moisture sorption isotherms can give an insight into the moisture binding character of foods (Bera et al, 1990). Hence, moisture sorption studies of *burfi* were taken up. Improvement of the processing quality of foods requires sorption characteristics to be examined and suitability of mathematical models to be checked. The models, based on theoretical considerations about water sorption, allow us to understand different aspects of the food water interaction.

Establishing proper proportions of ingredients in food products that results in maximum palatability is a tedious and expensive task. Response surface methodology (RSM) based on rotatable central composite experimental design in combination with optimization technique is useful to find out the quantitative effect of variables and to obtain the best combination of variables for an optimum response with minimum experimental combinations. It is thus thought to apply RSM to determine the effects of process parameters on the texture and overall quality for *burfi* with sugar and with sugar replacer, sorbitol.

Hence the present work investigates (1) The effect of operational parameters such as soluble solids (°B) at the end point and storage days on the texture and overall sensory quality of *burfi* with and without sugar. (2) Formulation and process standardization of sugar free *burfi* in comparison with control prepared with sugar. (3) Studies on ERH and sorption characteristics of milk *burfi* with and without sugar.

3.2 Materials and Methods

3.2.1 Materials

Same as described in chapter 2 under *jamun*. *Khoa* (semisolid concentrated milk) and hydrogenated vegetable fat were procured from the local market. *Khoa* used in this study is made out of buffalo milk and had a composition of moisture: 22%, protein: 25%, fat: 32%.

3.2.2 Preparation of *burfi*

Burfi was prepared by following the traditional method of preparation. A mixture of *khoa* (100g); sugar (30g) and fat (5g) were heated till the mass reached total soluble solids of 80-82°B. The hot mass was then transferred to a plate, cooled, spread evenly and cut into pieces of size 50 x 40 mm having uniform thickness of 10 mm. Sugar free or low sugar *burfi* was also prepared in the same manner, replacing sugar with a) sorbitol, b) sorbitol and mannitol (S+M, 80:20, 90:10), c) maltodextrin and polydextrose (MD+PD, 50:50); and d) polydextrose (PD). Intense sweetener aspartame was added to each of these batches to obtain sweetness level comparable to sugar (0.25g/100g of *burfi* for sorbitol and sorbitol + mannitol combinations; 0.7g/100g of *burfi* for maltodextrin and polydextrose).

3.2.3 Soluble solids

Product optimization was carried out for *burfi* prepared with sugar and sorbitol. The mixture of khoa, sugar / sorbitol and fat was heated till the total soluble solids content (TSS, °B) reached, 75, 78 and 80°B according to the experimental design shown in Tables 3.5 and 3.6. The TSS was measured using a hand refractometer. The TSS had good correlation with temperature (108 to 110°C). Moisture content of the final product plays an important role in determining the texture of *burfi.* Good snap is characteristic of a desirable *burfi.*

3.2.4 Storage studies

The *burfi* samples, prepared according to section 3.2.2, were stored in polypropylene boxes of thickness about 500 microns for 10 days at ambient condition (temperature: 24 - 30ºC, RH: 30 – 55%).

3.2.5 Texture measurement of *burfi*

The breaking strength or snap of *burfi* was measured using a Universal Testing Machine (Model LR 5K, Llyods Instruments, UK). The sample dimension was 50X40X10 mm (length x breadth x thickness) and a span length of 30mm and three point bending was performed using a load cell of 50N and replicated 6 times with a crosshead speed of 50mm/min. The force required to break the *burfi* into two pieces was recorded.

3.2.6 Sensory assessment

The details of sensory assessment of *burfi* are similar to those of *jamun* which has been discussed in detail under section 2.2.7. The judges were asked to mark the perceived attributes such as colour, snap, hardness, sweetness, lingering sweetness, off taste and overall quality.

3.2.7 Experimental design

The important independent processing variables selected were: TSS at end point (X_1) and storage days (X_2). The response variables were the texture of *burfi* measured by instrumental breaking force expressed in Newtons (N) as well as the overall sensory score. These two response functions were selected as the total quality indicators.

A central composite rotatable design (CCRD) developed by Box and Wilson (1951) was adopted to optimize the processing conditions. For two variable thirteen design points were experimented with a central point, replicated 5 times.

3.2.7.1 Statistical analysis

Experimental data were analyzed by the response surface regression procedure by using statistical software Statistica'99 (StatSoft, Inc, USA). The following quadratic polynomial equation was used to fit the second order response surface (Montgomery 1984), as detailed in Section 2, jamun.

$$Y= b_0 + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{22}X_2^2 + b_{12} X_1 X_2$$

Three dimensional response surfaces with independent variables against response variables were created from quadratic equation by the software

provided. Simultaneous optimization of independent variable with desired response values were done by desirability approach described by Derringer and Suich (1980) where the value of each desirability ranged from 0 (minimum) to 1 (maximum) as desirability of the associated response increased the one sided transformation suggested. The higher the desirability value the more desirable the system and thus, maximization of the response functions were achieved.

3.2.8 Colour measurement of *burfi*

The details are similar to those mentioned earlier in chapter 2, jamun.

3.2.8.1 Statistics

Duncan's Multiple Range Test (DMRT) was applied to differentiate among the means of different samples at a probability (P) of 0.05. In the present section, DMRT was employed to differentiate among the colour values of *burfi* containing sugar and selected sugar substitutes as these values were too close enough to differentiate.

3.2.9 HPLC analysis

HPLC analysis of aspartame was performed using Shimadzu LC –10AT pump attached to a Shimadzu SPD-10AVP UV visible detector controlled by class LC–10 workstation by the same procedures as described in chapter 2, *jamun*. The prepared *burfi* were stored at different storage conditions accelerated (37 ±1°C), ambient (27±1°C) and refrigerated (8±1°C).

3.2.9.1 Sample preparation of HPLC analysis

The *burfis* were drawn from storage at regular intervals and brought to room temperature and sample preparation is same described under chapter 2, *jamun*.

3.2.10 Microbiological studies

The details are similar to those mentioned earlier in chapter 2, *jamun*.

3.2.11 Sorption studies

Saturated salt solutions of lithium chloride, potassium acetate, magnesium chloride, potassium carbonate, magnesium nitrate, sodium nitrate, sodium chloride, potassium chromate and ammonium phosphate were used to obtain different RH combinations having water activity (a_w) values of 0.11, 0.22, 0.33, 0.44, 0.54, 0.64, 0.72, 0.86 and 0.92, respectively. These saturated salt solutions were taken in different desiccators. Prior to keeping the *burfi* in these desiccators, the samples were conditioned to 65% at 27°C which are normal ambient conditions in India. The initial moisture content (IMC) of these sweets was measured in triplicate on dry basis (db) by toluene distillation method (AOAC, 1995). The sorption experiments were carried out, by keeping approximately 10g of sample in each desiccators, removing them at frequent intervals and weighing until they reached constant weight (within±5%). All chemicals used were of analytical grade (AR).

3.2.12 Sorption models

A number of sorption isotherm models have been reported in literature. In the present study BET, Harkins-jura (Labuza 1968), Caurie (1970), Hasley, Smith Oswin, Bradley (Chirife and Iglesias 1978) and GAB models were used for fitting the sorption data. The equations were rearranged to linear form to determine the appropriate constants (Table 3.1) easily by regression analysis using MS Excel software (Microsoft, 2000). The sorption data were analysed according to the models and the corresponding constants were determined. The extent of fit of each model was computed in terms of coefficient of determination (r^2) from the plot of experimental (M_{exp}) and predicted (M_{pre}) moisture content. The root mean square error (RMSE) values calculated as follows

$$RMSE = \{[(M_{exp} - M_{pre})/ M_{exp}]^2/N\}^{0.5} \times 100$$

where M_{exp} = Moisture content experimental (%db)

M_{pre} = Moisture content predicted (%db) and

N = Number of observations

3.3 Results and discussion

3.3.1 Selection of alternative sweeteners for preparation of *burfi*

The present section mentions the results of preliminary studies conducted on various aspects of *burfi.* To impart desirable texture, crystallization of the ingredients, especially sugar and sugar replacers play an important role.

In order to select an ideal/appropriate sweetener for the preparation of traditional sweets such as *burfi* and *laddu*, some basic work on properties of alternatives, sorbitol and mannitol on solubility and crystallinity were studied in comparison with sucrose, as part of sucrose is in the crystalline state in these products.

The results from Table 3.2 indicate that sorbitol remains in liquid state even at 80% solids (80°B). Incorporation of mannitol into sorbitol induced crystallization; the degree depends on percentage of mannitol. On the other hand, incorporation of sorbitol to sucrose solutions inhibits crystallization. This property of blending sorbitol and mannitol was found to be satisfactory for preparation of *burfi* and *laddu* where crystallization of sugar is necessary to impart the desired texture. On the contrary, crystallization is not required for *jamun,* where thinner syrups (less than 70°B) are required. Sorbitol, maltodextrin and mixture of maltodextrin and polydextrose syrups did not crystallize; above 60°B the later two syrups MD+PD and PD formed a thick gel. These results revealed that addition of mannitol to sorbitol induces crystallization similar to sugar and hence may be suitable for preparation of *burfi* and *laddu,* where crystallization is one of the characteristics to impart desired texture.

Table 3.2 Solubility and crystallinity of syrups with and without sugar.

Type of Sugar	Concentration (% soluble solids)								
	70°B			75°B			80°B		
	Days			Days			Days		
	1	2	3	1	2	3	1	2	3
Sucrose	--	+	++	+++	++++	++++++	++++++	++++++	++++++
Sorbitol	--	--	--	--	--	--	--	--	--
Sorbitol+Mannitol (S+M)									
S+M (90:10)	--	--	--	--	--	--	--	--	--
S+M (85:15)	+	++	++	++	++	+++	+	++	++++
S+M (80:20)	+	+	+++	+++	+++	+++++	++++++	++++++	++++++
Sucrose + Sorbitol (SS)									
Su+S (90:10)	--	--	--	--	--	+	--	--	+
Su+S (80:20)	--	--	--	--	--	--	+	--	+
Su+S (75:25)	--	--	--	--	--	--	--	--	+
Maltodextrin and Polydextrose									
MD	--	--	--	--	--	--	--	--	-
PD	--	--	--	--	--	--	--	--	-
MD+PD (50:50)	--	--	--	--	--	--	--	--	-

S=sorbitol; M=manitol; MD=maltodextrin; PD=polydextrose; Su=sucrose;

-- - Not crystallized
\+ - Partially crystallized -
++ - Equal amounts of liquid and crystal
+++ - more than half crystallized
++++ - Fully crystallized

3.3.2 Preparation of *milk burfi* using sugar replacers

Studies were conducted on processing aspects of *burfi* with and without sugar to find out the effects of replacing sugar on process parameters and quality of the product. It was observed that products could be obtained by replacing sugar with bulk sweeteners like sorbitol and mixtures of sorbitol and mannitol (S+M) and also by using bulking agents such as polydextrose (PD) and mixtures of maltodextrin and polydextrose (MD+PD). *Burfi* could not be obtained using maltodextrin alone due to poor binding properties. Alternatives which yielded products having texture and sensory attributes similar to sugar containing counterpart were chosen for further studies.

Results of the preliminary studies indicated that the method of preparation i.e., the end point or total soluble solids (°B), at which the cooked mass (*khoa* and sugar) is removed and spread for setting was highly critical. The soluble solids (°B) at the end of cooking, thus plays a critical role in influencing the final moisture content and in turn the snap of *burfi*. The end point is judged by checking total soluble solids (TSS) by means of a hand refractometer. Soluble solids content less than 75% (75°B) was not capable of forming a hard flat surface on spreading. But soluble solids content higher than 82°B resulted in a dry and hard product. Final TSS was also correlated with final cooking temperature, which ranges from 106-110°C. Hence, measure of TSS was taken as end point.

Considerable variation of product quality, in experimental conditions was encountered over a range of soluble solids and storage period (days). These studies formed the basis for further detailed study on *burfi* that are discussed in the following subsections.

Moderately sweet taste, good snap and a slightly greasy body with smooth texture and very fine grains characterize a highly acceptable quality of *burfi*. Further, the texture was found to be a critical aspect of *burfi* preparation. During storage, the *burfi* samples became harder as evidenced by the breaking strength or snap (Table 3.3). The loss of moisture is high in *burfi* prepared with sugar and crystallization of sugar noticed as evident from texture.

3.3.2 .1 Texture measurements of *burfi*

An end point having soluble solids of 78°B, with 2-3 days of storage was found to be ideal for *burfi* with sugar to get desirable quality characteristics. In order to obtain a product similar to that of sugar, it was necessary to bring TSS with sorbitol, also to 78°B and store for 5 to10 days. Similarly final TSS of 80°B was suitable for *burfi* prepared with MD+PD and PD, to be comparable to that of sugar in textural qualities (Table 3.3). The breaking strength or snap of *burfi* between 12 to 15 N and with an overall sensory score of 7.9 to 8.9 was found to be ideal. This could be achieved at 78°B and 3 to 5 days of storage for *burfi* with sugar and 5-6 days of storage for *burfi* prepared with sorbitol. Crystallization of sugar is faster than sorbitol and this may be responsible for the delayed snap of *burfi* with sorbitol.

Graining, which is a desirable attribute in *burfi* is mainly responsible for snap. This is observed in products prepared with sugar. Snap was also observed in sorbitol containing products where normally crystallization does not occur. This could be explained by the fact that graining may occur after preparation and during storage influencing the snap, similar to *burfi* with sugar. Delayed crystallization was observed in *burfi* with sorbitol compared to that of sugar as revealed by textural characteristics.

For *burfi* prepared with mixtures of sorbitol and mannitol (90:10 and 80:20), MD+PD and PD required heating up to TSS of 80°B and 3 to 4 days storage to obtain products similar to that of sugar. MD+PD and PD when heated to TSS of 78°B and stored for 10 days, had a snap value in the optimum range of 12-15N but fungus growth was observed in these two products. Above 18N force, *burfi* was hard and dry and assessed unsuitable by the sensory panel.

Table 3.3 Texture/snap (N) of sugar and sugar free *burfi*

Soluble solids (°B)*	Days of storage	Sugar	Sorbitol	S+M (90:10)	S+M (80:20)	MD+PD	PD
75°B	1	4.4± 0.68	2.4± 0.39	3.3± 0.21	5.7± 0.09	2.6± 0.25	3.0±0.33
	3	6.8± 0.71	2.6± 0.71	4.4± 0.34	7.7± 0.10	2.9± 0.29	3.4±0.38
	5	7.6± 0.67	3.0± 0.30	8.6± 0.05	9.2± 0.11	3.50± 0.45	4.8±0.45
	10	7.9± 0.71	3.8± 0.76	11.0± 0.24	10.6± 0.16	4.1± 0.42	5.3±0.63
78°B	1	11.7± 0.71	9.5± 0.57	7.9± 0.23	8.9± 0.19	6.5± 0.41	6.2±0.64
	3	13.8± 0.61	11.2± 0.64	8.6± 0.54	9.1± 0.17	9.4±0.64	9.6±0.69
	5	14.6± 0.66	13.1± 0.43	11.8± 0.29	10.4± 0.21	12.5±0.27	12.9±0.42
	10	18.3± 0.69	14.3± 0.47	12.0± 0.54	11.6± 0.23	14.3±0.65	13.7±0.41
80°B	1	13.9± 0.68	10.8± 0.46	11.8± 0.67	12.1± 0.18	11.1±0.87	12.3±0.78
	3	15.6± 0.71	12.9± 0.33	13.6± 0.63	14.8± 0.16	14.3±0.36	13.6±0.69
	5	16.3± 0.74	14.1± 0.32	14.9± 0.54	15.7± 0.25	16.1±0.45	16.8±0.34
	10	19.7± 0.69	16.1± 0.45	16.8± 0.54	18.9± 0.14	18.8±0.55	18.6±0.33

S = sorbitol; M =mannitol; MD = maltodextrin and PD= polydextrose.

* Final TSS after cooking

3.3.3 Moisture content of sugar and sugar free *burfi*

The moisture contents of *burfi* samples are shown in Table 3.4. Initially the products were moist but after one day of storage, they became hard with an increase in snap (Table 3.3). Higher moisture content in *burfi* rendered the product soft, showed low snap or breaking strength and enhanced microbial growth, especially yeasts and molds. It was observed that the moisture content of products on storage from 1st to 10th day gradually decreased, thus increasing snap.

