EVALUATION ON EDIBLE COATINGS AND PACKAGING METHODS ON STORAGE OF SOLID JAGGERY

M.Tech. (Agril. Engg.) Thesis

by

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EVALUATION ON EDIBLE COATINGS AND PACKAGING METHODS ON STORAGE OF SOLID JAGGERY

Thesis

Submitted to the

Indira Gandhi Krishi Vishwavidyalaya, Raipur

by

Bogala Madhu

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in

Agricultural Engineering

(AGRICULTURAL PROCESSING AND FOOD ENGINEERING)

Roll No: 20151622679 ID No: 220115003

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CERTIFICATE – I

This is to certify that the thesis entitled **"Evaluation on Edible Coatings and Packaging Methods on Storage of Solid Jaggery"** submitted in partial fulfillment of the requirements for the degree of **"Master of Technology in Agricultural Engineering"** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **Mr. Bogala Madhu** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma or has been published/published part has been fully acknowledged. All the assistance and help received during the course of the investigations have been duly acknowledged by him.

Chairman

Date: 27/06/2017

THESIS APPROVED BY THE STUDENT'S ADVISORY COMMITTEE

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Member	**(Er. P. Sreedevi)**	
Member	**(Dr. Ajay Varma)**	27/6/17
Member	**(Dr. R. R. Saxena)**	27.6.17

CERTIFICATE – II

This is to certify that the thesis entitled "**Evaluation on Edible Coatings and Packaging Methods on Storage of Solid Jaggery**" submitted by **Mr. Bogala Madhu** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur, in partial fulfillment of the requirements for the degree of **Master of Technology in Agricultural Engineering** in the Department of Agricultural Processing and Food Engineering has been approved by the external examiner and Student's Advisory Committee after oral examination.

Signature External Examiner
(Name Dr. B. K. Goel)

Date: 29/06/2017

Major Advisor ____________ 29/6/2017

Head of the Department ____________ 29/6/2017.

Faculty Dean ____________ 29/06/2017

Approved/Not approved

Director of Instructions ____________

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Date: 27-06-2017
Place: Raipur

(Bogala Madhu)

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LIST OF ABBREVIATIONS

Abbreviation	Description
Agril.	Agricultural
Agril. Engg.	Agricultural Engineering
Engg.	Engineering
EMC	Equilibrium Moisture Content
FAE	Faculty of Agricultural Engineering
ANGRAU	Acharya NG Ranga Agriculture University
IGKV	Indira Gandhi Krishi Vishwavidyalaya
M. Tech.	Master of Technology
LDPE	Low density poly ethylene
HDPE	High density poly ethylene
PP	Polypropylene
AOAC	Association of official analytical chemists
BIS	Bureau of Indian Standards
C	GAB constant, dimensionless
Ea	Activation energy
ERH	Equilibrium relative humidity, %d.b.
GAB	Guggenheim, Anderson and de Boer
ΔHc	Difference in enthalpy/ heat of sorption between monomolecular layer and multimolecular layer of water
ΔH_k	Difference in heat of sorption of multimolecular layer of water and heat of condensation of water vapor
RH	Relative humidity, Percent
RMSE	Root mean square error, fraction
Z	Integral constant in Clausius Clapeyron equation, dimensionless
M_{pre}	Predicted equilibrium moisture content, % db.
MSI	Moisture sorption isotherm
S	Sample
T	Temperature ^{o}C
V	Volt
R	Universal gas constant, 8.314×10^{-3} kJ mol^{-1} K^{-1}

LIST OF SYMBOLS

Symbol	Description
%	percent
wb	Wet basis
db	Dry basis
et al.	Et alibi
Fig.	Figure
g	Gram
h	Hour
A	Ampere
V	Volt
^0C	Degree centigrade
µm	Micro meter
i. e.	That is
kW	Kilowatt
MT	Milliontonne
mm	Millimeter
m.c.	Moisture content
m/s	Meter per second
No.	Number
S	Second
wt.	Weight
K	Potassium
aw	water activity
$^{\circ}F$	Degree Fahren heat
ml/min	milliliter per minute
α and (Qo)	The characteristics parameters
M_{o^1}, C_o, K_o	The constants
%	Percentage

THESIS ABSTRACT

Title of the thesis	:	Evaluation on Edible Coatings and Packaging Methods on Storage of Solid Jaggery
Full name of the Student	:	Bogala Madhu
Major Subject	:	Agricultural Processing and Food Engineering
Name and Address of the	:	Dr. S. Patel
major advisor	:	Profesor & Head, APFE, SVCAET & RS. Faculty of Agricultural Engineering, IGKV, Raipur (CG)
Degree to be awarded	:	M.Tech (Agricultural Engineering)

Signature of the Student

Signature of the Major Advisor

Date: 27-06-2017

Signature of the Head of the Department

ABSTRACT

Jaggery production in our country is a traditionally labour intensive cottage industry mostly confined to rural areas. Jaggery is a natural eco-friendly nutritive sweetener and meets about 40% demand of sweeteners in the country. Jaggery has been in use as energy food and sweetening base for a number of preparations since time immemorial. Jaggery contains 70-85% sucrose, 10-15% reducing sugars, 1-2% minerals. In India, production of jaggery starts from October and continues up to May, depending on the location and variety. The total jaggery produced in India is not consumed immediately after production, and is stored for a period of 10 to 12 months. The major problem associated with the jaggery storage is the presence of invert sugars and mineral salts which being hygroscopic absorb moisture particularly during monsoon season when ambient humidity is high, and lead to spoilage. Edible films and coatings

has been successfully used in various food applications e.g., in maintaining purity of fruits, providing functionality (e.g. glaze to chocolate), controlling adhesion, cohesion, barrier properties, extending shelf life and providing mechanical integrity to the product. Knowledge of moisture sorption isotherms of granulated jaggery products at various storage temperatures could be a useful tool for its handling, storage, packaging system and in designing the drying facilities.

The moisture sorption isotherms (MSI) of solid jaggery, coated with different edible coatings (i.e. whey protein concentrate, wheat gluten, zein, gelatine and gum arabic) with 0.5%, 1.5% and 2.5% concentrations, was determined by the static gravimetric technique based on isopiestic vapour transfer technique using saturated salt solutions at three temperatures of 25, 35, and 45°C. The moisture sorption isotherms for solid jaggery samples are Type-III isotherms. The effect of temperature on sorption behaviour was more pronounced. Among the three MSI models tested with the experimental data of these coated jaggery, GAB model was found to be best fit with the experimental data followed by Halsey model and Iglesias and Chirife model. The monolayer moisture content (M_0) of the solid jaggery samples without edible coating varied from a maximum of 4.368% (db.) at 25°C and minimum 3.7402% (db.) at 45°C. A decreasing trend of monolayer moisture content (M_0) values of the solid jaggery samples coated with whey protein concentrate, wheat gluten, zein, gelatine and gum arabic edible coatings with increase of coating concentration (0.5% to 2.5%) and temperature (25°C to 45°C). The highest monolayer moisture content (M_0), 4.8861 (%db.) was obtained with 0.5% concentration of wheat gluten edible coating at 25°C temperature. The lowest monolayer moisture content (M_0), 3.3629 (%db.) was obtained with 2.5% concentration of whey protein concentrate edible coating at 45°C temperature. The net isosteric heat of sorption estimated from the Clausius – Clapeyron equation for solid jaggery without edible coating decreased from 3.257 kJ/mol to 2.667 kJ/mol with increased in moisture content from 5 to 45 %(db.). A similar decreasing trend of net isosteric heat of sorption to the solid jaggery with whey protein concentrate, wheat gluten, zein, gelatine and gum arabic edible coatings with increase of temperature and increased with increase of temperature for moisture content from 5 to 45 %(db.).

The process parameters for the optimization of the application of edible coating over solid jaggery were determined by using Design Expert 9.0 software. The numerical optimization results showed that the overall optimum area was predicted to be obtained by the application of edible coating over solid jaggery at the combined level of 25^{0}C, 0.1%, 0.5% and whey protein concentrate (i.e. edible coating 1) for temperature, water activity, coating concentration and edible coating, respectively with desirability of 0.884% by response surface plots and response optimizer.

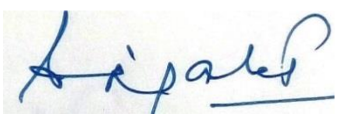
Sugarcane jaggery samples (25 g) were coated with the optimized concentration of edible coating (0.5% WPC and 0.5% gum arabic) and placed in LDPE, HDPE and PP pouches packed the nine pouches (three LDPE pouches, three HDPE and three PP pouches) with MAP machine. The samples were analyzed for important physico-chemical characteristics viz., sucrose, reducing sugars, colour, Hardness and moisture content. Sensory parameters i.e., colour, sweetness, flavour and texture/appearance are analyzed using fuzzy logic comprehensive model. The whey protein coated solid jaggery stored in PP packets under vacuum was found to be better i.e., low increase in reducing sugars and decrease in non-reducing sugars, as compared to the samples packed in LDPE, HDPE under vacuum and MAP at storage temperature of 25°C.

Accelerated storage studies were conducted for the sugarcane solid jaggery samples (50 g) coated with optimized concentration of edible coating (0.5% concentration of both protein (WPC) and polysaccharide (gum arabic) based) placed in LDPE, HDPE and PP pouches with vacuum and MAP packing and all these pouches were placed in the desiccator at 90% RH and this desiccator was kept in incubator at 45^{o}C. The maximum predicted storage life i.e. 255.44 days was obtained in the 0.5% WPC edible coated solid jaggery packed in LDPE with vacuum packaging machine.

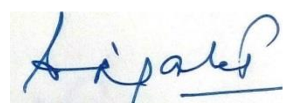
शोध सारांश

थीसिस का शीर्षक	:	ठोस गूड के भंडारण पर खाद्य कोटिंग्स और पैकेजिंग विधियों पर मूल्यांकन
छात्रों का पूरा नाम	:	बोगला मधु
मेजर विषय	:	कृषि प्रसंस्करण और खाद्य इंजीनियरिंग
प्रमुख सलाहकार का नाम और पता	:	डॉ एस। पटेल प्रोफेसर एंड हेड, एपीएफई, एसवीएएटीएटी और आरएस कृषि इंजीनियरिंग के संकाय, आईजीकेवी, रायपुर (सीजी)
म्मानित किया जाने वाला डिग्री	:	एम.टेक (कृषि अभियांत्रिकी)

छात्र के हस्ताक्षर



प्रमुख सलाहकार के हस्ताक्षर



तारीख: 27-06-2017

विभाग के प्रमुख के हस्ताक्षर

सारांश

हमारे देश में गूढ़ उत्पादन पारंपरिक रूप से श्रमिक गहन कुटीर उद्योग है जो ज्यादातर ग्रामीण क्षेत्रों तक ही सीमित है। गूड एक प्राकृतिक पर्यावरण-अनुकूल पोषक स्वीटनर है और देश में मिठास के 40% मांग को पूरा करती है। गौड़े का उपयोग अनाज के समय के बाद से कई तैयारियों के लिए ऊर्जा भोजन और मीठा आधार के रूप में किया गया है। गुड़ में 70-85% सूक्रोज, 10-15% शर्करा घटाना, 1-2% खनिज होते हैं। भारत में, गुड़ का उत्पादन अक्टूबर से शुरू होता है और मई तक चलता रहता है, स्थान और विविधता के आधार पर। भारत में

उत्पादित कुल गुड़ का उत्पादन के तुरंत बाद उपयोग नहीं किया जाता है, और इसे 10 से 12 महीनों के लिए रखा जाता है। गुड़ भंडार से जुड़ी प्रमुख समस्या ये है कि इनवर्ट शर्करा और खनिज लवण की उपस्थिति, जो कि हाइड्रोस्कोपिक नमी को विशेष रूप से मानसून के दौरान नमी को अवशोषित करती है, जब परिवेश नमी अधिक होती है और बिगड़ती जाती है। खाद्य फिल्मों और कोटिंग्स का सफलतापूर्वक विभिन्न खाद्य अनुप्रयोगों में उपयोग किया जाता है जैसे, फल की शुद्धता बनाए रखने में, कार्यक्षमता प्रदान करने (जैसे चॉकलेट से चकाचौंध), आसंजन को नियंत्रित करने, संयम, बाधा गुण, शैल्फ जीवन को बढ़ाते हुए और उत्पाद को यांत्रिक अखंडता प्रदान करने में। विभिन्न स्टोरेज तापमान पर दानेदार गुड़ उत्पादों के नमी सब्नेस इज़ोटेर्म्स का ज्ञान इसके हैंडलिंग, स्टोरेज, पैकेजिंग सिस्टम और सुखाने की सुविधा तैयार करने के लिए एक उपयोगी उपकरण हो सकता है।

0.5%, 1.5% और 2.5% सांद्रता के साथ अलग-अलग खाद्य कोटिंग्स (यानी मट्ठा प्रोटीन ध्यान केंद्रित, गेहूं लस, ज़ीइन, जिलेटिन और गम अरबी) के साथ लेपित ठोस गुड़ के नमी स्राशन इज़ोटेर्म्स (एमएसआई), स्थैतिक ग्रेमीमैट्रिक तकनीक द्वारा निर्धारित किया गया था 25, 35, और 45 डिग्री सेल्सियस के तीन तापमानों पर संतृप्त नमक समाधानों का प्रयोग करते हुए आईओपियास्टीक वाफे ट्रांसफर तकनीक पर आधारित ठोस गुड़ के नमूनों के लिए नमी शर्पोषण आइसोर्मस प्रकार-III isotherms हैं। सोर्पण व्यवहार पर तापमान का प्रभाव अधिक स्पष्ट था। इन लेपित गुड़ों के प्रायोगिक आंकड़ों के साथ परीक्षण किए गए तीन एमएसआई मॉडलों में, गैब मॉडल को हाले मॉडल और इग्लेसियस और चिरैफ मॉडल के बाद प्रयोगात्मक डेटा के साथ सबसे अच्छा फिट पाया गया। खाद्य कोटिंग के बिना ठोस गुड़ के नमूनों के मोनोलायर नमी सामग्री (एम 0) अधिकतम तापमान 4.368% (डीबी।) से 25 डिग्री सेल्सियस और न्यूनतम 3.7402% (डीबी।) 45 डिग्री सेल्सियस पर थी। घन प्रोटीन केंद्रित, गेहूं लस, ज़ीइन, जिलेटिन और गम अरबी खाद्य कोटिंग्स के साथ कोटिंग एकाग्रता (0.5% से 2.5%) और तापमान (25 डिग्री) के साथ लेपित ठोस गुड़ के नमूनों के मोनोलायर नमी सामग्री (एम$_0$) के मूल्यों में गिरावट सी से 45 डिग्री सेल्सियस) उच्चतम मोनोलायर नमी सामग्री (एम 0), 4.8861 (% डीबी।) 25 डिग्री सेल्सियस तापमान पर गेहूं लस खाद्य कोटिंग की 0.5% एकाग्रता के साथ प्राप्त की गई थी। सबसे कम मोनोलायर नमी सामग्री (एम 0), 3.3629 (% डीबी।) 45 डिग्री सेल्सियस तापमान पर मट्ठा प्रोटीन ध्यान केंद्रित खाद्य कोटिंग के 2.5% एकाग्रता से प्राप्त की गई थी। क्लॉसियस-क्लेपेयरोन समीकरण से अनुमानित शुद्ध आइसोस्टोर गर्मी की मात्रा में गूंज के लिए ठोस गूंध के लिए 3.257 किलोग्राम / एमओएल से 2.667 किलोग्राम / एमओएल की कमी हुई है, जो 5 से 45% (डीबी) में नमी की मात्रा में वृद्धि हुई है। मक्खन प्रोटीन ध्यान केंद्रित, गेहूं लस, ज़ीइन, जिलेटिन और गम अरबी खाद्य कोटिंग्स के साथ ठोस

गुड़ में तापमान की वृद्धि के साथ शुद्ध आइसोस्टरिक गर्मी का एक समान कम प्रवृत्ति और नमी सामग्री के तापमान में 5 से 45% (डीबी)।

डिजाइन विशेषज्ञ 9.0 सॉफ़्टवेयर का उपयोग करके ठोस गुड़ पर खाद्य कोटिंग के आवेदन के अनुकूलन के लिए प्रक्रिया मापदंडों का निर्धारण किया गया था। संख्यात्मक अनुकूलन के परिणाम बताते हैं कि तापमान के लिए 25 ^{0} सी, 0.1%, 0.5% और मट्ठा प्रोटीन कॉन्ट्रैक्ट (यानी खाद्य कोटिंग 1) के संयुक्त स्तर पर मस्त गुड़ पर खाद्य कोटिंग के आवेदन से समग्र इष्टतम क्षेत्र को प्राप्त करने की भविष्यवाणी की गई थी, पानी की गतिविधि, कोटिंग एकाग्रता और खाद्य कोटिंग, क्रमशः सतह भूखंडों और प्रतिक्रिया अनुकूलक द्वारा 0.884% की वांछनीयता के साथ।

गन्ने के गूदा के नमूने (25 ग्रा) खाद्य कोटिंग (0.5% WPC और 0.5% गम अरबी) की अनुकूलित एकाग्रता के साथ लेपित थे और एलडीपीई, एचडीपीई और पीपी पाउच में रखा गया था जिसमें नौ पाउच (तीन एलडीपीई पाउच, तीन एचडीपीई और तीन पीपी पाउच) एमएपी मशीन के साथ नमूने का महत्वपूर्ण भौतिक-रासायनिक विशेषताओं, जैसे सूक्रोज, शर्करा, रंग, कठोरता और नमी सामग्री को कम करने के लिए विश्लेषण किया गया था। संवेदी मापदंडों अर्थात, फजी लॉजिक कॉम्पेन्सि मॉडल का उपयोग करके, रंग, मिठास, स्वाद और बनावट / उपस्थिति का विश्लेषण किया गया है। वैक्यूम के तहत पीपी पैकेट में संग्रहीत मट्ठा प्रोटीन युक्त ठोस गुड़ बेहतर था, शर्करा को कम करने और शराब को कम करने में कम वृद्धि, एलडीपीई में नमूनों के मुकाबले एचडीपीई, वैक्यूम के तहत एचडीपीई और भंडारण तापमान पर एमएपी 25 डिग्री सेल्सियस।