Table 3.4 Moisture of sugar and sugar free *burfi*

Soluble solids (°B)	Days of storage	Sugar	Sorbitol	S+M (90:10)	S+M (80:20)	MD+PD	PD
75°B	1	18.7±0.18	16.3±0.21	16.8±0.11	16.8±0.25	17.3±0.06	17.1±0.22
	3	18.1±0.21	16.0±0.26	16.4±0.16	16.6±0.26	16.8±0.08	16.4±0.26
	5	17.7±0.24	15.8±0.23	15.3±0.14	15.7±0.21	16.3±0.04	15.7±0.31
	10	16.9±0.19	15.3±0.45	15.0±0.17	15.1±0.36	15.6±0.06	15.1±0.34
78°B	1	12.8±0.14	12.5±0.31	13.5±0.09	13.5±0.31	14.7±0.11	15.9±0.25
	3	12.2±0.16	12.0±0.25	13.1±0.08	13.0±0.29	14.4±0.15	14.7±0.28
	5	11.9±0.02	11.4±0.28	12.6±0.08	12.7±0.27	13.7±0.09	14.1±0.29
	10	11.0±0.14	10.4±0.22	12.0±0.10	12.2±0.24	12.4±0.17	11.8±0.27
80°B	1	12.8±0.18	12.6±0.37	12.9±0.22	12.8±0.25	13.1±0.14	13.2±0.36
	3	11.9±0.21	12.3±0.31	12.3±0.26	12.5±0.26	12.8±0.16	12.9±0.45
	5	11.0±0.11	12.0±0.36	11.4±0.24	11.3±0.22	12.6±0.17	12.5±0.47
	10	9.6±0.10	11.4±0.39	10.8±0.23	10.9±0.21	11.8±0.15	11.6±0.48

S = sorbitol; M = mannitol; MD = maltodextrin and PD= polydextrose

3.3.4 Sensory analysis of *burfi* with and without sugar

Although colour difference was observed initially, the sensory analysis of *burfi* with and without sugar (Table 3.5) revealed that there was marginal change in the colour of *burfi* during storage. Minor differences were observed among the sugar free products. Products prepared with sugar, sorbitol, sorbitol and mannitol (80:20 and 90:10) were creamish white in colour. The products containing MD+PD and PD samples were slightly darker in colour when compared to that of sugar. Marginal difference was observed in the sensory quality of *burfi* from the 3rd to the 5th day and therefore the values of the 3rd day have not reported in the Table 3.5. The snap which is an important attribute in *burfi* was highest in the product made with S+M (80:20), whereas those of sugar and S+M (90:10) were

similar. This similarity could be observed even in the instrumental texture of these two products (Table 3.3). Hardness of the products also showed results similar to those of snap, samples with S+M (80:20) showed increased hardness. Sweetness of all the products were comparable with that of sugar while lingering sweetness was marginally higher in *burfi* prepared with bulking agents, MD+PD and PD. The overall quality of the products showed high scores for products with sugar and S+M (90:10), followed by *burfi* with sorbitol and S+M (90:10), MD+PD and PD. In the preparation of *burfi*, *khoa* is the major ingredient while sugar and sugar substitutes were added in lesser amounts. Thus marginal difference was observed in overall acceptability among the products prepared using sugar replacers. The highest overall acceptability was observed during 3 to 5 days of storage. The first day and 10^{th} day showed slight decrease in overall acceptability as on the first day they were still soft, while on the 10^{th} day surface dryness was observed with an increased hardness. Based on these studies optimization of processing parameters for preparation of sugar free *burfi* were carried out by response surface methodology (RSM) for *burfi* prepared with sugar and sugar replacer, sorbitol.

Table 3.5 Sensory analysis* of *burfi* with and without sugar

Types of *burfi*	Days of storage	Colour	snap	Hardness	Sweetness	Lingering sweetness	Off taste	OQ
Sugar	1	2.8	3.9	7.3	7.4	1.0	1.0	7.2
	5	2.9	6.6	8.1	7.3	1.1	1.0	8.9
	10	3.0	6.8	9.1	7.3	1.0	1.0	8.3
Sorbitol	1	3.0	3.6	5.1	7.1	2.6	1.0	7.6
	5	2.9	3.6	5.5	7.0	2.8	1.0	7.9
	10	2.9	3.8	6.0	7.1	2.8	1.0	7.8
S+M (90/10)	1	2.5	5.0	8.2	7.1	3.5	1.0	8.0
	5	2.6	6.5	8.7	7.0	3.8	1.0	7.9
	10	2.6	6.6	8.8	6.9	3.7	1.0	7.6
S+M (80/20)	1	2.9	6.2	8.2	6.9	3.6	1.5	6.5
	5	2.9	7.3	8.9	6.8	3.6	1.6	6.6
	10	3.0	7.5	9.0	7.0	3.7	1.8	6.6
MD+PD	1	4.8	5.0	4.5	7.1	4.8	2.5	6.6
	5	4.5	5.2	7.3	7.2	4.1	2.6	6.7
	10	4.5	5.5	7.8	7.3	4.3	2.9	6.5
PD	1	6.1	5.3	4.8	7.0	4.2	2.8	6.1
	5	6.0	5.5	6.9	7.1	4.3	2.7	6.3
	10	6.1	5.7	7.7	7.1	4.1	2.8	6.0

S = sorbitol; M = mannitol; MD = maltodextrin and PD= polydextrose

*10 point scale

3.3.5 Effect of variables on quality of *burfi* with and without sugar

The response functions i.e., texture and overall quality were markedly influenced by the total soluble solids (°B) at the end of cooking and storage period (no. of days), which are reflected in the response values. *Burfi* made with sugar (75°B) had a snap value of 4.4 N on the 1st day, while the same with 80°B and 10 days storage had 19.7 N. For *burfi* with sorbitol, the values were 2.4 N and 16.1 N respectively (Table 3.3). It is evident that the syrup strength and storage days play a vital role in the quality characteristics of *burfi*. In order to get the best product characteristics, the processing conditions were optimized to obtain highest overall acceptability. The variables and their levels according to the experimental design are given in Table 3.6. The response functions obtained from the analysis for *burfi* prepared with sugar and sorbitol along with the overall quality is presented in Table 3.7.

The coefficient of determination (R^2) for *burfi* with sugar (Table 3.8) was 0.63 and 0.78 for texture and overall quality respectively. The variation of the data was adequately explained by the R^2 values. For *burfi* with sorbitol (Table 3.9) the R^2 values were 0.86 and 0.91 respectively.

The ANOVA showed that the adequacy of the model (lack of fit) was not significant ($P<0.05$) for texture and overall quality for *burfi* with sugar (Table 3.10) and with sorbitol (Table 3.11). These results indicated that the two fitted models adequately represented the data.

3.3.6 .1. Effect of syrup strength on quality of *burfi* with sugar

The ANOVA for texture of *burfi* revealed that the quadratic effect was highly significant along with the cross product. The effect of independent variables against each response is depicted in a three dimensional surface response graphs (Figures 3.1 to 3.4).

The overall sensory quality increased with increasing days of storage (Fig. 3.2) when prepared with syrup having low concentration but this trend is reversed when concentration of syrup was increased. However, high sensory scores were obtained with concentrated syrup and minimum storage period.

Regression coefficients for texture and overall quality of *burfi* with sugar were calculated and are shown in Table 3.8. The data collected for the sensory

scores and instrumental texture values predicted by the fitted equation for each of the treatment combinations were checked and these were within the significant levels ($p<0.05$).

In *burfi* prepared with sugar, the response surface plot showing the effect of storage days and total soluble solids (°B) showed a progressive increase in snap values with increase in days of storage and °B (Fig. 3.1). A combination of lowest syrup strength and storage days, results in soft texture values, i.e., no snap (about 5N at 75°B on 1st day) while the highest value of about 19N was observed with 80°B and 10th day of storage.

Increasing the TSS (°B) from 75 to 80°B showed that overall quality was significantly affected, it increased from 6 at 75°B to 9 at 80°B. A gradual decrease in overall quality was observed with increasing TSS (°B) (Fig. 3.1). In *burfi* with sugar due to higher moisture contents, the products were soft but on storage, due to loss of moisture and crystallization, they became harder gradually and surface dryness was observed.

3.3.5 .1 Effect of syrup strength on quality of *burfi* with sorbitol

The surface plot of texture as a function of storage days and TSS (˚B) showed a marginal increase in snap of *burfi* with sorbitol at lower TSS (°B) and initial days of storage (Fig. 3.3) (Sorbitol products did not exhibit any crystallization). On storage the snap increased indicating probable graining and loss of moisture which was rather slower compared to that of *burfi* with sugar (Table 3.4 and Fig. 3.3). *Burfi* with sorbitol at lower TSS tended to be too soft and thus were less acceptable. Increasing the storage days and brix showed a progressive increase in snap values (Table 3.3). A significant drop in texture values at initial days of storage was also observed. It appears that highest snap (14 to 16N) values were associated with about 10 days of storage.

The overall acceptability of *burfi* prepared with sorbitol is illustrated in Fig. 3.4. The overall quality generally increased with an increase in days of storage. At lower TSS, the overall quality was low 6.1 at 75°B and 2 days storage, which increased to 9.1 at 80°B and 5.5 days of storage. The concentration of syrup had a curvilinear effect on overall quality indicating that a concentration of about 78°B is suitable for *burfi* made with sorbitol.

3.3.5.2 Optimisation of *burfi* processing

The critical values for *burfi* with sugar and sorbitol were found to be outside the experimental conditions (Tables 3.12 and 3.13). In order to find the optimum conditions for obtaining a desirable *burfi* having maximum overall quality and optimum texture, simultaneous desirability function approach was followed.

The optimized values for *burfi* prepared with sugar were 80°B with 2 to 3 days of storage. This *burfi* had a desired optimum overall sensory score of 9.5 and snap of 13.3 N (Table 3.14).

For *burfi* prepared with sorbitol the values obtained by simultaneous optimization was 77.5°B and 5.5 days of storage for obtaining a product having an overall acceptability of 9.1 and breaking strength/snap of 12.9 N (Table 3.14). Results of the optimized study and that of preliminary studies showed similar results, with good correlation.

Table 3.6 Variables and their levels (in coded and actual) according to experimental design

Variables	Symbol	Level	
		Coded	Actual
Syrup strength (°Brix)	X_1	-1.414	75.0
		-1	75.7
		0	79.2
		1	77.5
		1.414	80.0
Storage days (Number of Days)	X_2	-1.414	1.0
		-1	8.2
		0	5.5
		1	8.8
		1.414	10.0

Table 3.7 Central composite rotatable design (CCRD) - and response Functions

Design points	Variable (Coded)		Variables (uncoded)		*Burfi* with Sugar			
					Response variables		Response variables	
	X_1	X_2	°Brix	Days	Breaking strength (N)	Overall Quality*	Breaking strength (N)	Overall Quality*
1	-1	-1	75.7	2.3	8.2	6.0	4.9	6.1
2	-1	1	75.7	8.6	8.8	6.8	6.1	7.1
3	1	-1	79.2	2.3	13.6	9.0	11.6	8.3
4	1	1	79.2	8.6	16.3	8.1	14.3	8.0
5	-1.414	0	75.0	5.5	13.6	7.4	13.7	6.2
6	1.414	0	80.0	5.5	16.3	8.6	14.1	8.6
7	0	-1.414	77.5	1.0	11.7	8.2	6.5	8.8
8	0	1.414	77.5	10.0	18.3	6.9	14.3	8.9
9 (C)	0	0	77.5	5.5	14.6	7.8	12.8	9.0
10 (C)	0	0	77.5	5.5	14.8	8.3	12.9	8.9
11 (C)	0	0	77.5	5.5	15.1	7.6	13.1	9.1
12 (C)	0	0	77.5	5.5	14.9	7.9	12.8	9.2
13 (C)	0	0	77.5	5.5	14.8	8.1	12.9	9.4

* Based on a maximum score of 10

Table 3.8 Regression coefficients for the response variables texture (A) and overall quality (B) for sugar

(A)

Factor	Regression Coefficient	Pure error	t	p
Mean	-1497.39	132.52	-11.29	0.000***
X_1 (L)	38.22	3.416	11.189	0.000***
X_1^2 (Q)	-0.242	0.22	-10.99	0.000***
X_2 (L)	-5.9	1.253	-4.738	0.000***
X_2^2 (Q)	-0.072	0.0068	-10.635	0.000***
X_1X_2	0.0933	0.0161	5.7800	0.004***
R^2 = 0.6349				

(B)

Factor	Regression Coefficient	Pure error	t	p
Mean	-157.75	198.04	-0.79	0.47
X_1 (L)	3.40	5.10	0.66	0.54
X_1^2 (Q)	-0.01	0.03	0.49	0.64
X_2 (L)	6.34	1.91	3.33	0.02***
X_2^2 (Q)	-0.02	0.01	-2.62	0.05***
X_1X_2	-0.07	0.02	-3.22	0.03***
R^2 = 0.7850				

* P< 0.05
** P< 0.01
*** P< 0.001

Table 3.9 Regression coefficients for response variables texture (A) and overall quality (B) for sorbitol

(A)

Factor	Regression Coefficient	Pure error	t	p
Mean	-549.38	89.77	-6.11	0.00***
X_1 (L)	13.55	2.32	5.85	0.00***
X_1^2 (Q)	-0.68	-0.14	-5.54	0.00***
X_2 (L)	-2.54	0.86	-2.94	0.04**
X_2^2 (Q)	-0.19	0.00	-41.62	0.00**
X_1X_2	-0.06	0.01	60.83	0.00***
R^2 = 0.8694				

(B)

Factor	Regression Coefficient	Pure error	t	p
Mean	9.12	0.09	106.02	0.00**
X_1 (L)	0.81	0.07	11.64	0.00**
X_1^2 (Q)	-1.05	0.07	-14.36	0.00**
X_2 (L)	0.11	0.07	1.55	0.20
X_2^2 (Q)	-0.32	0.07	-4.42	0.01**
X_1X_2	-0.33	0.10	-3.38	0.03**
R^2 = 0.9117				

* P< 0.05
** P< 0.01
*** P< 0.001

Table 3.10 Analysis of variance for texture (A) and overall quality (B) of sugar *burfi*

(A)

Factor	Sum of squares	Degrees of freedom	Mean SS	F- test	p
X_1 (L)	34.93	1	34.93	1058.72	5.32
X_1^2 (Q)	3.99	1	3.99	120.96	0.00**
X_2 (L)	19.95	1	19.95	604.59	1.62
X_2^2 (Q)	3.73	1	3.73	113.10	0.00**
X_1X_2	1.10	1	1.102	33.40	0.00**
Pure error	0.132	4	0.033		
Total SS	98.94	12			
R^2 = 0.6349					

(B)

. Factor	Sum of squares	Degrees of freedom	Mean SS	F- test	p
X_1 (L)	4.49	1	4.49	61.58	0.00**
X_1^2 (Q)	0.01	1	0.01	0.19	0.68
X_2 (L)	0.46	1	0.46	6.43	0.06
X_2^2 (Q)	0.50	1	0.50	6.94	0.05
X_1X_2	0.72	1	0.72	9.89	0.03**
Pure error	0.29	4	0.07		
Total SS	7.89	12			
R^2 = 0.7850					

* P< 0.05
** P< 0.01
*** P< 0.001

Table 3.11 Analysis of variance for texture (A) and overall quality (B) of sorbitol *burfi*

(A)

Factor	Sum of squares	Degrees of freedom	Mean SS	F- test	p
X_1 (L)	29.91	1	29.91	1993.51	0.00**
X_1^2 (Q)	0.37	1	0.37	24.84	0.00**
X_2 (L)	27.86	1	27.86	1857.62	0.00**
X_2^2 (Q)	27.31	1	27.31	1820.98	0.00**
X_1X_2	0.56	1	0.56	37.50	0.00**
Pure error	0.06	4	0.01		
Total SS	134.85	12			
R^2 = 0.8694					

(B)

Factor	Sum of squares	Degrees of freedom	Mean SS	F- test	p
X_1 (L)	5.27	1	5.27	142.47	0.00**
X_1^2 (Q)	7.63	1	7.63	206.32	0.00**
X_2 (L)	0.088	1	0.088	2.392	0.20
X_2^2 (Q)	0.723	1	0.723	19.554	0.01**
X_1X_2	0.422	1	0.422	11.4189	0.03**
Pure error	0.148	4	0.037		0.02**
Total SS	14.98	12			
R^2 = 0.9117					

* P< 0.05
** P< 0.01
*** P< 0.001

Table 3.12 Critical values for independent variables in coded levels (Sugar)

Independent variables		Response variable	Predicted response value	Stationary point
°Brix	Storage days			
2.00	1.79	Texture	18.34	Maximum
-3.84	2.57	OQ	6.18	Saddle point

Table 3.13 Critical values for independent variables in coded levels (Sorbitol)

Independent Variable		Response variable	Predicted response value	Stationary point
°Brix	Storage days			
4.94	0.93	Texture	18.55	Maximum
0.39	-0.03	OQ	9.27	Maximum

Table 3.14 Desired optimum parameters for *burfi* with sugar using simultaneous optimization method in actual level of variables

	Parameters		Desired optimum		Desirability
	°Brix	Storage days	Texture	OQ*	
Sugar	80.0	2.34	13.26	9.48	0.9736
Sorbitol	77.5	5.50	12.90	9.12	0.9506