खाद्य पदार्थ कोटिंग के अनुकूलित एकाग्रता (प्रोटीन (डब्ल्यूपीसी) की 0.5% एकाग्रता और पॉलीसेकेराइड (गम अरबी) आधारित) एलडीपीई, एचडीपीई और पीपी पाउच में वैक्यूम के साथ गन्ने के ठोस गूंध के नमूने (50 ग्राम) के लिए त्वरित भंडारण अध्ययन किया गया। और मैप पैकिंग और इन सभी पाउच को 90% आरएच पर डिसेकेटर में रखा गया था और यह डिसेकेटर को 45^0 सी पर इनक्यूबेटर में रखा गया था। अधिकतम पूर्वानुमानित भंडारण जीवन अर्थात वैक्यूम पैकेजिंग मशीन के साथ एलडीपीई में पैक किए गए 0.5% WPC खाद्य लेपित ठोस गुड़ में 255.44 दिन प्राप्त किए गए थे।

CHAPTER-I

INTRODUCTION

Sugarcane, *Saccharum officinarum* L., belongs to the Andropogonae tribe of the family Gramineae. It is a perennial plant which can grow up to 4-25 m. The names sugar and sugar cane have been derived from the Sanskrit word, *Sharkara*. It was first grown in South East Asia and Western India.

It is a tropical crop requiring a hot climate. However, it also grows well in a subtropical climate. It has wider adaptability and grows well where the temperature ranges between 20 and 35°C. It responds well to a long period of sunlight (12 to 14 hours). It requires high humidity (80-85%) and rainfall (1100- 1500 mm) during its vegetative growth followed by need for a dry ripening period.

Worldwide sugarcane occupies an area of 20.42 million ha with a total production of 1.81 billion tonnes. At present, 115 countries of the world cultivate sugarcane for sugar production and produce about 133 million tonnes of sugar which is three fourth of the total sugar production (169 million tonnes) of the world. Brazil has the highest area (5.343 million ha), while Australia has the highest productivity (85.1 tonnes/ha). Out of the total white crystal sugar production, approximately 70% comes from sugarcane and 30% from sugar beet.

In India, the states of Maharashtra, Uttar Pradesh, Punjab, and Bihar produce the maximum quantity of sugarcane. An annual produce of 341,400 thousand metric tonne was estimated in the year 2015. Sugarcane is cultivated for the production of crystal sugar, jaggery (Gur), and numerous alcoholic beverages. It is not, however, any wonder that India is one of the largest exporters of sugar worldwide. It is estimated that the nation's sugarcane industry provides employment for more than 6 million Indians. The country exports sugar to Sri Lanka, Bangladesh, Somalia, Sudan Indonesia and the United Arab Emirates. India’s sugar export to Iran is declining, however, especially over the past few years.

Jaggery is a traditional unrefined non-centrifugal sugar consumed in Asia, Africa, Latin America and the Caribbean. It is sticky and brown in colour and is considered a specialty sugar because of its inherent taste and aroma due to high molasses content. Containing all the minerals and vitamins present in sugarcane juice, it is known as healthiest sugar in the world. India is the largest producer and consumer of jaggery. Out of total world production, more than 70% is produced in India. It is consumed in almost all sections of the society as a sweetener, and as a source of energy. It is also used in animal feed mixtures (Guilbert *et al*., 1996).

Since a long, it has been used as blood purifier and base material for syrups. Jaggery is among major agro processing industries in India. Nearly 20-30% of total sugarcane produced in the country is used for manufacture of about 7 million tones jaggery, which is known as most nutritious agent among all sweeteners. This sector provides employment to about 2.5 million people (cooperative sugar).

Jaggery, a product of sugarcane, is rich in important minerals (*viz.*, calcium-40-100 mg, magnesium-70-90 mg, potassium-1056 mg, phosphorus-20-90 mg, sodium-19-30 mg, iron-10-13 mg, manganese-0.2-0.5 mg, zinc-0.2- 0.4 mg, copper-0.1-0.9 mg, and chloride-5.3 mg per 100 g of jaggery), vitamins (*viz*., vitamin A-3.8 mg, vitamin B1-0.01 mg, vitamin B2-0.06 mg, vitamin B5-0.01 mg, vitamin B6-0.01 mg, vitamin C-7.00 mg, vitamin D2-6.50 mg, vitamin E-111.30 mg, vitamin PP-7.00 mg), and protein-280 mg per 100 g of jaggery, which can be made available to the masses to mitigate the problems of mal nutrition and under nutrition (Singh *et al*., 2011).

Jaggery preparation involves extraction of juice from sugarcane, removal of lighter fraction comprising wax, carbon, undesirable solid particles and mud etc. by settling, followed by open pan boiling with added clarificant and removal of scum. Boiling is continued for 2 to 2.5 hours till the juice attains a temperature of 118°C. As soon as the juice attains a temperature of 118°C, properly concentrated juice is taken out of fire and is allowed for natural cooling with continuous stirring. For solidification the contents are transferred to wooden or aluminum moulds or earthenware pots. The shape of solid jaggery may vary from small round balls to large lumps. These are rectangular (250 g- 1 kg), bucket shaped (10-20 kg) and trapezoidal lumps (5 kg), etc. After solidification the moisture content of solid jaggery reduces to 10-12% (db.). In India, jaggery is mainly produced in the month of November to April and stored (Uppal and Sharma, 1999). Cold storage godown is being used in west Godavari and Vishakhapatnam districts of Andhra Pradesh, Kolhapur district of Maharashtra and Muzaffarnagar area of Uttar Pradesh (Jagannadha Rao *et al*., 2007).

Jaggery is packaged traditionally under different packaging materials like paddy straw, banana leaves, gunny bag, polythene sheet, etc., which possess poor barrier properties against moisture, light, air, etc., leading to spoilage or deterioration of jaggery quality. It has been reported that more than 10% of jaggery produced in the country, worth Rs. 40 crore, is lost every year due to product deterioration (Mandal *et al*., 2006). However none of these are completely satisfactory for preserving jaggery in good conditions particularly during the wet and humid monsoon conditions.

Application of edible films on the food products could also be used as a protective coating to extend the shelf life. An edible film coating is a thin continuous layer of edible material formed on or placed between food and food components (Guilbert *et al*., 1996). Edible film/coating has been successfully used in various food applications e.g. in maintaining purity of fruits, providing functionality (e.g. glaze to chocolate), controlling adhesion, cohesion, barrier properties, extending shelf life and providing mechanical integrity, etc. to the product. Whey protein concentrate (WPC) based films and coatings are generally made from water based materials and are flavourless, tasteless and flexible. Edible films and coatings may extend the shelf life of jaggery by providing a semi-permeable barrier to gases and water vapour. This barrier would reduce diffusion of gases, enzymatic browning and the loss of water from the product. However this technology is not developed for protection of jaggery from spoilage due to lack of detailed study.

Hence, it is essential to carryout research work to improve the quality of jaggery during storage. Hence, keeping above points in mind the present research entitled, "Evaluation on edible coatings and packaging methods on storage of solid jaggery" has been undertaken with the following objectives

1. To identify suitable protein and polysaccharide based edible coatings to improve the shelf life of the jaggery.
2. To study the effect of edible coating at different concentrations on quality characteristics of jaggery during storage and its optimization.
3. To identify suitable packaging method (Vacuum or MAP) and packaging materials (LDPE, HDPE and Polypropylene) for the storage of jaggery with optimized concentration of edible coating.
4. To work out the cost-economics of the edible coating over jaggery.

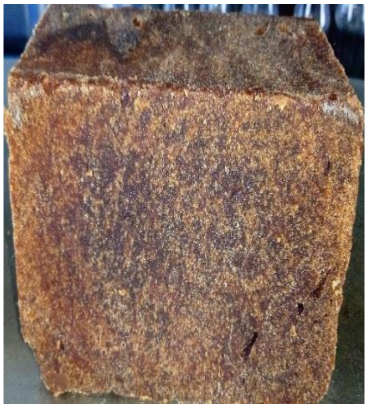
CHAPTER-II

REVIEW OF LITERATURE

Jaggery is a globally known concentrated sugar rich commercial product. It is traditionally manufactured from various juices by careful evaporation to get product of desirable quality. Various changes in properties occur during this process of preparation which has direct bearing to the quality of the final product. Edible coatings of food materials have been studied for their ability to provide a barrier to mass transfer of moisture and gases and to improve mechanical integrity of foods. Controlling oxygen and carbon dioxide transfer in and out of the product can extend the shelf life of food products. The solid jaggery made from sugarcane juice needs to be handled, packed and stored appropriately for which knowledge on physical and chemical properties of jaggery or sugar rich materials, such as moisture content, water activity, hardness, colour, sucrose, reducing sugars, sorption isotherm including their inter-relation and inter-dependence, are very helpful. Information obtained from published literature on different aspects of jaggery making process, various properties related to processing, handling, storage, preservation and quality of solid jaggery have been reviewed in this chapter.

2.1 Different Forms of Jaggery

Sugarcane jaggery is available in the market mainly in three forms namely solid jaggery, liquid jaggery and granular jaggery (Plate 2.1). Of the total production of jaggery in India, approximately 80% of the jaggery is prepared in the solid form and the remaining 20% is prepared in solid as well as granular form. Liquid jaggery is a part of diet in most parts of Maharashtra and West Bengal and is gaining commercial importance. The liquid jaggery is being utilized as sweetening agent in foods and drinks in Maharashtra, Gujarat, Kerala, Andhra Pradesh, West Bengal and Tamil Nadu. Also it is being used in pharmaceutical formulations. The granular jaggery is also popular particularly among rural masses (Jagannadha rao *et al.*, 2007).



2.1(a) Solid jaggery

2.1(b) Liquid jaggery

2.1(c) Granular jaggery

Plate 2.1: Forms of sugarcane jaggery

2.2 Composition of Jaggery

Cane sugar contains various types of carbohydrates like glucose, fructose, galactose, ribose and sucrose. Sucrose is further converted into glucose which provides energy to the body. Jaggery is a natural sweetener made from sugarcane juice simply by evaporation. It contains an enormous wealth of minerals, protein, vitamins and useful sugars (Makde, 2006). The nutritive value of jaggery and khandsari as compared to sugar is presented in Table 2.1

Table 2.1: Nutritive value of jaggery, khandsari and sugar per 100 g

S.No.	Particulars	Jaggery	Khandsari		
			Sulphur Process	Non-sulphur Process	Sugar
1	Sucrose, g	65-85	97.5	96.0	99.5
2	Reducing sugars, g	10-15	-	-	-
3	Proteins, g	0.4	-	-	-
4	Fats, g	0.1	-	-	-
5	Total Minerals	0.6-1.0	0.05	0.2	0.05
	Calcium, mg	8.0	100	100	-
	Phosphorus, mg	4.0	-	-	-
	Iron, mg	11	-	-	-
6	Moisture, g	3-10	0.3	0.5	0.2-0.4
7	Energy, Kcal	383	395	388	398

Source: Jaswanth singh (1998)

Khandsari owing to only a thin film of molasses coating on sugar crystal contains lower quantity of such ingredients, daily use of jaggery may increase human life span (Kumar, 1999). Incidence of less diabetes is reported in jaggery consuming areas compared to sugar consuming areas. (Singh, 1998). Sugar needs extra heat for digestion. It takes calcium and potassium from the body without which it just cannot be digested.

2.3 Manufacturing Process of Various Jaggery

2.3.1 Raw materials

Sugarcane is the major raw material for making jaggery. Besides sugarcane juice, jaggery is also made from other sources, like sap collected from various palm trees that contains around 10-12% total sugars; mainly comprised of sucrose along with small amount of reducing sugars, and other minerals and vitamins (Dalibard, 1999; Jagannadha Rao *et al*., 2009).

2.3.1.1 Sugarcane

Plate 2.2 shows the major sugarcane growing areas in India. Among different sugarcane varieties in India, the most important varieties for jaggery making are Bo 91, CoC 671, CoJ 64, S 362/95, CoP 211, Co 7602, Co 7706, Co 62175, Co 99006, Co 99004, Co 85 A 298, CoJ 8201, CoLK 8102, CoS 767, 87 A 298, 85 A 261, 93 A 145, and CoG 95077 (Singh, 2002). Cuban variety like C374-72 (Rimyantseva and Zhbankov, 1992) and Argentina varieties like Tuc 77-42 and CP 65-350 (Carrizo de Bellone and Bellone, 2006) are reported for making jaggery in these countries. Uppal *et al*. (2005) studied sixteen Indian varieties of sugarcane for quality and storage of jaggery obtained from them. According to them, quality of juice is best at the end of February because of high sucrose content (>17%) and purity (>84%) and less reducing sugar content (<0.29%), which are considered to be best for quality jaggery production. They also reported that varieties like, CoJ 64, CoJ 82, CoJ 88, S 362/95 and CoP 211 could be used to produce high quality jaggery having light golden yellow colour, and they do not require any clarificant during the process. Sugarcane varieties CoS-767, Co-1148, Co-66-17, Co-00421 found suitable for jaggery making in Rajasthan (Nath *et al.*, 2015).

(Source: Directorate of Economics and Statistics, Ministry of Agriculture)

Plate 2.2: Major sugarcane growing areas in India

2.3.2 Processing steps for making solid jaggery

2.3.2.1 Extraction or collection of juice

Juice extraction is the first operation in jaggery manufacture. The juice is extracted from sugarcane using a simple mechanical device, popularly known as crusher. It consisted of three rollers oriented either in vertical or horizontal position. The cane is fed to the crusher (Plate 2.3 a) and the expelled juice is collected into a masonry settling tank to separate suspended particles. The clear juice is drawn off from the tank, then filtered with muslin cloth and transferred to the boiling pan.

2.3(a) Crushing of sugarcane in the horizantal crusher

2.3(b) Collectinon of sugarcane juice

2.3(c) Filtration of juice in the filtration equipment

Plate 2.3: Extraction of juice from sugarcane and filtration of juice

2.3.2.2 Juice boiling and concentration

Juice boiling is the second step in preparation of jaggery. As the dilute juice (TSS around 13-17^0 Brix) is highly susceptible to fermentation by wild yeasts converting sugars to alcohol, the boiling process is initiated as quickly as possible (Kamble, 2003). The main objective of boiling is to concentrate the juice to make thick syrup (semi solid form) or solid form to increase its shelf life. During this process, several physical and chemical changes occur, which are closely monitored by the skilled workers. Over-heating may lead to dark colour product with bitter taste. Boiling is usually carried out in a pan made with mild steel, galvanized iron or aluminum sheet (Plate 2.4) and traditional furnace (Plate 2.5).

Plate 2.4: Sugarcane juice boiling in mild steel pan

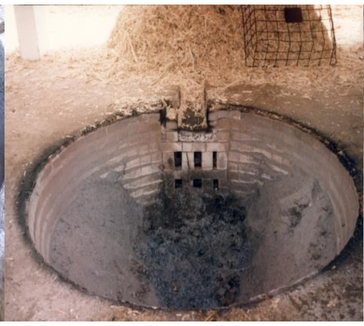


Plate 2.5: Traditional furnace for sugarcane jaggery

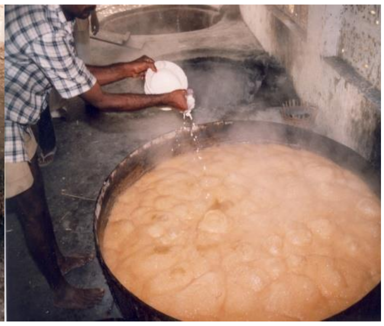


Plate 2.6: Lime Addition During Juice Boiling

Further clarification of juice during boiling is accomplished by adding lime [$Ca(OH)_2$] (Plate 2.6) that acts as a complexing agent and forms scum. The scum is periodically removed. Addition of lime simultaneously increases the pH of fresh juice i.e., from 5.2 - 5.4 (which depend on harvesting status, variety of cane and soil condition) to around 6.0 to 6.4. While preparation of jaggery from over-matured canes (in which sucrose content is low and decreases due to inversion), addition of lime improves the consistency of jaggery.

2.3.2.3 Cooling and moulding

Concentrated and caramelized hot syrup (liquid mass) is transferred into wooden or aluminium moulds (Plate 2.7), allowed to cool and finally it is solidified. The moisture content of solid jaggery remains within 10-12% (db.). About 10 to 12 kg of jaggery is obtained from 100 kg of sugarcane juice (Jadhav *et al*., 1999) while it is 13 to 14 kg from both the palm juices (Jagannadha Rao *et al*., 2006).

2.7(a) Sugarcane jaggery in wooden moulds | **2.7(b) Sugarcane jaggery in aluminium moulds** | **2.7(b) 1x1" (25 g) jaggery in aluminium moulds**

Plate 2.7: Moulds for jaggery making
(Source: Jagannadha Rao *et al*., 2007)

2.4. Storage of Jaggery

Storage of jaggery varies from region to region to protect the jaggery from ambient humidity. In respect of the shape and size, jaggery deteriorates fast and become watery within 3 or 4 months because of presence of moisture, invert sugar and its hygroscopic nature arises from non-sucrose constituents like glucose, fructose, protein etc. Further reported that for good keeping quality, moisture content of jaggery should not exceed 6% and it should be kept at a relative humidity of 43–61%. Cold storage godowns are being used in West Godavari and Visakhapatnam districts of Andhra Pradesh, Kolhapur district of Maharashtra and Muzaffarnagar area of Uttar Pradesh (Jagannadha Rao *et al*., 2007).