*OQ = Overall quality

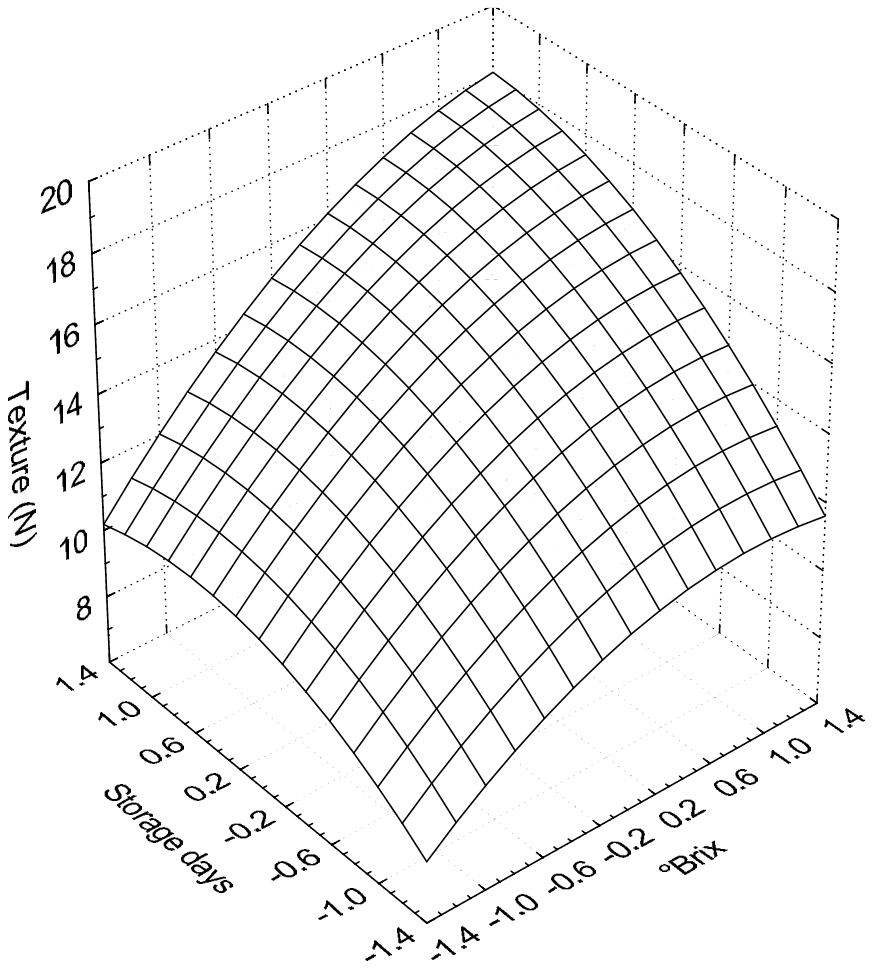


Fig. 3.1: Texture (snap) of stored *burfi* made with sugar at different syrup concentrations

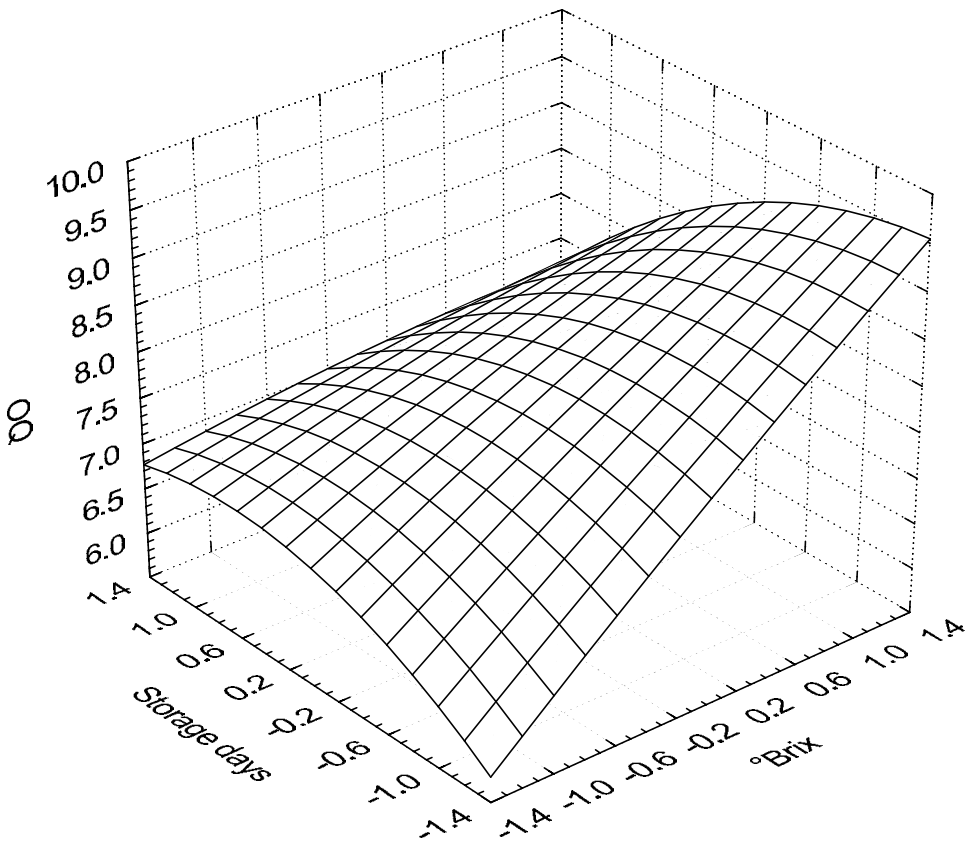


Fig. 3.2: Overall quality of stored *burfi* made with sugar at different syrup concentrations

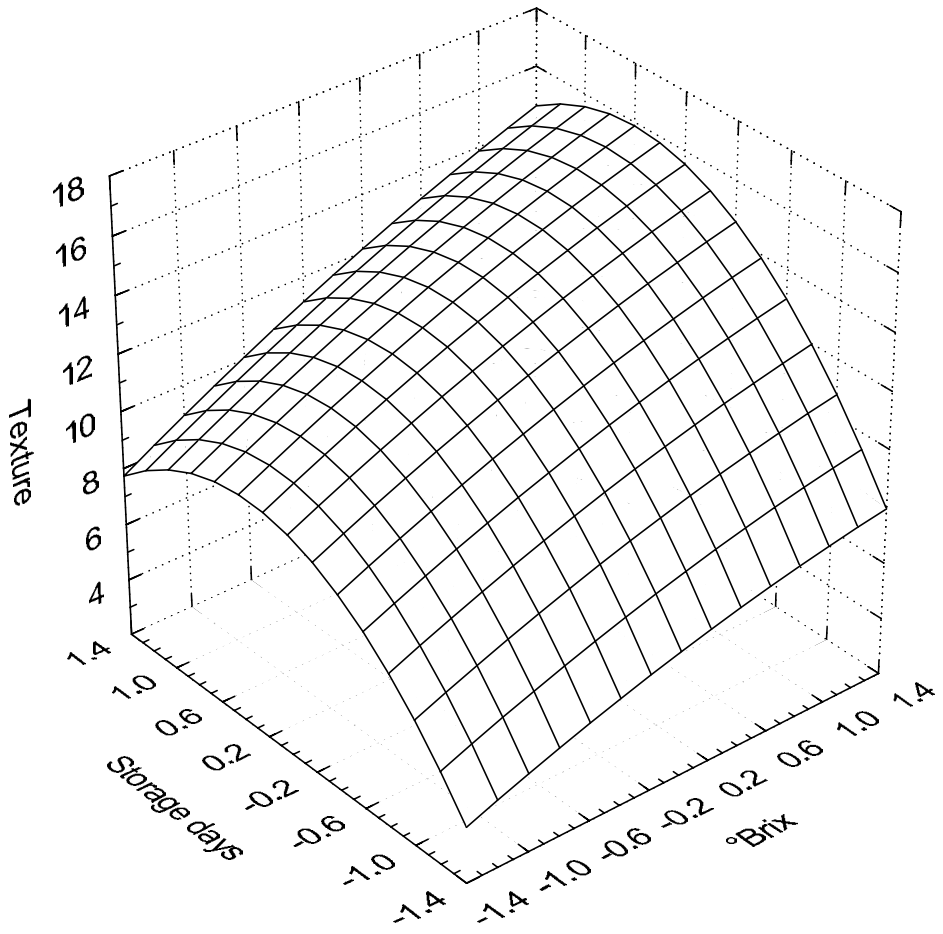


Fig. 3.3: Texture (snap) of stored *burfi* made with sorbitol at different syrup concentrations

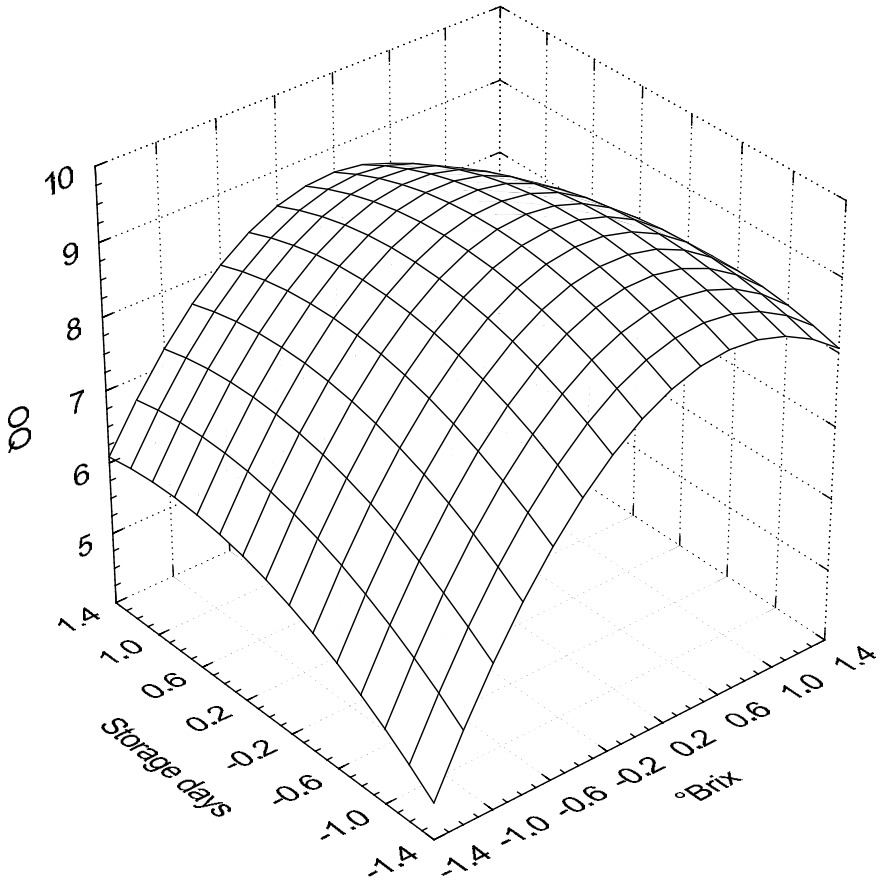


Fig. 3.4: Overall quality of stored burfi made with sorbitol at different syrup concentrations

3.3.6 Characteristics of *burfi*

Characteristics of products are a requirement for quality control and developing newer products with specific functions or applications. The following section describes the different important aspects of the product including appearance (colour), storage behaviour or sorption studies and microbial profile.

3.3.6.1 Colour changes during storage

Initially (0 day) all types of *burfi* had a moist appearance, but after the first day the moist appearance disappeared. No significant difference in colour parameters was observed on storage (Table 3.15), only marginal difference was observed among the samples in general. A gradual loss in moisture was observed during storage after 10 days. Initially the products were moist and hence the colour was determined on the 3rd day when *burfi* was fully set, crystallized in case of *burfi* with sugar and combination of sorbitol and mannitol *burfi* (80:20 and 90:10). The parameters of colour measurement (L*, a*, b* and ΔE*) are shown in Table 3.15.

Burfi prepared with sugar and mixtures of sorbitol and mannitol (80:20 and 90:10) showed the highest L* values indicating brighter products and no significant difference was observed among the three samples. *Burfi* prepared with sorbitol was significantly different from the others. L* values were the least for those containing MD+PD and PD, with no significant difference between the two samples. a* values which indicate redness, was observed in all the *burfi* samples with a significant difference ($p<0.05$) among all the samples, only that with PD showed a higher a* value indicating a minimum redness. Slightly higher yellowness (according to b* values) was obtained for *burfi* samples. *Burfi* prepared with sugar and S+M (80:20) were found to be similar and S+M (90:10) and MD+PD were comparable. The colour values of *burfi* with sorbitol and polydextrose were significantly ($p<0.05$) different. The total colour difference was highest for *burfi* prepared with PD, followed by that of MD+PD and *burfi*, with sorbitol but no significant difference was observed in *burfi* prepared with sugar and mixtures of sorbitol and mannitol.

In conclusion, *burfi* prepared using mixtures of sorbitol and mannitol was found to be comparable to that made with sugar and was brighter in colour. While those with sorbitol, MD+PD and PD were different. This could

be attributed to the fact that these products had a moist appearance, which was not observed in the other products due to crystallization.

Table 3.15 Colour of *burfi* made with different sugar substitutes measured on 3rd day

Type of *burfi*	L*	a*	b*	ΔE*
Sugar	68.31± 0.25^{d}	3.44± 0.03^{b}	27.43± 0.03^{a}	41.92± 0.19^{a}
Sorbitol	64.82± 0.29^{b}	5.45± 0.19^{e}	30.41± 0.56^{c}	46.21± 0.30^{b}
S+M (90:10)	68.79± 0.01^{d}	3.74± 0.04^{c}	28.52± 0.05^{b}	41.84± 0.03^{a}
S+M(80:20)	68.91± 0.41^{d}	3.13± 0.09^{a}	27.72± 0.42^{a}	41.14± 0.04^{a}
MDPD	61.50± 0.73^{a}	4.18± 0.18^{d}	29.17± 0.07^{b}	47.79± 0.59^{c}
PD	60.58± 0.49^{a}	9.44± 0.03^{f}	33.82± 0.35^{d}	52.21± 0.14^{d}

*S = sorbitol; M = mannitol; MD = maltodextrin and PD= polydextrose
Values in the same column with different superscripts differ significantly (P<0.05, according to Duncan's Multiple range test (DMRT)

3.3.6.2 Stability of aspartame

Stability of aspartame was studied as it was added to *burfi* in combination with sorbitol and with bulking agents MD+PD and PD to get equi-sweetness level compared to sugar. The prepared *burfis* were subjected to three different storage conditions such as ambient, refrigerated and accelerated conditions. The recovery obtained for sweetener aspartame is shown in Table 3.16. The standard aspartame showed a sharp peak at retention time 12.3 min. No interference of other peaks was observed, when the sweetener was extracted from the product. The chromatograms are shown in Fig. 3.5. The stability of aspartame was least under accelerated condition with the lowest recovery of aspartame (62.4%) at the end of 8 days. Under ambient conditions the lowest recovery was 74%. There was marginal difference in the percent loss at refrigerated conditions at the end of 28 days. Addition of aspartame in all types of *burfi* was at the end of product preparation i.e., at 70°C to avoid loss of aspartame due to processing. It was necessary to add the sweetener just before the *khoa* mass solidified to ensure mixing throughout the product. At lower temperatures, the mass solidified and thorough mixing was not possible. *Burfi* prepared with mixtures of S+M (80:20

and 90:10) showed similar recovery pattern with mean difference of 1.2 $\pm$ 0.9. Thus the combination of 80:20 has not been cited.