Karen *et al*. (2013) studied the quality evaluation of Muscovado in various packaging materials (LDPE, HDPE, Plastic, Glass containers, aluminium pouch) at different storage time. Muscovado is a nutritious sugar brown in colour, coarser and stickier texture, distinct taste and highly prized. The results revealed that standard plate count (SPC), mold and yeast count was steadily increased at 21 days after processing until 42^{nd} day and slowly declined until the 84^{th} day. Of the physic-chemical properties, only sucrose content was decreased with storage time. Moisture content, water activity and safety factor increased with storage time. The results also indicated that, glass container, aluminium pouch and HDPE plastic are appropriate muscovado packaging material. However flexible packaging material with combined properties of aluminium pouch and HDPE plastic is recommended.

Singh and Kulshrestha (2008) studied the jaggery storage behaviour with respect to ambient temperature and relative humidity (23.8 ±1°C and 84.7%) conditions for storage in various containers (Polythene Bag, IISR bin and open bag). Results showed that the overall quality of the jaggery in the stored IISR bin was better for 5 months when compared with open and polythene bag storage.

Jagannadha Rao *et al*. (2007) had studied storage of jaggery varies from region to region such as in earthen pots, wooden boxes, metal drums etc. sometimes, without any container, heap of jaggery is just kept covered with cane trash, bagasse, wheat straw, cotton seed, furnace ash, rice husk etc. to protect the jaggery from ambient humidity. Jaggery deteriorates fast and become watery within 3 or 4 months because of presence of moisture, invert sugar and its hygroscopic nature. The hygroscopicity arises from non- sucrose constituents like glucose, fructose, protein, etc. for keeping good quality, moisture content of jaggery should not exceed 6% and be kept at a relative humidity of 43- 61%. It was very difficult to stored jaggery during monsoon, especially in coastal areas of high rainfall and humidity. It was estimated that about 5-10% of stored jaggery get spoil every year.

Ramya *et al*. (2007) assessed the storage quality of commercially available jaggery with different packaging materials and reported that there was an increase in moisture content, reducing sugar and change in colour in jaggery packaged in polyethylene and jute bags. Storage containers of food grade polyethylene proved to be better for storage of jaggery without affecting the quality of jaggery.

Mandal *et al.* (2006) revealed that the best packing material for storing gur during monsoon season was heat-sealed LDPE (Low Density Polyethylene) of 150 gauge followed by glass jars. LDPE packets prevented moisture ingress, fall in pH value and inversion of sucrose in the stored gur to the maximum extent. However, colour of gur packed in LDPE was darker as compared to gur stored in glass jars. So among the packing materials heat sealed LDPE packets of 150 gauge was best in checking ingress of moisture during the monsoon.

Kumar (2003) had reported sweets based on jaggery and sugar like Sohan papri normally has a short storage life of 10 to 12 days as the critical moisture content is 3% with equilibrium relative humidity of 30%. In order to extend the shelf-life, product treated with an antioxidant butylated hydroxyl anisole (BHA) was packed in pouches made of HDPE (75 micron), PET/LDPE, paper/foil/PE and tinplate containers with nitrogen packing. Analysis for chemical and sensory parameters have indicated that the product could be stored for 30 days was PET laminate, 120 days in HDPE and more than 7 months in rigid container . It has also been found that vacuum packaging have shelf-life of 12 months. Moisture sorption studies on sugar/jaggery based gajak and rewri have indicated a critical moisture content of 4 percent for the former and 3.5% for the latter, whereas the packaging and storage studies on these products have indicated varying shelf-life at 27-30°C and 65% RH.

Uppal (2002) had conducted tests at different storage periods at low temperature (7°C - 9°C) to study the shelf life of jaggery. With increase in storage time, there was decrease in quality of Jaggery but there was complete check of microbial growth till storage period of 2 years 8 months with some changes in physicochemical characteristics and visual observations. But storage of Jaggery up to 1 year 8 months was very safe with no changes in quality.

Singh (1996) had studied at normal ambient temperature, good quality jaggery can withstand atmospheric relative humidity up to 65% and poor quality jaggery up to 50%. Thus, majority of jaggery can be safely stored up to 50% relative humidity, but protection against moisture migration is required over 65% R.H. the ordinary earthen pots, which have been very common in use in rural areas, were painted from inside as well as outside and storage studies were conducted to overcome the problem of moisture migration. The jaggery stored in pot remained hard and dry even during moisture migration.

High moisture content invites microbial contamination (Singh *et al*. 2009). It has been estimated that more than 10 % of gur produced in the country worth Rs. 40 crore is lost every year due to these problems. Browning of jaggery is a major problem for the jaggery industry.

Anwar *et al*. (1994) studied the jaggery packaged in different packaging material like polyethylene, perforated polyethylene, cellophane paper, The results indicated that moisture loss was almost equal in jaggery packaged in perforated polyethylene and unpacked control followed by cellophane paper and polythene without perforation.

Saxena *et al*. (1991) had studied the storage behaviour and packaging studies of inderse - an Indian traditional sweet. It was found that, the samples stored well upto 45 days in LDPE (150 gauge) and polypropylene (120 gauge) without affecting the quality characteristics significantly at room temperature (30±5°C).

Khanna and Chakravarti (1948) conducted studies on storage of jaggery and reported that there was more than 10% loss in sucrose, 50% increase in acidity, 2% increase in the moisture content and 20 to 30% increase in the total colour change in the jaggery stored in open atmosphere between August and October months compared to jaggery stored under closed condition inside the blankets.

2.5 Moisture Sorption Isotherms (MSI) of High Sugar Foods

Moisture sorption characteristics provide the necessary information regarding quality, stability and shelf life during packaging and storage of dried foods (Ayranci *et al.,* 1990; Vilades *et al*., 1995). Hygroscopic nature of jaggery granulated product initiate caking and follows deterioration by mould and yeast. Knowledge of moisture sorption isotherms of granulated jaggery products at different storage temperatures could be a useful tool for its handling, storage and packaging system design and drying (Van den Berg, 1984). The effect of moisture adsorption on storage quality of solid form of sugarcane jaggery under different agro-climatic regions was investigated by Sastry *et al*. (1965). The moisture adsorption isotherms of solid sugarcane jaggery have been reported by Verma and Narain (1990). They observed that, increase in both temperature and relative humidity increased the equilibrium moisture content of the jaggery. Various workers have reported sorption behaviour of sugar rich foods like sugar beet root (Iglesias *et al*., 1975), sultana raisins (Saravacos *et al*., 1986), dried fruits (Tsami *et al*., 1990; Ayranci *et al*., 1990), date paste (Alhamdan and Hassan, 1999), and they have adopted various sorption models to explain the experimental data.

Bellagha1 *et al*. (2008) conducted experiment for determination of the desorption isotherms of fresh and osmotically dehydrated apples at different sugar concentrations (0%, 30% and 40% w/w) was conducted. A static gravimetric method, based on the use of 9 saturated salts solutions was used to determine the sorption isotherms of fresh apple and apple subjected to osmo-dehydration processes in sucrose syrup solution at 30% and 40% concentration and at three different temperatures: 30, 40 and 50°C. The sorption isotherms of fresh apples show a type II sigmoid shape. The activity water above 0.6 and at constant relative humidity, an increase of temperature decreases relative humidity. However, in the water activity below 0.6, temperature effect seems to be negligible. Several models were adjusted to the experimental sorption data and the GAB equation gave the best fit. Sorption isotherms curves of osmotically dehydrated apples showed the same shape and for a constant water activity the equilibrium water content decreased with increasing sugar concentration. Thus, for 40%, sucrose solution, the equilibrium water content is lower for the same equilibrium RH.

Singh and Kulshrestha (2008) studied the Jaggery storage behaviour with respect to ambient temperature and relative humidity (23.8±1°C and 84.7%) conditions for storage in various containers (Polythene Bag, IISR bin and open bag). Results showed that the overall quality of the jaggery in the stored IISR bin was better for 5 months when compared with open and polythene bag storage.

Chirife and Iglesias (1978) applied their model for sorption data of nine high sugar fresh fruits, predominantly containing reducing sugars (glucose and fructose).

For dried apricot, fig and raisin, Ayranci *et al*. (1990) found Halsey equation was a better fit than the Iglesias and Chirife equation. Verma and Narain (1990) observed that, Smith model explain well their experimental data.

Labuza (1985) had studied the shelf life testing procedures are becoming more and more a standard practice that is used to estimate the quality and stability and stability of a given food during its storage and transportation. Depending on the product nature, various properties or quality indices must be experimentally followed as a function of time in order to evaluate the degradation of the product quality in terms of the sensory, microbiological and physicochemical properties. In order to fully account for all the degradation criteria, a well-planned experimental investigation and analysis must be adopted.

2.6 Edible Coatings

Application of edible films or coating was done to protect the food from microbial decay. An ideal edible coating is the one that can extend storage life of fresh fruits and vegetables without causing anaerobiosis and reduces decay without affecting their quality (Akthar *et al*., 2015) or it is the thin layer of material which can be consumed and provide a barrier to oxygen, microbes of external source, moisture and solute movement for food (Baldwin, 1996; Park, 1999).

Edible coatings are used for extension of shelf life of fruits and vegetables and are environment friendly. These can also be safely eaten as part of the product and do not add unfavorable properties to the foodstuff (Baldwin *et al*., 1994). Edible coatings can enhance the shelf life of food products by reduction of moisture loss solute migration, gas exchange and reduction of physiological disorders. Also, edible coatings have high potential to control browning, discolour activity, off flavour, microbial activity and can extend shelf life (preethisukla, 2012; Dhall *et al*., 2013).