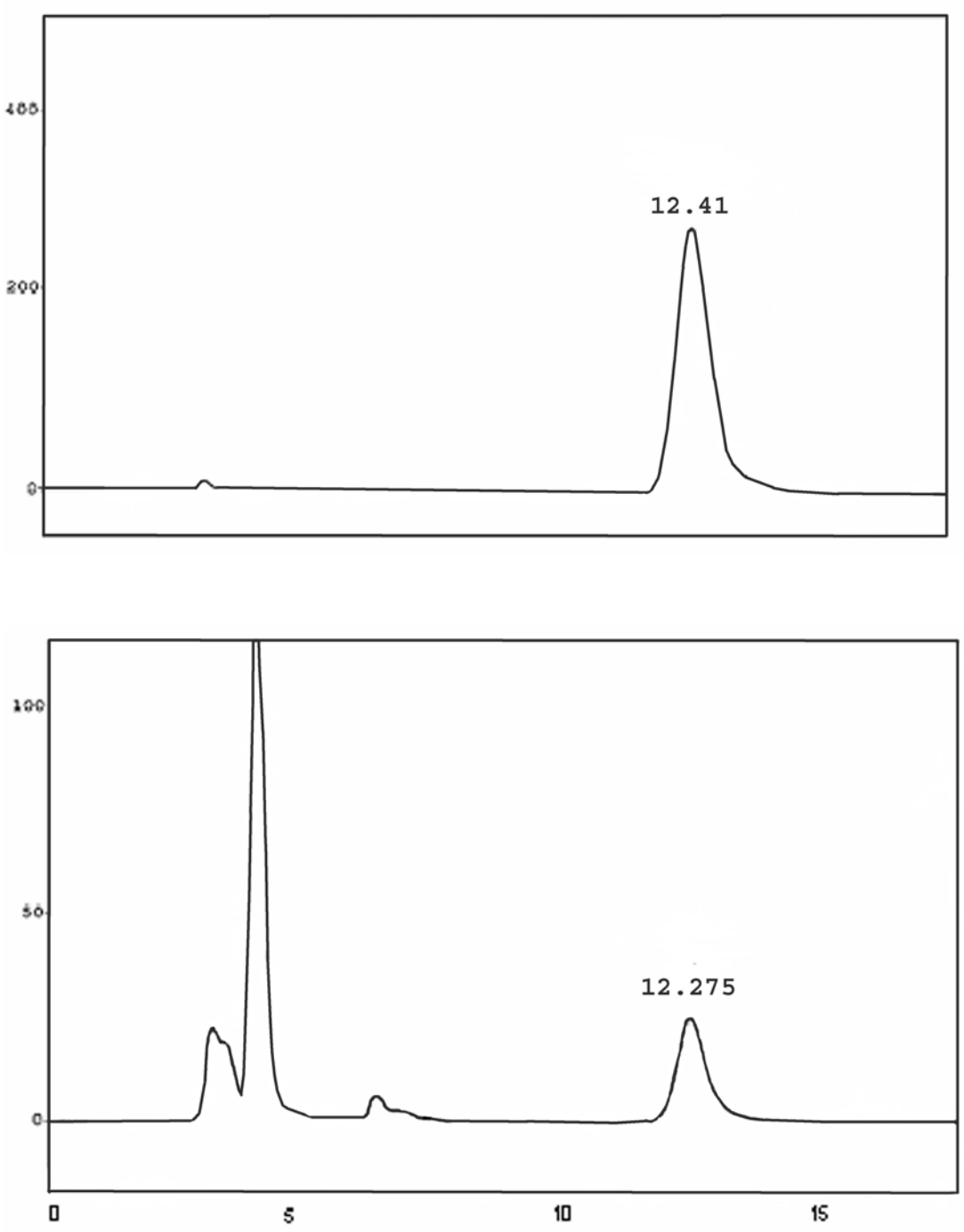
Table 3.16 Recovery of aspartame in *burfi* samples stored under ambient, accelerated and refrigerated conditions

Type of *burfi*		Percentage recovery of aspartame in sugar free *burfi*		
	Withdrawals*	**Refrigerated**	**Ambient**	**Accelerated**
Sorbitol +Aspartame	0	87.3	87.1	86.9
	1	86.1	83.4	80.8
	2	85.4	79.8	75.3
	3	83.7	73.9	69.7
	4	82.9	71.1	66.6
S+M (90:10)+ Aspartame	0	88.3	88.1	89.2
	1	87.1	84.4	82.8
	2	85.4	80.8	78.3
	3	84.7	74.9	70.7
	4	82.9	72.1	64.6
PD+ Aspartame	1	86.1	83.4	80.8
	2	85.4	79.8	75.3
	3	83.7	73.9	69.7
	4	82.9	71.1	66.6
MD+PD+ Aspartame	0	91.4	90.7	91.5
	1	89.2	86.5	80.7
	2	87.1	80.0	71.6
	3	86.3	77.1	65.5
	4	85.8	74.0	62.4

S = sorbitol; M = mannitol; MD = maltodextrin and PD= polydextrose

* Withdrawal days **-** Acc : 0, 2, 4, 6, 8; Amb: 0,5,10,15,20 and Ref: 0,7,14,21,28 days

Fig: 3.5 HPLC chromatogram of standard aspartame (A) and the sweetener extracted from *burfi* (B)



3.3.6.3 Microbiological profile

The microbial profile of *burfi* after preparation and during storage was studied. It was observed that the proliferation of microbial population was higher in products prepared with MD+PD and PD containing samples in general compared to *burfi* made with sugar, sorbitol and mixtures of sorbitol and mannitol (Table 3.17). The microbial count showed a progressive increase in *burfi* prepared with sugar and replacers. The safety indicator organisms such as *E. coli* and *S. aureus* were absent in all the samples. Staphylococcal contamination in food is normally attributed to food handlers. In the case of *burfi, khoa* which is the main ingredient is excessively handled and intimate contact takes place during large scale preparation. However, the mere presence of these will not tender the products unfit for consumption. All the products mentioned here were prepared hygienically and followed GMP thus ensuring the safety of the product.

The specification for microbiological quality in terms of total plate count (TPC) is available for milk *burfi* IS 5550 (1970), which stipulates a maximum plate count of 30,000/g and yeast and mold count of 10/g. Keeping this standard in view, *burfi* with sugar had a shelf life of 10 days and *burfi* with sorbitol, mixtures of S+M (90:10 and 80:20) had a shelf life of 20 days. Whereas products prepared with bulking agents MD+PD and PD were found to be acceptable for 5 to 6 days only as per the regulatory specification of Bureau of Indian Standards (BIS). These results revealed that sorbitol/mannitol had better preservative properties compared to sugar.

Table 3.17 Microbiological profile of *burfi* prepared with and without sugar

Type of *burfi*	Storage period (Days)	Mesophilic aerobes Log $_{10}$CFU/g	Yeasts and molds Log $_{10}$CFU/g	Staphylococcus Log $_{10}$CFU/g
Sugar	0	1.11	<1.00	<2
	5	1.36	<1.00	<2
	10	1.70	1.63	<2
	15	3.71	2.05	3.01
	20	6.11	4.32	5.87
	25	7.78	4.90	6.93
Sorbitol	0	<1.00	<1.00	<2
	5	1.20	<1.00	<2
	10	1.68	1.44	<2
	15	2.36	1.62	<2
	20	2.50	1.95	2.11
	25	3.68	3.21	3.07
S+M* (90:10)	0	<1.00	<1.00	<2
	5	1.15	<1.00	<2
	10	1.56	1.38	<2
	15	2.32	1.49	<2
	20	2.53	1.94	2.11
	25	4.56	3.14	2.89
MD+PD	0	1.32	<1.00	<2
	5	1.53	<1.00	<2
	10	1.83	1.70	3.06
	15	2.88	2.32	3.64
	20	6.41	4.55	6.6
	25	8.37	5.73	7.8
PD	0	1.25	<1.00	<2
	5	1.46	1.28	<2
	10	1.80	1.68	3.31
	15	2.83	2.35	4.17
	20	6.44	4.51	6.52
	25	8.37	5.65	7.45

S = sorbitol; M = mannitol; MD = maltodextrin and PD= polydextrose

*S+M (80:20 and 90:10) *burfi* sample showed similar trend in microbial profile therefore only one is reported in the table.

3.3.6.4 Proximate composition of sugar and sugar free *burfi*

The proximate composition was determined for *burfi* with and without sugar. The moisture content of all the products ranged between 10 to12%, protein between 12.5 to 14% and fat between 22 to 25% (Table 3.18). The calorific value was lowest for *burfi* prepared with PD, followed by sorbitol and mixtures of sorbitol and mannitol. The reduction in calories is low in *burfi* as the major ingredient is *khoa*; only 30% of sugar used is replaced by sugar substitutes. The products could be labeled as *burfi* with "no added sugar", Diabetics and weight watchers may have to restrict their total calorie intake in order to consume these products.

Table 3.18 Proximate composition of sugar and sugar free *burfi*

Type of *burfi*	Moisture (%)	Protein (%)	Total Ash (%)	Fat (%)	Kcal / 100g
Sugar	10.83± 0.74	13.35±0.65	3.47±0.22	22.50±0.13	370±1.22
Sorbitol	12.82±0.18	13.97±0.52	3.54±0.37	22.14±0.44	270±1.35
S+M(90/10)	12.23±0.37	13.56±0.72	3.57±0.18	22.05±0.32	272±1.66
S+M(80/20)	12.18±0.28	13.33±0.56	3.54±0.24	22.47±0.68	274±1.21
MD+PD	13.57±0.32	13.23±0.29	3.52±0.07	23.90±0.54	332±1.39
PD	12.76±0.24	12.48±0.52	3.60±0.18	22.35±0.33	266±1.45

S = sorbitol; M =mannitol; MD = maltodextrin and PD= polydextrose

3.4 Sorption behaviour

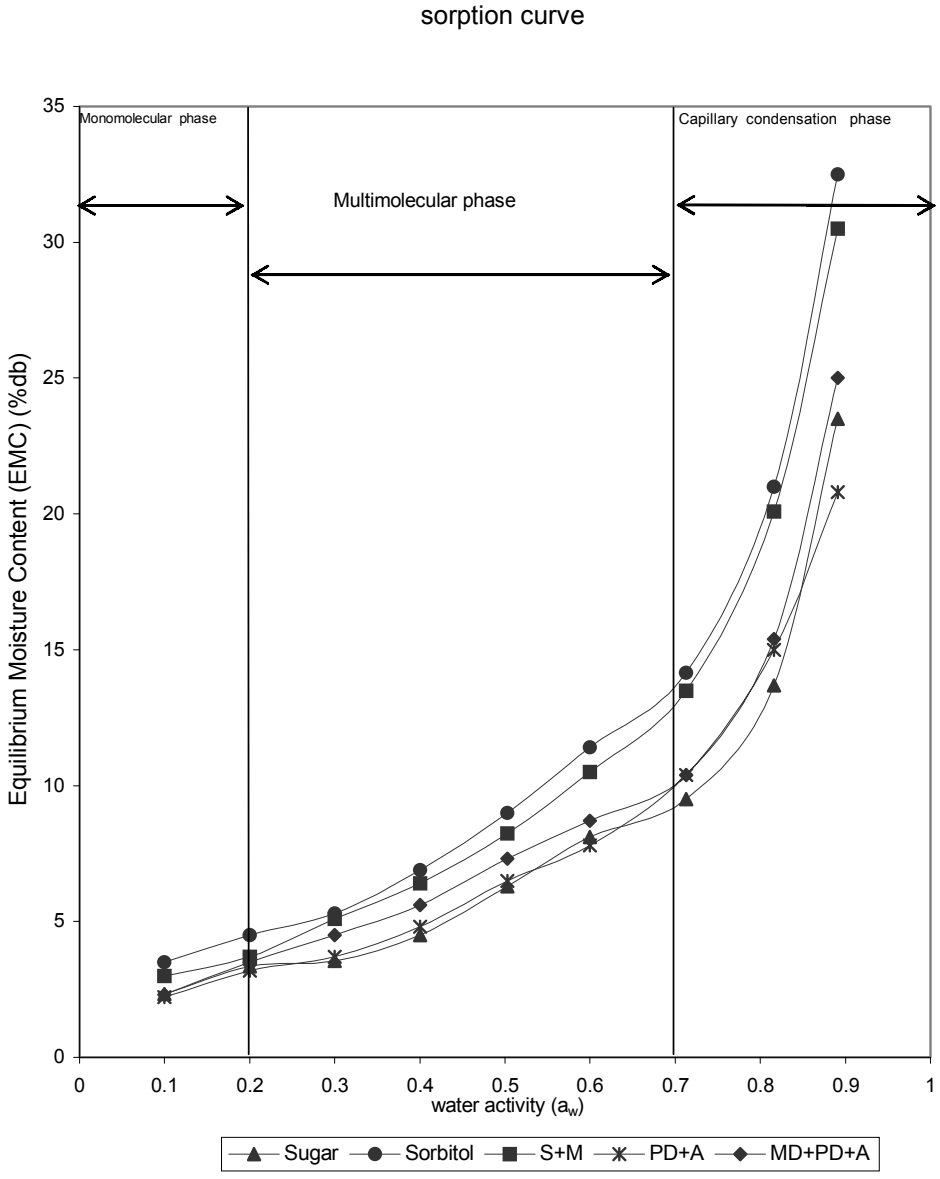
The importance of studying sorption behaviour is that these studies can predict the appropriate condition of storage and consequently, the shelf life of the product.

The most commonly used two parameter model is the Brunauer-Emmet-Teller (BET) model. Its use, however, is limited to lower water activities up to about 0.3 to 0.5. To account for a wider range of water activity, at least one more constant ought to be added to the model format. The most successful three parameter model is probably the Guggenheim-Anderson-De Boer (GAB) model which is applicable upto water activities of about 0.9. The GAB equation has been successfully applied to various foods (Vandenberg, 1984) and it is also recommended by the European project (COST 90) on physical properties of foods (Wolf et al, 1984).

The relationship between a_w and moisture content (at constant temperature) are described by moisture isotherms. The time to reach equilibrium was about 20 to 25 days for different *burfi* samples and at 92% RH and mold growth was detected by visual inspection at the end of 25 days. The sorption isotherms measured for different types of milk *burfi*: sugar, sorbitol, S+M, PD and MD+PD are shown in Fig. 3.6. The curves are of sigmoidal shape depicting one inflection point, characteristic of materials with high sugar content, similar to that observed in Sultana raisins (Weisser, 1985). The curves showed three regions (Fig. 3.6) similar to those reported for milk proteins and *dhud churpi* (Hossain et al, 2002). Region A corresponding to < 0.2 of $a_{w,}$ which relates to adsorption of monomolecular film of water. Region B, corresponding to adsorption of additional layers over this monolayer at a_w 0.22 to 0.7 and region C for a_w > 0.7 corresponding to condensation of water in the pores of the material followed by dissolution of soluble material. At lower $a_{w,}$ the slope of the curve was less, with increase in a_w the slope increased rapidly. Similar curves have been obtained for rough rice (Agarwal and Clary 1971) and also for *dudh churpi* (Hossain et al, 2002) and other dairy products like casein and *khoa* (Sawhney et al, 1991 a, b and Bandyopadhyay, 1987). In general, the equilibrium moisture content increases rapidly at low water activity a_w (0 to 0.15), then raise slowly between a_w 0.15 to 0.7 followed by a steep rise above a_w 0.7.

The sorption curves for *burfi* prepared with bulk sweeteners, sorbitol and/or mannitol along with aspartame were the farthest from sugar shifting towards left. Whereas, *burfi* prepared using bulking agents such as maltodextrin and polydextrose (MD+PD) along with aspartame were closer to *burfi* made with sugar (Fig. 3.6).

Fig 3.6 Experimental sorption isotherms of *burfi* with and without sugar



Experimental and predicted sorption isotherm curves of *burfi* prepared with sugar and with substitutes, by various models are shown in Fig. 3.7. Various equations for fitting water sorption isotherms of foods have been reviewed and fitting of the seven mathematical equations on experimental moisture sorption data yielded the results as shown in Table 3.19. The corresponding equations and constants are shown in Table 3.19. Out of the seven equations fitted to the sorption data in the range of 0.1 to 0.9, BET, Kuhn, Smith and Harkins–Jura equations exhibited high RMSE values. However, these equations fitted well in a split range of isotherm. GAB, Caurie and Oswin were found to have good fit over the full range of isotherms as these were found with low % RMSE values.

3.4.1 Sorption models

Although BET model holds good only for a limited range of a_w, two familiar constants – monolayer constants (M_m) and energy constants were obtained. The best fit was obtained for the *burfi* prepared maltodextrin and polydextrose (MD+PD) with a high correlation coefficients for all the products. The monolayer moisture constants ranged from 3.20 to 4.73 (Table 3.19).

The Caurie model holds good for a_w ranging from 0.1 to 0.9. This range was in conformity with the goodness of fit. Caurie constants varied from 0.32 to 0.9 and from 2.52 to 2.78 respectively for *burfi* prepared with and without sugar.

The Kuhn model holds good for a_w ranging from 0.4 to 0.9 and the constants ranged from 'a' 2.42 to 3.64 and 'b' from –2.03 to 3.23. Higher RMSE values were observed for *burfi* prepared with sorbitol and polydextrose.

The Smith model is represented by equation which holds good for a_w ranging from 0.1 to 0.9 and the constants M_a ranged from –2.4 to 0.99 and M_b ranged from – 8.29 to – 13.05. Only *burfi* with sugar showed high RMSE value.

The linear form of the Oswin model was applied to experimental data by linear regression analysis. The equation gives an acceptable correlation and the constants varied from 6.19 to 8.57 and 'n' varied from 0.50 to 0.60 (Table 3.19)

Table 3.19: Estimated coefficient of determination (R^2) and RMSE values of different models for sorption isotherms for milk *burfi* with and without sugar.

Model Isotherm	Range of water activity (a_w)	Type of *Burfi*	Constants of linear fitting		R^2	RMSE
BET	0.1 – 0.5		M_m	c		
		Sugar	3.20	8.14	0.99	10.43
		Sorbitol	4.73	11.31	0.99	8.91
		S+M	4.42	10.62	0.99	6.46
		PD	3.56	12.53	0.99	8.50
		MD+PD	3.90	10.87	0.99	2.20
Caurie	0.1-0.9		a	b		
		Sugar	2.78	0.32	0.89	9.10
		Sorbitol	2.7	0.9	0.98	9.36
		S+M	2.8	0.75	0.98	7.16
		PD	2.52	0.64	0.98	5.90
		MD+PD	2.63	0.67	0.98	9.84
Kuhn	0.4-0.9		a	b		
		Sugar	2.42	-2.40	0.95	6.79
		Sorbitol	3.64	-3.23	0.97	11.0
		S+M	3.34	-3.06	0.97	9.01
		PD	3.07	-2.03	0.95	11.40
		MD+PD	2.90	-2.44	0.98	7.77
Smith	0.3-0.9		M_a	M_b		
		Sugar	-9.82	0.24	0.99	10.09
		Sorbitol	-13.05	0.50	0.99	6.95
		S+M	-12.7	0.05	0.97	7.72
		PD	-8.29	0.99	0.98	4.77
		MD+PD	-9.77	0.61	0.98	5.93
Oswin	0.1-0.9		a	n		
		Sugar	6.19	0.60	0.99	10.89
		Sorbitol	9.27	0.55	0.98	6.06
		S+M	8.57	0.56	0.99	10.19
		PD	6.67	0.50	0.99	6.38
		MD+PD	7.26	0.52	0.99	4.95

Harkin Jura						
	0.3-0.9		a	b		
		Sugar	18.33	-0.34	0.95	12.29
		Sorbitol	26.28	-0.25	0.98	8.66
		S+M	18.72	-0.30	0.96	10.82
		PD	10.74	-0.32	0.95	10.28
		MD+PD	11.4	-0.38	0.90	14.12
GAB	0.1 – 0.9		Mo	G	K	
		Sugar	3.28	14.6	0.96	0.92	6.32
		Sorbitol	4.86	13.66	0.96	0.96	5.70
		S+M	4.64	10.12	0.96	0.95	6.08
		PD	3.61	10.43	0.93	0.94	6.14
		MD+PD	4.16	9.84	0.92	0.97	3.25

The Harkins-Jura model was applicable for a_w range between 0.3 to 0.9. High RMSE values were observed for all products except for *burfi* prepared with sorbitol.