2.6.1 History of edible coatings

Edible coatings or edible films have been used for centuries in the food industry to preserve food products. This is not a new preservation technique. Wax was the first edible coating used on fruits. The Chinese applied wax coatings to oranges and lemons in the 12th and 13th centuries (Hardenburg, 1967).

2.6.2 Characteristics of edible coatings

Characteristics of edible coatings are based on their molecular structure, molecular size and its chemical composition (Arvanitoyanni and Gorris, 1999). A good edible coating should contain no toxic, allergic and non-digestible components, provide structural stability and prevent mechanical damage during handling, control water migration both in and out of protected food to maintain desired moisture content, provide semi-permeability to maintain internal equilibrium of gases involved in aerobic and anaerobic respiration, thus retarding senescence, prevent loss or uptake of components that stabilize aroma, flavor, nutritional and organoleptic characteristics necessary for consumer acceptance while not inversely altering the taste or appearance, provide biochemical and microbial surface stability while protecting against contamination, pest infestation, microbe proliferation, and other types of decay (Akthar, 2015).

2.6.3 Advantages and disadvantages of edible coatings

The advantages of edible coatings are to reduce weight loss and firmness loss, decrease polymer packaging and waste, improve retention of acids, colour, flavour and sugar, maintain quality of fruits and vegetables during storage, and consumed along with fruits and vegetables, they contain health beneficial nutrients (Guilbert and Biquet, 1996; Park, 1999). The disadvantages are edible coatings have good gas barrier properties which causes anaerobic respiration due to which normal ripening process is disturbed in fruits and vegetables, thick coating can prohibit oxygen exchange, causes off- flavour development and some edible coatings are hygroscopic in nature, which helps to increase microbial growth (Park *et al*., 1994; Ghaouth, 1991).

2.6.4 Types of edible coatings

Edible coating materials are generally made up of polysaccharides, proteins and lipids (Pascall and Lin, 2013). The edible coatings are mainly divided into three classes i.e., Hydrocolloids: e.g., polysaccharides, proteins and alginate; Lipids: e.g., fatty acids, acryl glycerides; Waxes and Composites: e.g., protein/protein, polysaccharides/protein, lipid/polysaccharides (Donhowe and Fennema, 1993; Pramod *et al*., 2016).

2.6.4.1 Protein based edible coatings

Protein based edible coatings are derived from animals and plants (Pramod *et al.*, 2016). The plant based protein edible coating material are milk protein casein, whey protein, zein (from maize), gluten (from wheat), soy protein etc. and the animal based protein are egg albumen, collagen etc., (Baldwin, 1995).

2.6.4.1.1 Whey protein

Whey protein is a byproduct from the cheese production and is particularly rich in *β*-lactoglobulin. Whey proteins (20% of total milk proteins) when appropriately processed produce flexible but brittle films (Kaya and Kaya, 2000). It is used as a food supplement, as an alternative to milk for people with lactose intolerance, for replacing or supplementing milk-based infant formulas. Whey protein concentrate coating in combination with antibrowning agents effectively prolonged the shelf-life of minimally processed apple slices by two weeks when stored in packed trays at 3ºC (Lee *et al.*, 2003; Perez Gago *et al.*, 2005).

2.6.4.1.2 Gelatine

Gelatine is a protein made from animal products. It is an important biopolymer derived from collagen and is extensively used by various industries because of its technological and functional properties. Gelatine is used for weight loss and for treating osteoarthritis, rheumatoid arthritis, and brittle bones (osteoporosis) and it is used for strengthening bones, joints, and fingernails. Also, it is used for improving hair quality and to shorten recovery after exercise and sports-related injury (Anonymous, 2016). The use of gelatin in the formation of films or coatings has been investigated by different authors on fruits and vegetables like carrots (Wang *et al.*, 2015), cherry tomatoes (Zhang *et al.*, 2016), oranges (Youssef *et al.*, 2015), strawberries (Fakhouri *et al.*, 2014), blueberry fruit (Feng *et al.*, 2014) and pineapple fruit (Bizura Hasida *et al.*, 2013).

2.6.4.1.3 Corn zein

Corn zein protein is effective to prevent colour change, firmness, weight loss and to increase the shelf life of fruits and vegetables. It has good barrier property to O_2. Corn zein coatings and films have excellent barrier property to water vapour; about 800 times higher than other edible coatings and wrapping films. All properties of zein coatings depend upon coating thickness (Park *et al.*, 1994).

Park *et al.* (1994) revealed that corn- zein film delayed colour changes, reduced weight loss, inhibited ethanol production, delayed ripening, and reduced firmness loss of tomatoes. The degree of colour change was mainly dependent on the thickness of coating.

2.6.4.1.4 Wheat gluten

Wheat gluten is composed mainly of gliadins and glutenins (alkali- and acid-soluble) fractions. Gliadin, the viscous component, constitutes a heterogeneous protein group characterized by single polypeptide chains associated by hydrogen bonding and hydrophobic interactions, having intramolecular disulfide bonds. Glutenins form an extensive network of intermolecular disulfide bonds (Hernandez-Munoz *et al*., 2003). Strawberries with gluten coatings presented lower weight loss and softening when compared to uncoated ones (Tanada Palmu and Grosso, 2005).

2.6.4.1.5 Soya protein

Most of the protein in soybeans is insoluble in water but soluble in dilute neutral salt solutions. Edible films based on soya protein can be produced in either of two ways: surface film formation on heated soymilk or film formation from solutions of soy protein isolate (SPI) (Gennadios and Weller, 1992). The use of soya protein in the formation of films or coatings on food products has been investigated by different authors (Baker *et al*., 1994; Gennadios *et al*., 1994; Stuchell and Krochta, 1994; Kunte *et al*., 1997; Rhim *et al*., 2000).

2.6.4.2 Polysaccharide based edible coating

The most common polysaccharides used for edible coating of fruits and vegetables are starch, alginate, chitosan, cellulose, pullulan, carrageenan, gellan gum etc., (Han and Gennodios, 2005). Polysaccharides based edible coatings having poor moisture barrier properties and water soluble (Baiand Plotto, 2012).

2.6.4.2.1 Starches

Starches are polymers of d-glucopyranosyl, consisting of a mixture of the predominantly linear amylose and the highly branched amylopectin (Kramer, 2009). Application of starch films is limited by two major drawbacks. The films are often very brittle, requiring the presence of plasticizers to improve their flexibility (Peressini *et al*., 2003; Mali *et al*., 2004). Moreover, the high hydrophilicity of starch causes its barrier properties to decrease with increasing relative humidity; therefore, starch is not the best option when working with minimally processed fruits (Olivas and Barbosa Canovas, 2009).

Ariane *et al*. (2012) studied the effect of the three different levels of and carboxymethyl starch (1, 3, and 5%) on sensory characteristics of papayas during storage. The results indicated that the 3 and 5% cassava starch coating gave greater brightness to the fruits. 5% CMS favored the presence of fungi and damaged the fruit surface at the 14^{th} day of storage.

Fakhouri *et al*. (2007) evaluated the effect of the association of gelatin with suspensions of wheat native starch, sorghum, and potato on crimson grapes. The results for overall appearance, color, brightness and intention of purchase of the fruits with coating were higher in relation to the control (without coating).

2.6.4.2.2 Alginates

Alginates, which are extracted from brown seaweeds, are salts of alginic acid, a linear copolymer of d-mannuronic and l-guluronic acid monomers. Films can be formed either from evaporating water from an alginate gel or by a two-step procedure involving drying of alginate solution followed by treatment with a calcium salt solution to induce cross-linking (Janjarasskul and Krochta, 2010). The strength and permeability of films may be altered by changing calcium concentration and temperature, among other factors (Kester and Fennema, 1986). Alginate based edible coating used on fresh-cut papaya pieces exhibited slightly improved water barrier properties for both types of coatings, as compared to the uncoated samples (Tapia *et al.,* 2008).

2.6.4.2.3 Chitosan

Chitosan, a linear polysaccharide consisting of β (1→4) linked residues of *N*-acetyl-2-amino-2-deoxy-d-glucose (glucosamine) and 2-amino-2-deoxy-d-glucose (*N*-acetyl-glucosamine). Chitosan coatings were effective in extending shelf life of several fruits; reducing rates of water loss (Dong *et al*., 2004; Hernández-Muñoz *et al*., 2006; Chien *et al*., 2007; Lin *et al*., 2011), ascorbic acid loss (Dong *et al*., 2004; Chien *et al*., 2007), softening (Ali *et al*., 2011), and enzymatic browning (Dong *et al*., 2004; Jiang *et al*., 2005); and delaying the ripening process by decreasing respiration rates (Ali *et al*., 2011; Lin *et al*., 2011).