The most successful three parameter model is the GAB model for the full range of water activity 0.1 to 0.9. This model has received great application in sorption studies of foods (Van den Berg 1984). From Table 3.19, the lowest RMSE values were observed to be from 3.2 to 6.3 for this model. The Mo values ranged from 3.28 to 4.86. The best fit and lowest RMSE values were obtained from this equation and is valid for the whole range of a_w, similar to those observed for most foods, like casein, lactose, channa powder, *dhud churpi*, etc. (Hossain et al 2002, Caurie, 1970, Patil & Singh, 1998, Bandyopadhyay et al, 1987).

Sorption analyses of different models showed extremely good fit as determined by RMSE and R^2 values. The constants derived from different sorption models are useful in the evaluation and stability of sugar free *burfi*. The applicability of water activity values may also decide the suitability of packaging material for specific purposes. The constants derived from the respective models could be utilized to predict equilibrium moisture content (EMC) in comparison with the experimental values. It can be observed from the results that all models could successfully predict the EMC values for all sugar and sugar free sweets.

However, the GAB model had the lowest RMSE and highest R^2 values indicating it to be the best suitable model. Linear model with high R^2 and low RMSE are considered to be statistically acceptable.

Venkatesh et al, (1984) have reported ERH of *sohan halwa* as 25%, whereas ERH of soft products like *pedha* (Biradar et al, 1985) or Cashewnut *burfi (*Rao et al, 1993) varied between 79 and 92%. Packaging and storage studies have been carried out for milk *burfi* (Ramanna et al, 1983), *gajak* and *rewadi* (Chakraborti et al, 1980), s*ohan papdi* and s*ohan halwa* (Venkatesh et al, 1983) and *inderse* (Saxena et al, 1991). Studies on flour based products such as *besan burfi* (Sharma et al 1992), fried wheat snacks (Thakur and Arya, 1990) and *holige* (Rao et al, 1990 a, b) have indicated the role of flour solids and sugar on the ERH of products. In this study the ERH of *burfi* prepared with sugar was found to be 75 to 78%, while the ERH of *burfi*

prepared with sorbitol ranged between 65-66%. The ERH *burfi* with sorbitol + mannitol was 70 to 72%. *Burfi* prepared with polydextrose and mixture of MD+PD showed the highest value with 78 to 82%. Thus due to this high range of ERH the products prepared with bulking agents showed an early mold growth as confirmed by microbiological studies.

Conclusions

Studies indicated that *burfi* could be prepared using bulk sweetener, sorbitol; mixtures of sorbitol and mannitol; and bulking agents such as, polydextrose (PD) and mixture of maltodextrin and polydextrose (MD+PD). Products could not be prepared using maltodextrin alone. It was observed that the total soluble solids (TSS) at the end of cooking the *khoa* mass along with sugar and days of storage had marked influence on the quality of the product.

RSM was used to find out the effect of these variables and to optimize these parameters. The optimum conditions for *burfi* with sugar was 80°B and 2.34 days for obtaining a *burfi* with a breaking strength/snap of 13.3N and an overall sensory score of 9.5. In the case of *burfi* with sorbitol to obtain a product close to its sugar counterpart, 77.5°B and 5.5 days of storage were needed for obtaining a *burfi* with 12.9N with an overall acceptability score of 9.1. These parameters were well correlated with experimental values and were found to be satisfactory.

Colour measurements indicated that *burfi* prepared with sugar and mixtures of sorbitol and mannitol (80:20; 90:10) were similar and were lighter in colour, compared to sorbitol, polydextrose, mixture of polydextrose and maltodextrin. Stability of aspartame in these products showed least loss at refrigerated temperature and highest loss at accelerated temperature. The microbial profile of *burfi* indicated that *burfi* prepared with sugar had a shelf life of 10 days, *burfi* with sorbitol and mixtures of sorbitol and mannitol had a shelf life of 20 days, whereas products prepared using MD+PD and PD were found to be safe for consumption for 5 to 6 days only. The total reduction in calories was marginal, as only 30 % of the sugar used in *burfi* preparation is replaced by sugar alternatives.

Moisture sorption isotherms of sugar and sugar free milk *burfi* showed sigmoidal pattern, similar to sugar rich products. The curves of *burfi* with sorbitol shifted towards left compared to that of sugar, products with bulking agents like MD, PD or combination of these two were found to be similar to those of sugar counterpart. The GAB model showed a better fit compared to other models, as it is applicable to a wide range of water activity.

Milk *burfi* could be prepared with quality characteristics similar to that of *burfi* with sugar using sorbitol and mixture of sorbitol and mannitol (90:10).

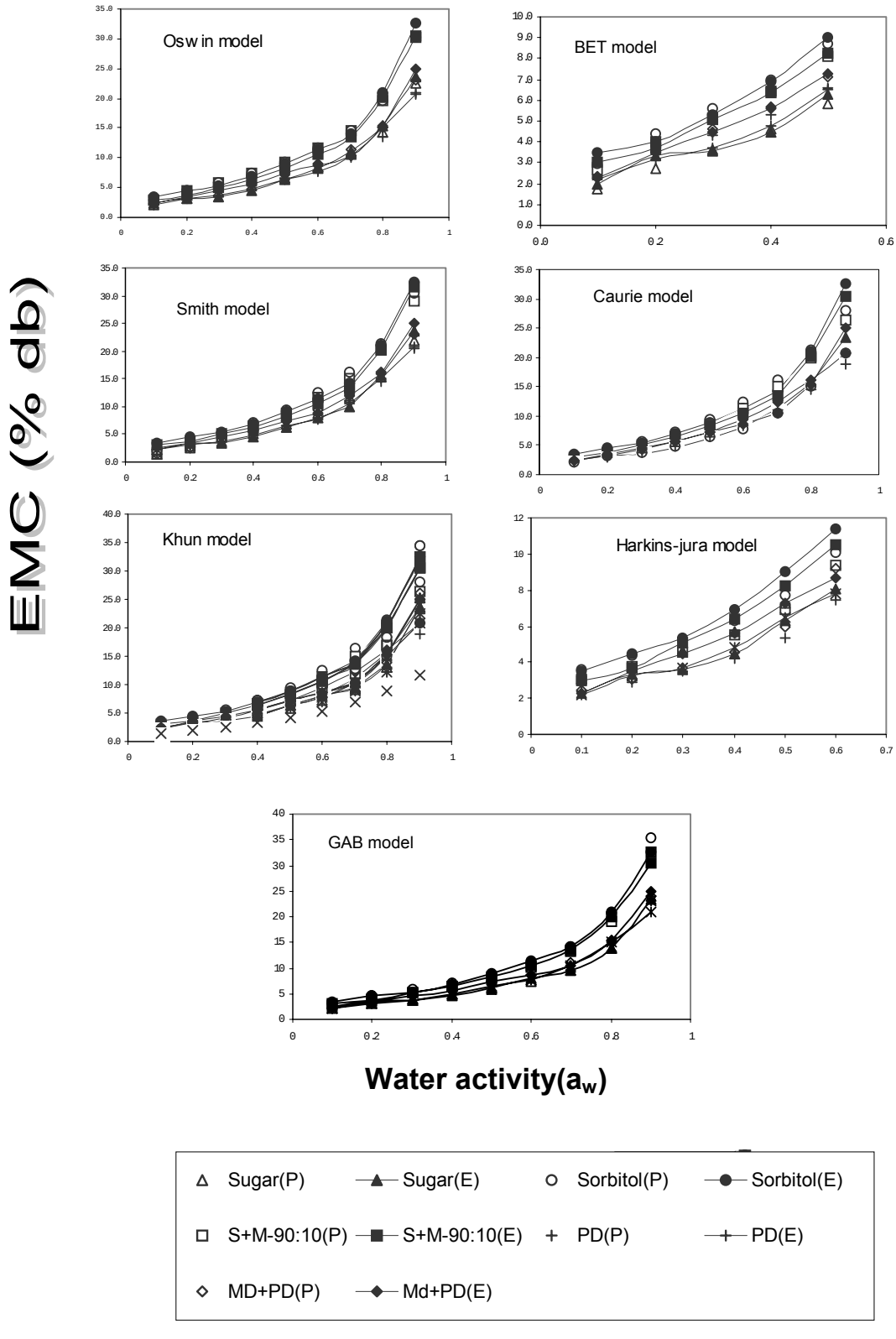


Fig. 3.7: Experimental (E) and predicted (P) sorption isotherms of *burfi* prepared with and without sugar.

Fig. 3.8: *Burfi* with sugar

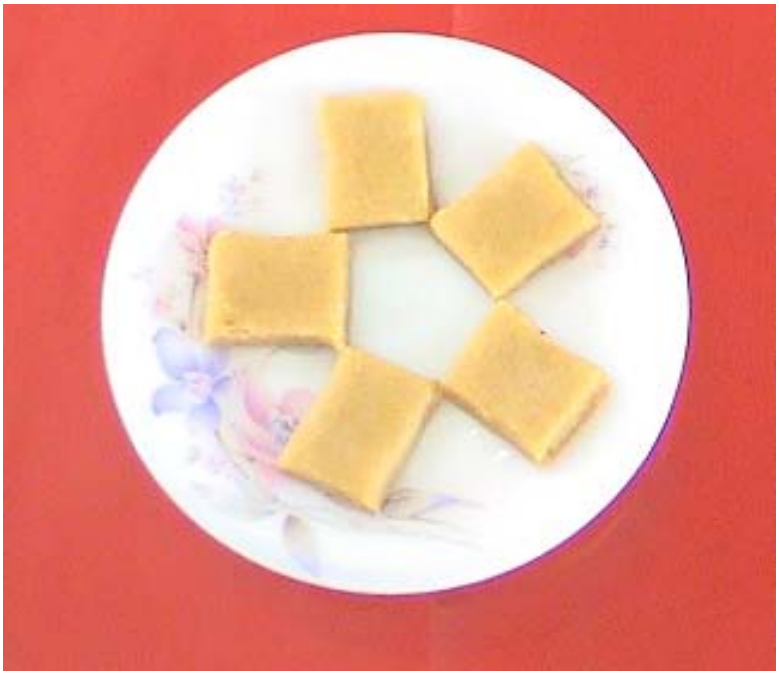


Fig. 3.9: *Burfi* with sorbitol

Fig. 3.10: *Burfi* with sorbitol + mannitol

Fig 3.11: *Burfi* with maltodextrin + polydextrose (50/50)

Fig. 3.12

Polydextr

Chapter 4

Laddu

Chapter IV
Laddu

4.1 Introduction

Laddu is a legume based sweet, popular in India. It is made from *boondi* (spherical, crisp, deep fat fried product from *bengal gram* flour) which is made by dropping the batter of *bengal gram* flour through sieves into hot oil, followed by deep fat frying. *Boondi* is then mixed with sugar syrup and moulded into round balls are called "*laddu*s" or "*boondi laddu*" or "*motichur laddu*" as they resemble small balls. *Boondi* is also used in salted form as a savory snack. Sweet balls prepared with rice or pulse flours and sugar were termed *laddu*kas or *modakas* and are of very ancient lineage. *Laddu* is one sweet product that is still going strong since ancient times (Achaya, 1994).

Many studies have been reported on the physico-chemical characteristics of *boondi*, which is used to make both savory and sweet items. The deep fat frying characteristics of *bengal gram* flour suspensions have been reported (Bhatt et al, 2001), that *boondi* of a large size absorbs less oil than smaller *boondi*. Since, in the preparation of legume based snack foods, the emphasis is on deep fat frying of the batter, efforts have been made to reduce the oil content by incorporating various additives. Priya et al, (1996) have reported studies on addition of carboxylmethyl cellulose (CMC) and hydroxypropymethyl cellulose (HMC) as additives in reducing the oil content of fried *boondi*.

Attempts to lower the fat content of *boondi* by adding maize flour during its preparation have also been made. Addition of 30% maize flour to *bengal gram* flour reported to have no adverse effect on the product quality. At higher levels of addition the *boondi* was reported to be hard and solid and lacked the desired crispness. Storage studies did not show any distinct quality change up to 60% RH, but at RH values above 65 to 70% RH, the product became soft. At 80% RH, the products were unacceptable. Mould growth appeared on the 7^{th} day, when the moisture level had increased to 90% RH (Beerh et al, 1980).

Preparation of *boondi* having a perfect round or circular shape depends on the water content in the batter. Batter consistency plays a very critical role. At lower levels of water addition, *boondis* are oblong in shape whereas, at higher water levels, the batter tends to spread in the frying fat again leading to oblong shaped *boondis* with a tail like shape (Priya et al, 1996).

Literature on *laddu* is scanty. Traditionally *laddu* is prepared by first making sugar syrup of a definite strength. The fried *boondi* is mixed with this syrup and then moulded into balls. Binding is very important and is imparted by sugar syrup. On storage, the sugar in *laddu*, is partly crystallised which is a desirable attribute. These desirable properties have to be matched by any alternative sweetener that may be used to prepare sugar free *laddu*.

In the present study, sugar has been replaced by sorbitol, or sorbitol + mannitol (S+M, 80:20 and 90:10); and the processing parameters were standardized to obtain the desirable binding and other quality attributes of *laddu.* The main objectives of the study were: (1) to prepare sugar free *laddu* and study the effect of processing parameters on product quality; (2) to examine the stability of the intense sweetener, aspartame in *laddu* by HPLC; (3) to study storage stability of these products by measurement of colour, texture, microbiological profile and ERH.

4.2 Materials and Methods

4.2.1 Materials

Same as described in chapter 2 under *jamun. Bengal gram* flour and refined sunflower oil used for the preparation of *laddu* were procured from the local market.

4.2.2 Preparation of *laddu*

Laddu was prepared following the traditional method. 100g *bengal gram* flour, passing through a 60 mesh sieve (US sieve), was mixed with 120 ml of water to prepare batter. This batter was forced through a perforated ladle to form spherical balls, into frying (refined sunflower) oil heated to 160-165°C and fried for 60-75 sec before removal from the hot oil. The fried *boondi* thus obtained was mixed with the sugar syrup or sugar free syrup in the ratio 100:120 and further heated till no syrup was left. A constant weight of *boondi* (40g) was weighed and moulded into a spherical ball (viz *laddu)*, of diameter 14.5 cm with constant force. The moulding was done using a prototype gadget, designed in the laboratory.

4.2.2.1 Syrup preparation

Sugar syrup of 75% solids (75°B) was prepared. Sorbitol syrup was concentrated to 75°B. Sorbitol and mannitol (S+M) were mixed in the ratios 90:10 and 80:20 and these syrups were then heated to obtain 75°B. Aspartame was added to sorbitol, sorbitol and mannitol syrups at equi-sweetness levels (0.25g/100ml syrup) as compared to sugar.

4.2.3 Texture measurement of *laddu*

The hardness of *laddu* was measured using a Universal Testing Machine (model LR 5K, Llyods Instruments, UK). The maximum force required to compress the *laddu* by 50% was recorded. Compression was carried out with a load cell of 50N; the test was replicated 5 times with a crosshead speed of 50mm/min.

4.2.4 Sensory analysis

The details of sensory assessment of *laddu* are similar to those described under chapter 2 *jamun* in section 2.2.7. The judges were asked to mark the perceived attributes such as colour, sugar crystals, moistness, hardness, sweetness, lingering sweetness, off taste and overall quality.

4.2.5 Colour measurement of *laddu*

Colour measurement of *laddu* was carried out in the same way as described earlier under *jamun* (See chapter 2).

4.2.5.1 Statistics

Same as described in chapter 2 for *jamun.*

4.2.6 HPLC analysis

Same as described in chapter 2 for *jamun.*

4.2.6.1 Sample preparation of *laddu*

Same as described in chapter 2 for *jamun.*

4.2.7 Microbiological studies

Same as described in chapter 2 for *jamun.*

4.2.8 Sorption studies

Same as described in chapter 3 for *burfi.*

4.2.8.1 Sorption models

Same as described in chapter 3 for *burfi.*

4.3 Results and discussion

The syrups used for making *laddu* were prepared with: (1) sugar, (2) sorbitol, (3) mixtures of sorbitol and mannitol (90:10; 80:20); (4) polydextrose and (5) mixtures of maltodextrin and polydextrose. *Boondi* was prepared first and then, different syrups were added in the required amounts, (100g *boondi* and 120g of 75°B syrup). This mixture was further heated to increase the percentage of solids 80 to 82°B in the mixture to facilitate binding. The resultant mixture had good moulding properties and could be moulded at 70°C for sugar and 60°C for sorbitol and mixtures of sorbitol and mannitol using a laboratory designed prototype gadget. 40g of weighed mixture was used for moulding to obtain a compact spherical shape.

The syrup strength was found to be critical for binding the *boondi* into *laddu*. At a lower syrup strength (<75°B) no binding was observed, the *boondi* and sugar syrup separated out. At a higher >85°B *laddu* was soft initially, but became very hard after one day. Although, some mixing could be achieved if mixed quickly, the sugar syrup crystallized and the resultant *laddu* was very hard and unacceptable. In the case of sorbitol syrup no problems were encountered during moulding, the *laddus* were very soft; binding could be observed at TSS of 80 to 82°B, similar to that of sugar.

Unlike *laddu*s prepared with sugar, those prepared with sorbitol appeared moist even on storage and did not show the desired crystallization (fine white crystals) in the product. In order to induce some crystallization similar to sugar containing *laddu*s, mannitol was added at 10 and 20% levels to the sorbitol syrup. Since mannitol addition to sorbitol induces crystallization as mentioned earlier (Table 3.2 in chapter 3).

Laddu could not be prepared using polydextrose alone, as the latter gelled and no binding could be observed. The *boondi* had an unacceptable off taste and was rejected. Mixtures of maltodextrin and polydextrose (MD+PD) syrups resulted in weaker binding, as the *laddu* slowly opened up and disintegrated. Only sorbitol and mixtures of sorbitol and mannitol were found to be suitable for preparation of *laddu* (Fig 4.1 to 4.4).

Fig. 4.1: *Laddu* prepared with sugar

Fig. 4.2: *Laddu* prepared with sorbitol

Fig. 4.3: *Laddu* prepared with S+M (90:10)

Fig. 4.4: *Laddu* prepared with MD+PD

4.3.1 Texture of *laddu*

Compression of *laddu* prepared with and without sugar revealed that they became hard on storage, the hardness value increased from 28 to 43N in 10 days for *laddu* prepared with sugar. A similar trend was observed in all other *laddu* samples (Table 4.1). Initially the products were soft and moist and hardened slowly. This could be due to loss of moisture as observed (Table 4.2) and also due to crystallization in the products that were made with sugar and mixtures of sorbitol and mannitol. *Laddu* prepared using sorbitol were soft and moist and they could not be compared with sugar containing products. Addition of 10% mannitol increased the hardness of *burfi* after 5 days of storage, this product had similar texture as that of sugar containing product on the 1st day of storage. Similarly addition of 20% mannitol showed results comparable to that of sugar in hardness. *Laddu* prepared with mixture of maltodextrin and polydextrose (MD+PD) was soft, without any binding in the syrup. Texture measurements of *laddu* with MD+PD were made immediately after moulding as the spherical ball began to disintegrate slowly after 10 to 20 mins.

Table 4.1 Texture/compression (N*) of sugar and sugar free *laddu*

Type of *laddu*	Days of storage			
	1	**3**	**5**	**10**
Sugar	28.1	35.9	37.9	43.4
Sorbitol	8.9	10.2	10.8	18.9
SM(90:10)	17.6	19.2	28.8	43.3
SM(80:20)	21.3	29.8	35.2	41.8
MD+PD	11.1	13.0	15.0	20.3

S=sorbitol; M=mannitol; MD=maltodextrin and PD=polydextrose

* Force (N) extended at 50% compression.

4.3.2 Moisture of *laddu*

The moisture contents of *laddu* with and without sugar were determined. The results are tabulated in Table 4.2.

Table 4.2 Moisture content of sugar and sugar free *laddu*

Type of *laddu*	Days of storage			
	1	3	5	10
Sugar	15.9±0.13	14.9±0.21	14.5±0.13	10.7±0.22
Sorbitol	14.6±0.18	13.4±0.24	12.8±0.47	12.7±0.27
SM(90:10)	15.0±0.14	14.7±0.22	13.5±0.25	11.5±0.31
SM(80:20)	15.7±0.11	14.5±0.18	13.9±0.28	11.7±0.36
MD+PD	18.0±0.19	14.6±0.16	13.5±0.31	13.1±0.28

S=sorbitol; M=mannitol; MD=maltodextrin and PD=polydextrose

The results showed a decrease in moisture content on storage (Table 4.2) and hence increased the hardness of the products. The loss of moisture was slower in *laddu* prepared with sorbitol. Although, a loss in moisture was observed in *laddu* prepared with sorbitol and MD+PD, they appeared moist throughout the study. This could be attributed to the fact that crystallization might not have taken place in these two products, as indicated in Table 3.2 in chapter 3, relating to *burfi*.

4.3.3 Sensory analysis of *laddu* with and without sugar

The sensory analysis of *laddu* was determined after 1, 3, 5 and 10 days of storage. The mean sensory scores obtained are shown in Table 4.3. The results of the sensory scores showed that the colour of *laddu* prepared with sugar, decreased gradually from the 1st day to the 10th day. Initially all products had a moist appearance and hence looked darker in colour. Due to gradual crystallization, the products prepared with sugar, S+M 90:10 and S+M 80:20 showed a decrease in colour or increased lightness in the product. S+M 80:20 showed an extremely high degree of crystallization compared to *laddu* of S+M 90:10, whereas only marginal changes were observed in *laddu* prepared with sorbitol.

In the case of *laddu* made either with sugar, S+M 90:10, or S+M 80:20, crystallization occurred during storage. *Laddu* prepared with sorbitol and MD+PD showed marginal change in colour up to 10 days of storage (Table 4.3). The products appeared soft and moist throughout without any crystallization. Products could not be obtained with MD+PD, even though a round ball could be made, it slowly disintegrated into a shapeless mass (Fig. 4.4) as mentioned earlier. This product also had a high score for off taste and low score for overall quality.

The overall quality of *laddu* prepared with sugar S+M 90:10 was found to be comparable with those of sugar, scoring slightly higher. *Laddu* prepared with sorbitol also was acceptable and had similar overall quality scores but were found to be softer than those of sugar. *Laddu* prepared with MD+PD had the lowest overall quality scores and thus was found to be unacceptable (Table 4.3). *Laddus* prepared with S+M 80:20 were comparable in appearance and other sensory attributes and instrumental hardness (Table 4.1) with those of sugar containing *laddu*. However, their overall sensory scores were lower as the crystals on the surface had a waxy mouthfeel on the tongue. Thus *laddu* with S+M 90:10 was closer to *laddu* compared with that of sugar. *Laddu* prepared with sorbitol was softer but was still acceptable, whereas *laddu* prepared with MD+PD were found to be unacceptable.

Table 4.3 Mean sensory scores of *laddu* prepared with and without sugar

Type of *laddu*	Days	Colour	Sugar crystals	Moistness	Hardness	Sweetness	Lingering sweetness	Off taste	OQ
Sugar	1	7.39	3.48	6.88	5.20	6.94	2.86	1.50	8.09
	3	6.84	5.17	6.29	7.17	6.95	2.97	1.00	7.38
	5	6.44	5.50	6.10	7.50	6.70	2.50	1.00	7.25
	10	6.11	5.81	5.78	7.50	5.90	2.00	1.00	7.00
Sorbitol	1	7.82	3.32	6.73	5.00	6.90	3.80	1.00	7.83
	3	7.36	3.45	6.70	5.20	7.10	2.90	1.00	7.88
	5	7.14	3.51	6.66	5.20	7.00	2.60	1.00	7.74
	10	7.08	3.51	6.63	5.10	7.20	2.80	1.00	7.00
S+M (90:10)	1	6.58	4.54	6.92	4.83	5.27	2.66	1.00	7.59
	3	6.14	4.97	6.10	7.04	5.53	2.49	1.00	6.27
	5	5.07	5.32	5.76	7.32	5.51	2.50	1.00	6.17
	10	5.00	6.01	5.53	7.54	5.32	2.50	1.00	6.03
S+M (80:20)	1	3.65	5.43	4.54	5.54	5.90	2.71	1.00	5.41
	3	3.28	5.80	4.06	5.60	4.94	2.70	1.00	5.39
	5	3.04	8.00	4.04	6.80	4.57	2.60	1.00	5.28
	10	2.78	6.78	4.71	8.22	4.50	2.60	1.00	5.17
MD+PD (50:50)	1	8.61	2.02	7.35	4.3	6.7	7.0	6.6	3.1
	3	8.32	1.00	7.16	3.8	6.5	7.1	6.5	3.0
	5	8.10	2.00	7.11	3.7	6.1	7.0	6.5	2.8
	10	Visual fungus observed							

*10 - point scale
S=sorbitol; M=mannitol; MD=maltodextrin and PD=polydextrose

4.3.4 Colour measurement of *laddu*

Colour was determined for all the *laddu* samples over a storage period of 10 days (1, 3, 5, 10 days). The L* values increased gradually in *laddu* prepared with sugar (Table 4.4). This could be attributed to the fact that crystallization increased gradually in the sugar containing product. The a* value was highest on the 1st day and decreased on subsequent days. Initially a moist appearance is seen in freshly prepared *laddu*, as crystallization sets, they look drier. The b* value showed a decreasing trend.

In *laddu* prepared with sorbitol, no difference was observed in the L*, a* and b* values for all 10 days, the product appeared fresh and moist throughout. Sorbitol is a known humectant and this could be the reason for the increased moist appearance of samples prepared with sorbitol although the content ranged from 14.6 to 12.7%. Moisture loss in *laddu* with sorbitol is less than that observed in sugar containing products (Table 4.2).

Laddu samples prepared with S+M 90:10 showed an increase in L* values indicating some crystallization. L* values of *laddu* prepared with sorbitol and mannitol were higher than those of the sugar containing product, indicating crystallization of mannitol. A similar trend was observed in the studies conducted on solubility and crystallinity (Table 3.2 in chapter 3). The a* and b* values also showed a decreasing trend, thereby increasing the lightness / brightness.

Increasing proportion of mannitol to 20% with sorbitol the levels the *laddus* showed an increased lightness. L* values were comparable with those of sugar containing products, but the products with mannitol had a slight waxy mouthfeel. This could be attributed to the fact that mannitol has needle shaped crystals and low solubility which give rise to a waxy mouthfeel. This attribute was not detectable in samples having 10% of added mannitol but was clearly observed in samples with 20% of added mannitol. Similar results were also observed with the sensory analyses product determined discussed earlier.

Laddu prepared with a mixture of MD+PD showed decreased L* values and increased a* values. They appeared moist throughout the study. Since the binding of syrup was less, products could not be given a spherical shape. They slowly loosened out and crumbled. Also the product had lower sensory scores due to increased off taste. It was observed that there was a high correlation (0.92) between the instrumental colour (L*) values and the sensory perception of colour (0.92) among all the products, which are reflected in the sensory scores (Table 4.3)

Table 4.4: Colour measurement of *laddu* prepared with and without sugar

Type of *laddu*	No. of Days	L*	a*	b*
Sugar	1	45.16±0.78	7.62± 0.12	40.47± 0.33
	3	52.58± 0.92	4.67± 0.18	34.63± 0.38
	5	57.76± 0.83	4.12± 0.16	27.52± 0.35
	10	61.71± 0.75	4.07± 0.07	25.19± 0.34
Sorbitol	1	49.65± 0.34	7.68± 0.10	28.86± 0.20
	3	49.50± 0.36	7.45± 0.23	26.17± 0.19
	5	50.03± 0.48	7.45± 0.20	26.24± 0.21
	10	51.63± 0.09	7.43± 0.15	26.07± 0.31
S+M(90:10)	1	50.61± 0.29	7.40± 0.18	38.95± 0.09
	3	51.41± 0.31	5.49± 0.21	35.37± 0.15
	5	52.61± 0.36	4.16± 0.23	25.07±0.21
	10	55.00± 0.33	4.15± 0.29	24.37± 0.17
S+M(80:20)	1	54.62± 0.43	5.22± 0.17	35.62± 0.13
	3	58.19± 0.46	5.46± 0.26	35.92± 0.17
	5	60.54± 0.52	4.22± 0.32	30.62± 0.16
	10	64.23± 0.63	4.07± 0.11	30.48± 0.13
MD+PD(50:50)	1	46.22± 0.33	8.71± 0.13	37.74± 0.08
	3	46.37± 0.42	7.15± 0.18	37.56± 0.11
	5	44.88± 0.53	6.49± 0.19	34.08± 0.19
	10	44.44± 0.63	7.46± 0.13	32.37± 0.17

S=sorbitol; M=mannitol; MD=maltodextrin and PD=polydextrose

4.3.5 Stability of aspartame

The stability of aspartame added to *laddu* prepared without sugar was studied under ambient, accelerated and refrigerated conditions. The recovery obtained for the added sweetener is given in Table 4.5.

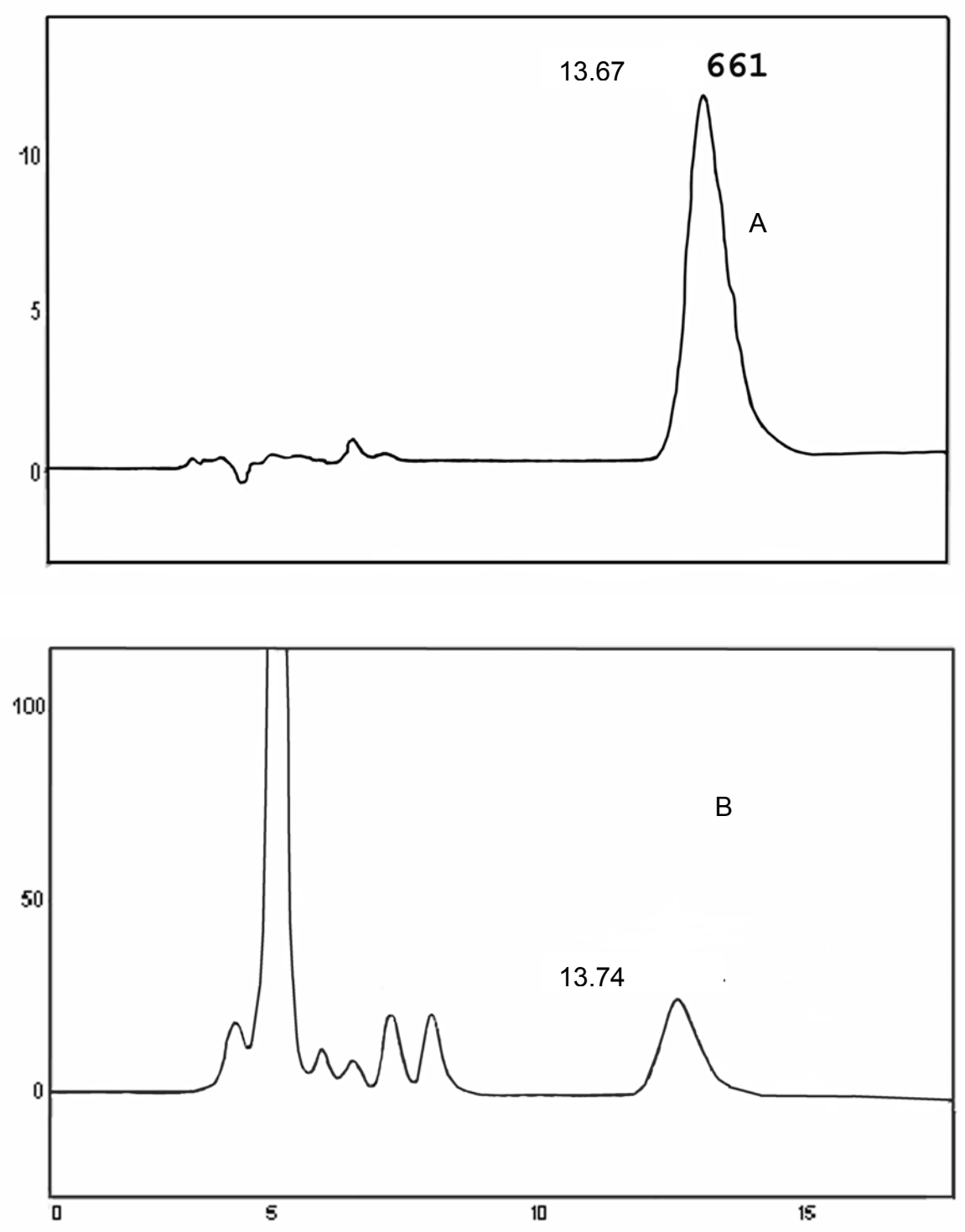
The recovery pattern was similar to that was observed in *burfi*. Chromatograms obtained for standard aspartame and that extracted from *laddu* prepared with sorbitol are shown in Fig. 4.5. The stability of aspartame was least under the accelerated conditions, with the lowest recovery of aspartame (75.6%) recorded at the end of 8 days. Under ambient conditions, the lowest recovery was 83.1%. Minimal loss was observed at the refrigerated condition with a mean difference of 1.7± 0.16. Aspartame was added to *boondi* and syrup mixture at 65–70º C to avoid loss of the sweetener during processing. In products prepared with sorbitol, or with mixtures of sorbitol and mannitol, no problems were encountered in molding even after the mass had cooled. Thus, the sweetener could be added at even lower temperatures, provided proper mixing throughout was ensured.