2.6.4.2.4 Cellulose and its derivatives

Together with starch, cellulose and its derivatives (such as ethers and esters) are the most important raw materials for elaboration of edible films (Peressini *et al*., 2003). Cellulose, the most abundant natural polymer on earth, is an essentially linear natural polymer of (1→4)-β-d-glucopyranosyl units. Methyl cellulose based coatings lower the water loss rate of fresh apricots and green peppers and inclusion of ascorbic acid or citric acid in the coating formulation as antioxidants lower the vitamin C loss (Ayranci and Tunc, 2004).

Avocados coated with methyl cellulose based coating demonstrates lower respiration rates, greener color and higher firmness as compared with the uncoated control during the entire storage (Maftoonazad and Ramaswamy, 2005)

2.6.4.2.5 Gums

Almost all gums are polysaccharides, consisting of sugars, which are used for preparation of edible coating on fruits and vegetables because of its texture capability and soluble in water. Generally, gums are divided into three types: (a) exudate gums (e.g., gum arabic), (b) extractive gums (e.g., guar gum) and (c) microbial fermentation gums (e.g., xanthan gum) (Mei *et al*., 2002).

Xanthan gums are prepared by microbial extraction by fermentation process. It is rapidly spread in water due to this high viscosity are found readily in cold and hot both stages. A mixture of gum arabic, guar gum and xanthan gum are used to form equal coatings with good adhesion property in wet batters (Mei *et al*., 2002).

Ali *et al*. (2010) evaluated the performance of a novel coating based on gum arabic on tomato fruits. When compared to uncoated fruits, tomatoes coated with 10% gum arabic resulted in significant lower rates of changes in weight, colour, firmness, titrable acidity, soluble solids content, ascorbic acid content, and decay percentage.

2.6.4.3 Lipid based edible coating

The lipid based edible coatings are being used from many years for preservation of fruits and vegetables. They provide shiny and glossy appearance to food. Lipids are having good water barrier capacity (Morillon *et al*., 2002). Most common lipid based coating materials are waxes, lacs, fatty acids and alcohols, acetylated glycerides and cocoa-based material.

2.6.4.3.1 Waxes

Waxes are esters of long-chain aliphatic acids with long-chain aliphatic alcohols (Rhim and Shellhammer, 2005). They are more resistant to water diffusion than most other edible film materials because of their very low content of polar groups (Kester and Fennema, 1986) and their high content in long-chain fatty alcohols and alkanes (Morillon *et al*., 2002). Addition of galctomannans in traditional wax based formulation of citrus fruits reduced weight loss of the fruit during respiration in a manner similar to a wax-based coating without gum (Chen and Nussinovitch, 2010).

2.6.4.3.2 Acetylated glycerides

Acetylation of glycerol monosterate by its reaction with acetic anhydride yields 1-stearodiacetin. This acetylated monoglyceride displays the unique characteristic of solidifying from the molten state into a flexible, wax-like solid (Feuge *et al*., 1953).Most lipids in the solid state can be stretched to only about 102% of their original length before fracturing. Acetylated glycerol monostearate, however, can be stretched up to 800% of its original length (Jackson and Lutton, 1952), water vapor permeability of this film is much less than that of polysaccharide films with the exception of methyl cellulose or ethyl cellulose (Kester and Fennema, 1986).

A film formed by milk protein (casein) and lipid (acetylated monoglyceride) for lightly processed apples and potatoes was reported to provide protection from moisture loss and oxidative browning for up to three days (Baldwin *et al.,* 1995).

2.6.4.4 Composite films

Composites or multicomponent films and coatings contain combination of protein, polysaccharides and lipid based material. Edible films and coatings may be heterogeneous in nature, consisting of a blend of polysaccharides, protein, and/or lipids. This approach enables one to utilize the distinct functional characteristics of each class of film former (Kester and Fennema, 1986). The main objective of producing composite films is to improve the permeability or mechanical properties as dictated by the need of a specific application (Bourtoom, 2008). The combination of gelatine with other biopolymers with different characteristics, such as whey proteins (Taylor *et al*., 2014), starch (Fakhouri *et al*., 2015), chitosan (Benbettaieb *et al*., 2016) or pectin (Gupta B *et al*., 2014), could be a good strategy for the development of films with improved mechanical and water resistance properties. A composite coating of WPC protein and rice bran oil with added glycerol as plasticizer effectively preserved the colour, firmness, taste, and the overall acceptability of the fruits during storage (Hassani *et al*., 2012).

Bertan *et al*. (2005) found that composite edible/degradable films produced with hydrocolloids and lipids can result in better functionality than films produced with the components, especially with respect to their barrier properties. Of the lipids, waxes produce the best water vapor barrier properties, but produce fragile/brittle films. Films with the addition of acids, and the blend with elemi presented better water vapor barrier properties as compared to the gelatin/triacetin film. The mechanical resistance decrease with the addition of the lipids. However the opacity and soluble matter increased.

2.6.5 Plasticizers

Plasticizers contain low molecular weight, it is mixed with protein coating material for enhance and change its structural ability (Krochta, 2002; Sothernvit and Krochta, 2005). Water is also natural and effective plasticizer. The most common plasticizers added in coatings are glycerol, fatty acids, sorbitol, propylene glycol, sucrose polyethylene glycol and monoglycerides (Krochta and Johnson, 1997).

2.6.6 Formation of edible coating

As per the requirement, edible coating is dissolved in distilled water and mix thoroughly to form uniform solution. The solution is denatured at 90ºC on water bath for 30 minutes to provide functionality to edible film. The solution is cool down to room temperature in chilled water. 5% glycerol is added to solution as plasticizer and mix thoroughly. Then, the prepared solution is will be again reheated at 50ºC for 10 minutes, then cooled to room temperature (Fig.1) (Mishra *et al*., 2016).

2.6.7 Edible coating application method

Better uniform application of edible coating can be promoted by adding surfactants to solution to reduce surface tension. This strategy helps to reduce the superficial and in turn reduce water loss (Roth and Loncin, 1984). Edible coating should be applied on fruits and vegetables by dipping, brushing, extrusion, spraying and solvent casting.

The dipping method is used widely for applying edible coatings on fruits and vegetables, in this method fruits and vegetables are dipped in coating solution for 5-30 s (Valverde *et al*., 2005). Brushing method gives good result generally, edible Coatings applied on beans and highly perishable fruits and vegetables such as strawberry, berries. Spraying, extrusion and solvent castings are also used in food industry. Extrusion method depends on thermoplastic properties of edible coatings and best technique for applying of edible coating for industrial purpose as compared to other methods (Pramod *et al*., 2016).

2.6.8 Effect of edible coatings on shelf-life of jaggery

Mishra *et al*. (2016) conducted studies on coating composed of carboxymethyl cellulose and whey protein concentrate on the storage characteristics of coated jaggery for 15 weeks, They concluded that coating of jaggery sample could help in retaining the desirable moisture up to some extent and the quality of jaggery could be overcome by applying edible coating based on carboxymethyl cellulose and whey protein concentrate.

Chand *et al*. (2013) studied the effect of edible coating of whey protein concentrate (WPC) on quality characteristics of jaggery stored in drying-cum-storage bin for 4 months and reported that the total effects of edible coating during storage was good in comparison to uncoated jaggery and concluded that edible coating of whey protein concentrate may be helpful in maintaining the quality and enhance the shelf life of jaggery.

Preethi Sukla (2012) studied the effect of whey protein edible coating of jaggery packed under different packaging materials and methods and stored at 30±1 ºC for 18 weeks on quality parameters of jaggery. The results indicated that the absorption of moisture and microbial attack could be overcome by applying protein based edible coating on jaggery, packing it under vacuum and storing it under controlled conditions of temperature and relative humidity.

2.7 Evaluation of Sensory Quality

Sensory evaluation of any developed food product is the ultimate criterion for deciding its acceptance by consumers. Subjective aspect of quality attributes of the dried products are judged by experts through sensory evaluation of the product in terms of its colour, aroma taste and mouth feel (Das, 2005). Fuzzy logic is a tool, which allows to build a numeric-linguistic interface between experts' opinions and numerical data. In statistical analysis of the sensory evaluation data, average scores of attributes are generally calculated and compared with a certain significance level among the samples (Meilgaard *et al*., 1987; Stone and Sidel, 1985). The fuzzy model can be used to determine the importance of individual factors to the overall quality of a product (Zhang and Lichfield, 1991). It is well adapted to take human ambiguous linguistic descriptions (not satisfactory, excellent, fair etc.) and the reasoning into account. Analysis of sensory data by fuzzy logic helps identifying the strong and weak quality attributes of the developed product that influence its final acceptance. Fuzzy reasoning was applied to the sensory evaluation of various products like sausages (Seung and Young, 2007), mango drinks (Jaya and Das, 2003), and cooked rice (Lee *et al*., 1994).

2.8 Accelerated Storage Studies

Accelerated shelf life studies are conducted by changing the storage conditions to hasten the deteriorative processes that occur during storage. In confections, elevated temperatures and humidities are often used to enhance product degradation in accelerated shelf life tests. A product with a one-year shelf life may be evaluated under accelerated storage conditions within perhaps a month in certain circumstances (Ergun *et al*., 2010).