Table 4.5 Recovery of aspartame in *laddu* samples stored under ambient accelerated and refrigerated conditions

		Percentage recovery of aspartame in sugar free *laddu*		
Type of *laddu*	**Withdrawals***	**Refrigerated**	**Ambient**	**Accelerated**
Sorbitol +Aspartame	0	96.4	96.4	96.1
	1	93.8	91.3	90.8
	2	92.7	89.7	87.4
	3	90.3	86.4	84.6
	4	89.7	84.1	80.8
S+M(90:10)* +Aspartame	0	93.1	93.3	93.1
	1	90.6	88.4	86.4
	2	89.1	84.7	81.3
	3	86.3	80.1	78.7
	4	84.2	78.3	74.2
MD+PD +Aspartame	0	94.2	94.2	94.2
	1	92.8	90.2	88.6
	2	91.1	88.7	83.2
	3	90.0	85.2	79.1
	4	89.7	83.1	75.6

S=sorbitol; M=mannitol; MD=maltodextrin and PD=polydextrose
*Withdrawal days - Accelerated : 0, 2, 4, 6, 8; Ambient: 0,5,10,15,20 and Refrigerated: 0,7,14,21,28 days
S+M (80:20 and 90:10) showed similar recovery pattern therefore only one is reported in the table.

Fig. 4.5 HPLC Chromatogram of standard aspartame (A) and the sweetener extracted from *laddu* (B)



4.3.6. Microbiological study of *laddu* prepared with and without sugar

Microbial quality of traditional sweets normally depends on the observance of hygiene and good manufacturing practices followed during preparation. As they are normally prepared on cottage scale, the shelf life (microbiologically) is short. In this study, the emphasis is on the preservative properties of sugar alternatives in comparison with sugar.

The microbial profile of *laddu* immediately after preparation and during storage was studied. In general, the microbial count showed a progressive increase in all the products prepared (Table 4.6). Microbiological profile of *laddu* samples was similar to that observed in *burfi* samples. In general, the proliferation of microbial population was higher in products prepared with MD+PD and PD samples, than in samples made with sorbitol, or a mixture of sorbitol and mannitol. The microbial count showed progressive increase in all the samples of *laddu* prepared with and without sugar. The safety parameters, *E. coli* and *S. aureus* were absent in all the *laddu* samples studied.

Staphylococcal contamination in traditional sweets is normally attributed to the food handlers. In *laddu,* the *boondi* and syrup mixture is mixed by hand and then moulded. Excessive handling and close contact takes place during molding of *laddu*. This could be responsible for the high proliferation of *staphylococci*. However, the mere presence of these organisms does not render the products unacceptable or unfit for consumption. In the laboratory all the products were prepared hygienically to ensure safety of the product.

There are no standard specifications relating to the microbiological quality for *laddu.* Taking into consideration the PFA of milk *burfi,* as reported in the earlier chapters, *laddu* made with sugar, had a shelf life of one week, while *laddu* prepared with sorbitol or mixtures of sorbitol and mannitol had a shelf life extended up to 20 days. *Laddu* with MD+PD was safe up to 5 days only.

The most significant aspect of micro flora of sweetmeats is the high incidence of yeasts and moulds, the only possible opportunity of contamination would occur is when the products are allowed to solidify or crystallize uncovered as observed in most cases (Dwarkanath and Srikanta, 1977).

Table 4.6 Microbiological profile of *laddu* prepared with and without sugar.

Type of *laddu*	Storage period (Days)	Mesophillic aerobes Log $_{10}$CFU/g	Yeasts and molds Log $_{10}$CFU/g	Staphylococcus Log $_{10}$CFU/g
Sugar	0	1.38	<1.0	<2
	5	1.50	1.25	<2
	10	2.93	1.74	2.73
	15	3.72	2.02	3.01
	20	7.59	4.27	6.83
	25	8.89	4.38	7.11
Sorbitol	0	1.27	<1.0	<2
	5	1.41	<1.0	<2
	10	1.85	1.34	<2
	15	2.48	1.86	2.28
	20	2.91	2.07	2.59
	25	4.32	2.29	3.18
S+M (90:10)*	0	1.20	<1.0	<2
	5	1.32	<1.0	<2
	10	1.82	1.43	<2
	15	2.44	1.79	2.13
	20	2.85	2.08	2.34
	25	4.25	2.26	3.04
MD+PD	0	1.58	<1.0	<2
	5	1.63	1.43	<2
	10	3.64	1.84	3.14
	15	4.00	2.12	3.97
	20	6.66	4.44	5.68
	25	7.04	6.32	6.82

S=sorbitol; M=mannitol; MD=maltodextrin and PD=polydextrose

*S+M (80:20 and 90:10) *laddu* sample show similar trend in microbiological profiles therefore only one is reported in the table.

4.3.7 Proximate composition

The proximate composition of *laddu* prepared with and without sugar is presented in Table 4.7. The mean moisture content ranged from 6.20 to 16.32; protein 5.6 to 6.6%; total ash from 0.84 to 1.28%: fat 16.2 to 19.9%. The total calories showed a decrease of about 100 Kcal for *laddu* without sugar. Compression of *laddu* samples showed that *laddu* prepared with sorbitol was soft and not comparable with that of sugar (Table 4.1). Addition of mannitol induced crystallization and also increased hardness comparable to that of sugar.

Table 4.7 Proximate composition of *laddu* with and without sugar

	Moisture (%)	Protein (%)	Total Ash (%)	Fat (%)	K Cal/ 100g
Sugar	6.20	5.69	0.87	19.93	593
Sorbitol	8.21	6.19	0.84	20.07	501
S+M	8.29	5.81	0.79	16.23	508
MD+PD	16.32	6.65	1.28	19.41	497

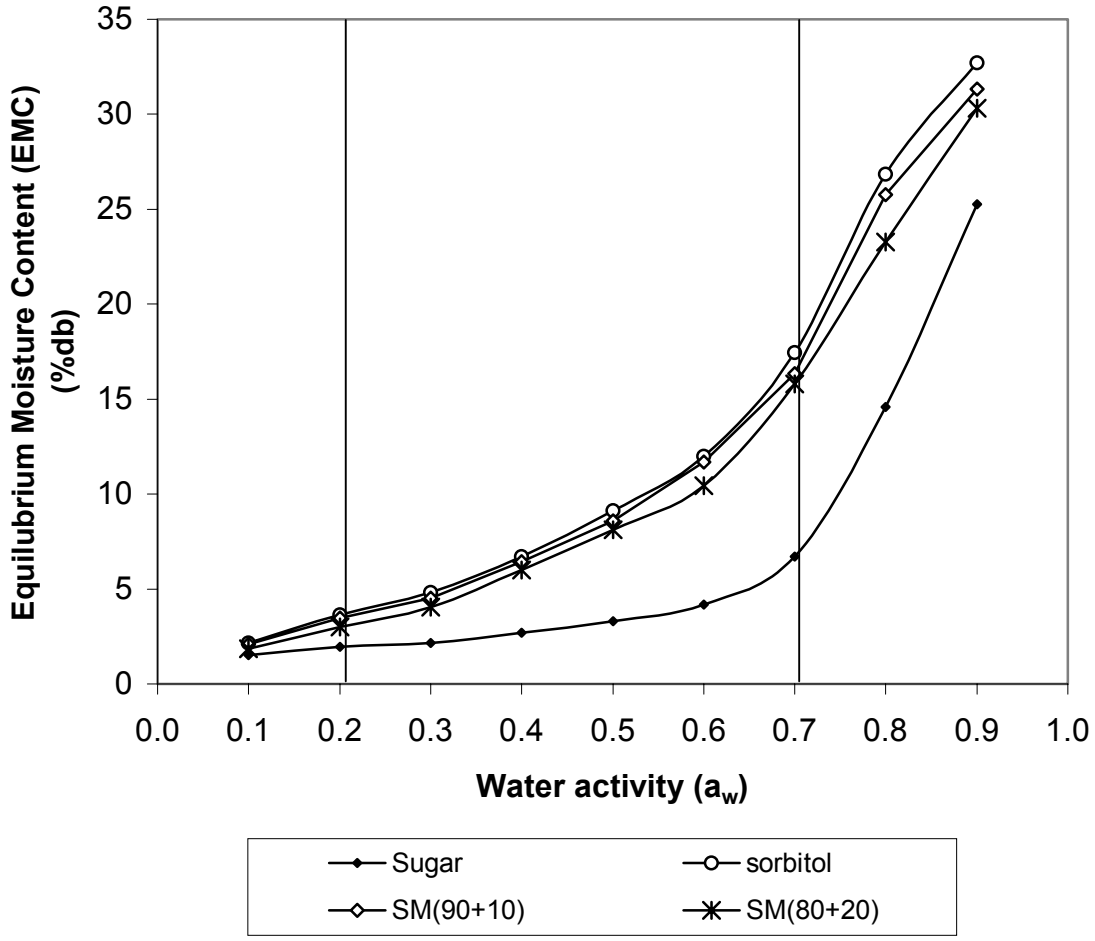
S=sorbitol; M=mannitol; MD=maltodextrin and PD=polydextrose

4.3.8 Sorption behaviour

As mentioned earlier, sorption behaviour is important for the study of ERH and consequently for the packaging requirements of products, as it governs predicting the storage conditions and shelf life of the product. The sorption behaviour of *laddu* with and without sugar was studied. The time to reach equilibrium was about 20 to 25 days for different samples of *laddu* stored at 92%, RH; mold growth was detected by visual inspection at the end of 25 days.

The sorption isotherm curves for equilibrium moisture content (db) obtained for different samples are shown in Fig. 4.6. The isotherm showed 3 regions: region A**,** corresponding to a_w < 0.2 relates to adsorption of a monomolecular film of water; region B, Corresponding to a_w 0.22 – 0.7, relates to adsorption of additional layers over this monolayer at and region C for a_w > 0.7 relates to condensation of water in the pores of the material, followed by dissolution of soluble material. At lower a_w values, the slope of the curve was small, but the slope increased rapidly as a_w increased.

Fig 4.6 Experimental sorption isotherms of *laddu* with and without sugar



In general, the equilibrium moisture content (EMC) increased rapidly at lower water activity a_w (0 – 0.15), then increased slowly between a_w 0.15-0.7, followed by a steep increase above a_w 0.7. Similar curves have been obtained for rice (Agarwal and Clary, 1971) and also for *dudh churpi* (Hossain et al, 2002). The curves are of sigmoidal shape depicting one inflection point characteristic of material with high sugar content, similar to those observed in the case of sultana raisins (Weisser, 1985) and of other products like casein and *Khoa* (Sawhney, et al 1991a and 1991b, Bandopadhyay et al, 1987). The experimental and predicted sorption curves of *laddu* prepared with and without sugar by various models are shown in Fig. 4.7. Various attempts at fitting the seven mathematical equations on experimental moisture sorption data yielded the results as shown in Table 4.8.

4.3.8.1 Sorption models

Seven mathematical models of the moisture isotherm were fitted to the moisture sorption data for sugar containing and sugar free *laddu* over a whole range of water activity. The constants for the respective models and root mean square error (RMSE) were tabulated in Table 4.8. The goodness of fit of a particular model may be judged by the R^2 and RMSE values.

The applicability of the BET model is limited to a low range of water activity (0.1-0.5). *Laddu* prepared with sugar showed the best goodness of fit with this model with its low RMSE value. All the others showed high RMSE values for BET model. The monolayer (M_m) constants for *laddu* with and without sugar varied from 1.6 – 5.3 and energy constant C ranged from 4-44 indicating a poor fit (Table 4.8).

The GAB water sorption isotherm model named after Guggenheim-Anderson De Boer is the most popular one in the area food technology. Sorption isotherms for many food materials fit extremely well over a wide range of water activity (Bizot, 1984). The most successful three parameter model is the GAB model as it is applicable for the full range of water activity (0.1-0.9). The GAB constants $M_{0,}$ G and K were computed from linear regression of 1/M vs $a_{w.}$ The lowest RMSE values were observed in the range 6.8 to 10.7. The M_o

values ranged from 1.60 to 5.98. The best fit and lowest RMSE values were obtained from this equation (Table 4.8). Lomauro, et al (1985) found that the GAB model gave a very good fit for over 50% of 75 food isotherms for fruits and vegetables and over 75% of 88 isotherms for coffee, tea, nuts etc.

The Smith model, which shows a good fit for Virginia type peanuts above a_w 0.3 (Young, 1976), showed a poor fit for *laddu*, prepared with sugar. However, it showed good fit for *laddu* prepared without sugar. The smith constants M_b and M_a ranged from –10.56 to –14.9 and 0.22 to 2.56 for *laddu* with and without sugar.

The Oswin model was found very suitable for the isotherms of proteins and starchy foods. Boquet et al, 1978 and Lomauro et al, 1985 concluded that this model fitted quite well with the sorption data for a very large number of nuts, oilseeds, spices coffee, tea and vegetables. In the present study the experimental sorption data for Oswin model fitted in the a_w range of 0.1 to 0.8, showed poor fit for *laddu* prepared with sugar, but showed a good fit for *laddu* prepared without sugar or using sugar substitutes.

Caurie model is valid from 0.1 to 0.9. The R^2 values for *laddu* prepared with sugar substitutes were observed to be 0.99 and showed a good fit (RMSE 5.4-6.5). But *laddu* prepared using sugar showed high RMSE values indicating a poor fitness of the model (Table 4.8).

The Kuhn model holds good for a_w ranging from 0.4 to 0.9; the constant 'a' ranged from 0.12 to 3.83 and 'b' from –2.74 to –3.49. The RMSE values ranged from 9.1 to 16.8 for all the samples studied, indicating a poor fit.

The Harkins-Jura sorption isotherm model was applicable over the a_w range between 0.1 to 0.6. *Laddu* with sugar showed low RMSE values of 2.5 and 1.5, indicating a good fit. But for *laddu* prepared using bulk sweeteners like sorbitol and mixtures of sorbitol and mannitol (80:20 and 90:10) RMSE values were very high indicating a poor fit.

Sorption analyses of different models show extremely good fit as determined by RMSE values and R^2 values. The degree and range of fitness depends on the model and type of product. The constants derived from different sorption models are useful in the evaluation of stability of sugar free *laddu*. The applicability of water activity values will throw up valuable information on the suitability of packaging material for specific purpose. The constants derived from the respective models could be utilized to predict equilibrium moisture content (EMC) in comparison with the experimental values mentioned earlier in chapter 3, Table 3.1. It may be noted, that all models could successfully predict the EMC values for *laddu* with and without sugar. However, the GAB model showed the lowest RMSE and highest R^2 values that it is to be the best model. Linear models with high R^2 and low RMSE values are considered to be statistically acceptable. The GAB model showed a better fit compared to other models, as it is applicable to a wide range of water activity. These studies will help in deciding storage behaviour and packaging aspects of *laddu*.

Conclusions

The studies indicated that *laddu* could be prepared using sorbitol and mixtures of sorbitol and mannitol (80:20; 90:10), whereas acceptable products could not be made with PD. *Laddu* with MD+PD gave rise to problems in moulding, as the spherical ball slowly disintegrated into individual *boondi.* Increasing the total soluble solids (°B) did not improve the moulding characteristics. Laddu prepared with sorbitol though moist and soft were acceptable. *Laddu* prepared with S+M 90:10 and 80:20 showed crystallization like sugar but *Laddu* prepared with S+M 90:10 was more acceptable than S+M 80:20 because 80:20 imparted a waxy taste due to mannitol.

Colour measurements indicated that *laddu* prepared with sugar and mixtures of sorbitol and mannitol (80:20; 90:10) were lighter in colour. *Laddu* prepared with sorbitol or with MD+PD were moist throughout. Stability of aspartame in these products showed marginal loss at refrigerated temperatures. Highest loss was observed at accelerated temperatures. The microbial profile of *laddu* indicated that *laddu* made with sorbitol or with mixtures of sorbitol and mannitol had a shelf life of 20 days whereas, products prepared using MD+PD were found to be safe for consumption for 5 days only although sensorily the product scored least in overall quality.

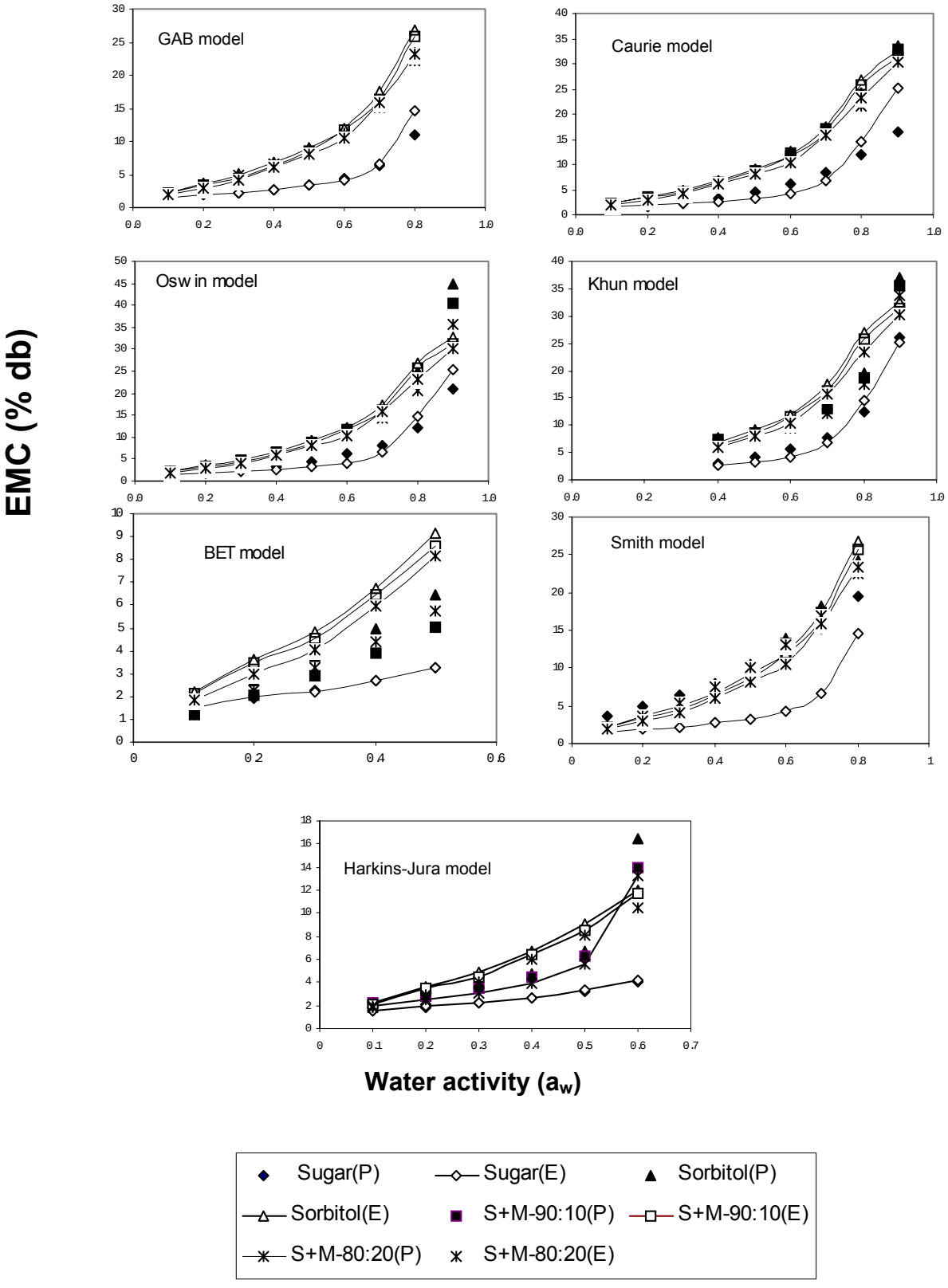
Moisture sorption data is useful in choosing suitable packaging material having a desirable water vapour barrier property and also in addition to determining the stability of the product. Moisture sorption isotherms of sugar and sugar free *laddu* showed sigmoidal pattern, similar to sugar rich products. Addition of sugar replacers tended to shift the isotherm to the left. The GAB model showed a better fit compared to other models, as it is applicable to a wide range of water activity.

Table 4.8 Estimated coefficient of determination (R^2) and RMSE values of different models for sorption isotherms for milk burfi with and without sugar values for sugar and sugar free *laddu*

Model Isotherm	Range of water activity	Type of *laddu*	Constants of linear fitting			R^2	RMSE
			M_m	C			
		Sugar	1.67	37.24		0.99	2.38
BET	0.1-0.5	Sorbitol	5.35	4.74		0.97	27.0
		S+M(90:10)	5.02	4.91		0.97	39.8
		S+M(80:20)	4.88	4.04		0.99	27.0
			A	b			
		Sugar	3.33	-0.18		0.91	27.82
Caurie	0.1-0.9	Sorbitol	3.33	0.54		0.99	6.55
		S+M(90:10)	3.33	0.5		0.99	5.61
		S+M(80:20)	3.4	0.35		0.99	5.45
			A	b			
		Sugar	0.12	-2.74		0.98	16.86
Khun	0.4-0.9	Sorbitol	3.83	-3.49		0.88	13.82
		S+M(90:10)	3.61	-3.35		0.89	13.71
		S+M(80:20)	3.09	-3.23		0.9	12.84
			Ma	Mb			
		Sugar	-10.56	2.56		0.9	153.71
Smith	0.3-0.9	Sorbitol	-14.9	0.22		0.98	12.03
		S+M(90:10)	-14.21	0.26		0.95	12.29
		S+M(80:20)	-13.61	0.55		0.99	15.47
			A	n			
		Sugar	4.58	0.69		0.92	27.55
Oswin	0.1-0.8	Sorbitol	9.10	0.72		0.98	7.20
		S+M(90:10)	8.67	0.7		0.99	6.12
		S+M(80:20)	7.95	0.68		0.99	6.47
			A	B			
		Sugar	4.96	-0.20		0.99	2.54
Harkins-Jura	0.1-0.6	Sorbitol	9.63	-0.47		0.85	21.27
		S+M(90:10)	9.12	-0.47		0.86	20.03
		S+M(80:20)	7.03	-0.47		0.86	22.19
			Mo	G	K	I	
		Sugar	1.60	41.69	1.07	0.96	9.13
GAB	0.1-0.8	Sorbitol	5.98	4.19	0.95	0.92	6.97
		S+M(90:10)	5.60	4.30	0.96	0.91	6.84
		S+M(80:20)	5.60	4.29	0.95	0.92	10.72

S=sorbitol; M=mannitol; MD=maltodextrin and PD=polydextrose

Fig. 4.7 Experimental (E) and predicted (P) sorption isotherms of *laddu* prepared with and without sugar.



Summary & Conclusions

Summary and conclusions

Sweet taste or sweetness is liked by most of the people, if not all. A number of traditional foods, whether prepared at cottage scale /home scale or manufactured by organized food industries possess sweet taste, employing mostly sucrose or sugar. The different sucrose sources used include sugar (cane or beet sugar), honey, jaggery etc.

Sweetness appears to be a very generally attractive quality in a food. However, of late, sucrose not only increases body weight, but also raises the plasma insulin level. Sugar has been blamed for conditions leading to diabetes, obesity and dental caries, thus people with diabetic disorder cannot take such products. Considering the increasing number of diabetic persons throughout the world, there is a need to develop sweet products, that are equally acceptable like the conventional sugar based products but without the addition of sugar. The application of well known sugar replacing agents is a solution to this problem.

Sugar replacers are important components of low calorie / low sugar foods. Consumers select low calorie foods sweetened with sugar substitutes for a variety of reasons; primarily, to decrease calorie intake and aid control of diabetes and hyperglycemia. Added benefits of some sugar substitutes available in low calorie foods are their non-cariogenicity or cariostatic properties. Sugar replacers may be either caloric or non caloric, depending on their metabolism in the body. High intensity sweeteners do not contribute significant calories to the products. High intensity synthetic sweeteners include aspartame, alitame, acesulfame-K; saccharin etc. Naturally occurring high intensity sweeteners include glycyrrhizin, thaumatin, stevioside and neohesperidin dihydrochalcone (NHDC) etc.

A number of sugar substitutes are currently available, or under development or regulatory review for the manufacture of low calorie / low sugar foods. Additional substances have been recently discovered or patented. It is clear that the perfect sugar replacer does not yet exist. Each sweetener has

certain advantages and disadvantages- such as bitter after taste, instability during heating and or storage, or lack of bulk etc.

Though the sugar replacers can provide sweetness to these products, other problems arise simultaneously. Sucrose, in addition to providing sweetness, does many other functions including body, desired texture, binding and adhesion etc., to the product that may not be available when sugar replacers are used. For this reason, polyols and or polymeric bulking agents are needed when producing sugar free sweets. Polyols alone or combined with other sweeteners can be used to produce sweets/confections that are safe for diabetics. Bulking agents such as polydextrose and maltodextrins are also used in combination with sugar replacers.

Still, a question remains to be answered. For a particular food it is difficult to ascertain the exact sugar replacers that would lead to the exact or a closely simulated product. The simulation is highly complex for Indian traditional sweets because of lack of data compounded by the limited number of research investigations in the whole arena of Indian sweets.

The main emphasis is to prepare traditional sweets *jamun, laddu* and *burfi* without sucrose and employing appropriate alternative sweeteners. With this objective, the work has been carried out.

For the present investigation the functional suitability of sorbitol and other bulking agents like polydextrose (PD) and mixture of maltodextrin and polydextrose(MD+PD) in combination with the intense sweetener, aspartame were undertaken. The important findings of the present investigation have been summarised for the three products studied.

Jamun

Jamun is a traditional *khoa* based sweet and sugar syrup is an integral part of *jamun* preparation which influences its quality.

1. Studies on the rheological characteristics of syrup showed that sugar and sorbitol solutions, behaves like Newtonian fluids while all other

syrups studied exhibited shear thinning, non-Newtonian behavior with yield stress. However, flow behavior of the latter type of syrups could be well represented by the Herschel-Bulkley model. The yield stress, flow behavior index and consistency index were dependent both on temperature and concentration of solids.

2. The activation energy, as calculated by using Arrhenius equation, increased with an increase in concentration of solids. The requirements of sugar substitutes (PD and MD+PD) were lesser than that of sugar alone to produce solutions/dispersions with viscosities similar to those of sugar. The colour of syrups showed that sorbitol syrup was brighter than the others and matches closely with sugar syrup. Whereas for sorbitol it was similar to that of sugar.

3. In the preparation of *jamun*, the processing conditions such as syrup strength, temperature and duration of soaking markedly influenced the texture and overall acceptability of the product. To prepare *jamun* without sugar, these parameters were need to be optimised to get a product having similar texture and quality compared to that made with sugar syrup. Response surface methodology (RSM) was found to be an useful tool to know the effect of variables for optimisation of these parameters. The optimum conditions for *jamun* with and without sugar were : syrup strength 51 and 54°B; temperature of soaking 54 and 65°C, and time of soaking were 4 and 3 hrs, respectively. Based on these conditions, *jamun* without sugar could be prepared without significantly affecting the quality of the product.

4. Instrumental colour measurements indicated that *jamun* prepared with sorbitol was lighter in colour, compared with that of sugar, mixture of maltodextrin and polydextrose (MD+PD) and polydextrose (PD) syrups.

5. The added intense sweetener aspartame showed the least loss at refrigerated temperatures and highest loss at accelerated temperature.

6. The microbial profile of *jamun* also indicated that *jamun*s prepared with sugar had a shelf life of 4 days for sugar, while *jamun*s in MD+PD and PD syrups had a shelf life of 2 days. Interestingly, sorbitol was found to be microbiologically safe for the entire storage period of 8 days. The lower calorific value of *jamuns* prepared with sorbitol compared to *jamuns* prepared with sugar is an added advantage for this product.

Jamun could be prepared by using sorbitol, similar to that of the traditionally prepared product. *Jamun* prepared using bulking agents along with intense sweetener aspartame though matched the traditional product in textural qualities scored lower in sensory overall acceptability compared to *jamuns* with sugar and sorbitol.

Burfi

Traditionally, *Burfi* is prepared by heating a mixture of milk solids (*Khoa*) and sugar to a homogenous consistency followed by cooling and cutting into small cubes.

1. Studies indicated that *burfi* could be prepared using bulk sweetener, sorbitol, mixtures of sorbitol+monnitol(S+M 80:20;90:10) and bulking agents such as, polydextrose and mixture of maltodextrin and polydextrose. Products could not be prepared using maltodextrin alone. It was observed that the total soluble solids at the end of cooking the *khoa* mass and days of storage had marked influence on the quality of the product.

2. Response surface methodology was used to study the effect of these variables on response functions , such as texture and overall acceptability and to optimize process parameters. The optimum conditions for *burfi* with sugar was 80°B and 2.3 days for obtaining a *burfi* with a breaking strength /snap of 13.3N and a sensory overall acceptability score of 9.5. In the case of sorbitol to obtain a product close

to its sugar counterpart, 77.5°B and 5.5 days of storage was needed for obtaining a *burfi* with 12.9N with an overall acceptability score of 9.1.

3. Instrumental colour measurements indicated that *burfi* prepared with sugar and mixtures of S+M (80:20; 90:10) were similar and were lighter in colour compared to those of polydextrose, mixture of polydextrose and maltodextrin.

4. Stability of aspartame in these products were similar to that obtained in *jamun.*

5. The microbial profile of *burfi* indicated that *burfi* prepared with sugar had a shelf life of 10 days, *burfi* with sorbitol and mixtures of sorbitol and mannitol had a shelf life of 20 days, whereas products prepared using MD+PD and PD were found to be safe for consumption for 5-6 days only.

6. Moisture sorption isotherms of sugar and sugar free milk *burfi* showed sigmoidal pattern, similar to sugar rich products. The isotherm curves of *burfi* with sorbitol shifted towards left compared to that of sugar, Products with bulking agents like PD or combination of MD+PD were found to be similar to those of sugar counterpart. The GAB model showed a better fit compared to other models, as it is applicable to a wide range of water activity.

Burfi could be prepared with sorbitol and mixtures of S+M (90:10) without affecting the desirable quality of the traditionaly prepared sweet.

Laddu

Laddu is a legume based sweet, popular in India. Sweet *boondi* (spherical crisp, deep fat fried product from bengal gram dispersion) bound together with sugar syrup and molded into round balls are called ” *laddu*s” or “ *boondi laddu*” or “ *motichur laddu*” as they resemble small balls.

1. Studies indicated that laddu could be prepared using sorbitol and mixtures of sorbitol and mannitol (80:20; 90:10), whereas products could not be made using maltodextrin or polydextrose (MD+PD). *Laddu* with MD+PD had problems of molding, the spherical ball slowly disintegrated into individual boondi. Increasing the total soluble solids (°B) in the product did not improve the molding characteristics.

2. *Laddu* prepared using sorbitol was soft and could not be compared with sugar containing counterpart. Addition of mannitol to sorbitol increased the instrumental hardness and also crystallisation. *Laddu* prepared with S+M (90:10) was comparable with those prepared with sugar both in terms of texture and sensory quality. *Laddu* prepared using bulking agents MD+PD were uncacceptable because of poor binding and sensory acceptability.

3. Instrumental colour measurements indicated that *laddu* prepared with sugar and mixtures of S+M (80:20; 90:10) were lighter in colour. Laddu prepared with sorbitol and MD+PD appeared moist.

4. Stability of aspartame in these products were similar to that observed in *jamun* and *burfi* samples.

5. The microbial profile of laddu indicated that *laddu* with sugar had a shelf life of 10 days. *Laddu* with sorbitol and mixtures of sorbitol and mannitol had a shelf life of 20 days whereas products prepared using MD+PD were found to be safe for consumption for 5 days only. Similar findings were also obtained for *burfi* samples.

6. Analysis of moisture sorption data is useful in choosing suitable packaging material having a desirable water vapour barrier property in addition to determining the stability of the product. Moisture sorption isotherms of sugar and sugar free *laddu* showed sigmoidal pattern, similar to sugar rich products. Addition of sugar replacers tended to shift the isotherms towards the left. The GAB model showed a better fit compared to other models used.

It was concluded that sugar replacers could also be used to prepare traditional sweets. Three sweets selected such as *jamun, burfi* and *laddu* were prepared with sorbitol mixtures of S+M and were found to have quality attributes similar to those of corresponding sugar counter parts. Among these three products, the most appropriate condition for making *jamun* with sorbitol is 54°B, 65°C and 3 h of soaking. For burfi with sorbitol the conditions were 77.5°B at the end of cooking and at 5 days of storage. Whereas, for laddu, a combination of sorbitol and mannitol (90:10) at 80°B was found to be appropriate.

Interestingly, sweets prepared with sugar replacer sorbitol and/or mannitol increased the shelf life of *jamun burfi* and *laddu* by almost two folds. The sorption model of GAB is suitable sorption studies of *burfi* and *laddu*.

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Outcome of the thesis

Publications from this thesis

1. Chetana, R., Krishnamurthy, S. and Yella Reddy, S. (2004).
Rheological behavior of syrups containing sugar substitutes. European Food Research and Technology, 218: 345-348.

2. Chetana, R., Manohar, M. and Yella Reddy, S (accepted)
Process optimization of *Gulab jamun*, an Indian traditional sweet using sugar substitutes. European Food Research and Technology.

3. Chetana, R., Srinivasa, P.C. and Yella Reddy, S (accepted)
Moisture sorption characteristics of *Burfi*, an Indian traditional sweet using sugar substitutes. European Food Research and Technology.

4. Chetana, R., Srinivasa, P.C. and Yella Reddy, S (finalized for publication)
Moisture sorption characteristics of *Laddu*, an Indian traditional sweet using sugar substitutes. European Food Research and Technology.

Patent

1. A sugar-free syrup formulation for Indian traditional sweets and a process for preparation thereof. ( )
Chetana, R. and Yella Reddy, S.