Deepika Devi *et al*. (2016) studied the shelf life of the vacuum puffed honey powder at accelerated storage environment (90% relative humidity and 36°C) by determining the sticky-point moisture content as the critical parameter of the honey powder. Shelf life of the honey powder was predicted to be 222 days when the powder was packaged in aluminium foil-laminated polyethylene pouches with permeability value of $5.427X10^{-8}$ kg/m^2/day/Pa whereas the actual shelf life of honey powder was experimentally determined as 189 days.

Ramachandra and Srinivasa Rao (2011) predicted the shelf-life of the Aloe vera gel powder, produced through dehumidified air drying of Aloe vera gel at optimized conditions of temperature, relative humidity and air velocity of 64°C, 18% and 0.8 m.s^{-1}, respectively, on the basis of free flowness of product under accelerated storage condition (38±1°C, 90± 1% relative humidity) and was calculated to be 33.87, 42.58 and 51.05 days in biaxially oriented polypropylene (BOPP), polypropylene (PP) and laminated aluminum foil (AF), respectively.

Jaya and Das (2005) studied the shelf-life of the Vacuum-dried mango powder was produced from mango pulp. The mango powder was packed in aluminum foil-laminated pouches and stored in an accelerated storage environment maintained at 90% relative humidity (RH) and 38±2C. The sticky-point moisture content at 38±2C was considered as the maximum moisture content to which the mango powder would remain stable. The shelf life of the powder predicted from this consideration and the Guggenheim-Anderson-de Boer (GAB) model for the water activity moisture content relationship was 114.68 days, whereas the actual shelf life was 105 days.

From the foregoing discussion on critical aspects of jaggery making process, storage methods and quality of the final product, the following knowledge gaps have been identified. Considering the above knowledge gaps and the scope exist for further work, the present study has been undertaken with the following objectives:

1. To identify suitable protein and polysaccharide based edible coatings to improve the shelf life of the jaggery.
2. To study the effect of edible coating at different concentrations on quality characteristics of jaggery during storage and its optimization.
3. To identify suitable packaging method (Vaccum or MAP) and packaging materials (LDPE, HDPE and Polypropylene) for the storage of jaggery with optimized concentration of edible coating.
4. To work out the cost-economics of the edible coating over jaggery.

CHAPTER –III

MATERIALS AND METHODS

This chapter deals with raw material and edible coating selection, procurement, procedure to determine moisture sorption isotherms (MSI), modelling and statistical analysis, and procedure to determine packaging of jaggery under vacuum and MAP packaging of jaggery at different storage temperature in low density polyethylene

(LDPE), high density polyethylene (HDPE) and polypropylene (PP). The methodology used for application of edible coating over solid jaggery samples and to determine moisture sorption isotherms, description of the vacuum and MAP packaging machine, methodology to determine the physiochemical characteristics.

3.1 Materials and Equipment

3.1.1 Raw materials

Fresh jaggery, edible coatings i.e. whey protein concentrate (WPC), wheat gluten, gelatin, corn zein and gum arabic, glycerol and packaging material i.e. low density polyethylene, high density polyethylene and polypropylene were the main raw material.

3.1.2 Material source

3.1.2.1 Jaggery

Fresh Jaggery cubes of dimensions 25×25×25 mm moulded by using the metal frame (developed to obtain the jaggery cubes of desired dimension), made from sugarcane juice (variety 93 A 145) at jaggery manufacturing unit situated at RARS, Anakapalle. After manufacturing the solid jaggery cubes, the samples were dried in electric dryer up to the moisture content of the sample reaches to 10% (db.).

3.1.2.2 Edible coatings

The suitable and availability of protein and polysaccharide based edible coatings will be selected to improve the shelf life of jaggery.

3.1.2.2.1 Protein based edible coatings

Whey protein concentrate (WPC), wheat gluten, gelatin and corn zein edible coatings were selected and procured from ideal chemicals, Raipur.

3.1.2.2.2 Polysaccharide based edible coatings

Gum arabic edible coating was selected from polysaccharide based edible coatings and procured from Ideal chemicals, Raipur.

3.1.2.3 Glycerol

Glycerol as plasticizer procured from lotus chemicals, Visakhapatnam.

3.1.2.4 Packaging materials

Low density polyethylene, high density polyethylene and polypropylene Packaging materials procured from local market of Anakapalle.

3.1.3 Equipments

Electronic balance, water bath, vacuum desiccator, BOD incubator, texture analyser, water activity meter, vacuum packaging machine and MAP packaging machine were used in this study.

3.2 Preliminary Experiments

Preliminary studies were conducted on the basis of review conducted on various edible coatings to decide the concentration of edible coating for the formation of edible coating. In the view of results obtained in preliminary experiments the variable and actual levels were decided.

3.3 Formulation of Edible Coating

Edible coatings are prepared by dissolving the edible coating material in 100 ml distilled water and mixed thoroughly to form uniform solution. The solution was denatured at 90ºC on water bath for 30 minutes to provide functionality to edible film. The solution was cool down to room temperature in chilled water. 5% glycerol was added to solution as plasticizer and mixed thoroughly. Then the prepared solution was again reheated at 50ºC for 10 minutes after that solution was cooled to room temperature as shown in fig. 3.1 (Mishra *et al.*, 2016).

100 ml distilled water + edible coating

(As per requirement)

↓

Denaturation at 90ºc (water bath) for 30 minutes

↓

Cooled at room temperature

↓

Add 5% glycerol

(Proper mixing)

↓

Reheated at 50ºc for 10 minutes

↓

Apply on Jaggery samples

Fig. 3.1: Formulation of edible coating

3.4 Application of Edible Coating over Solid Jaggery Sample

The prepared edible coatings were applied on solid jaggery cubes by dipping method. Plate 3.1. shows the preparation and application of edible oating over solid jaggery cubes. The dipping method is used widely for applying edible coatings on fruits and vegetables, in this method fruits and vegetables are dipped in coating solution for 5-30 s (Valverde *et al*., 2005). After applying of edible coating the samples were allowed to dry in room temperature.

3.1(a). Solid jaggery cubes **3.1(b). Edible coating solution (WPC)** **3.1(c). Jaggery cubes after dipping in edible coating solution**

Plate 3.1: Preparation and application of edible oating over solid jaggery cubes

3.5 Determinations of Physico-chemical Characteristics of Solid Jaggery

3.5.1 Water activity

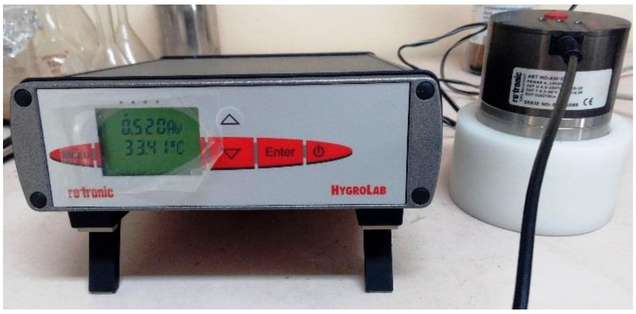


Plate 3.2: Water activity meter

The measurement of water activity is a key parameter in the quality control of moisture sensitive products or materials. If there is too much water in a product, there is a risk of microbial growth and water migration. This can lead to clumping, changes in consistency and reduced shelf life. The water activity of edible coated solid jaggery samples was measured by using HygroLab C1 Bench-Top Indicator (plate 3.2), Rotronic AG Bassersdorf, Switzerland. The sample was placed in the a_w probe and the reading will be showed in the display.

3.5.2 Colour

For the measurement of colour of samples combination of digital camera, computer and Adobe Photoshop 7.0 software provides a less expensive and more versatile way to determine colour parameters of food products than traditional colour measuring equipment's and also good colour of sample depends upon the intensity of light and distance between sample and camera. This colour measuring technique involves setting up a lighting system, high resolution digital camera to capture images of food samples reported by Spyridon *et al.* (2000).

Method

The samples was placed under the source of light at minimum distance and intensity of light over the sample should be uniform for good quality colour. Digital camera (Sony 7.2 mega pixels) was used to capture the image of sample. The L*, a*, b* values of samples were measured by using Adobe Photoshop 7.0 software. To obtain lightness, a and b values obtained from the Histogram window to L*, a* b* following formulas were used.

$$L^* = \frac{Lightness}{250} \times 100 \quad (3.1)$$

$$a^* = \frac{240 \times a}{255} - 120 \quad (3.2)$$

$$b^* = \frac{240 \times b}{255} - 120 \quad (3.3)$$

Colour difference (ΔE) indicates the degree of overall colour change of a sample in comparison to colour values of an standard sample having colour values of L*, a*, and b*.The colours of the samples represents in terms of L (whiteness/darkness), a (redness/greenness), b (yellowness/blueness). Colour difference was calculated using equation 3.4.

$$\Delta E = [(L - L^*) + (a - a^*) + (b - b^*)^2]^{0.5} \quad (3.4)$$

3.5.3 Hardness

The texture attribute of hardness or degree of softening was measured by determining the maximum penetration force for stored edible coated jaggery samples. A texture analyser model TA XD plus as shown in plate 3.3 was used to measure the hardness in terms of force (Newton) required for penetration of probe (P/75) into the sample using the following parameters. A cylindrical probe of 5mm diameter was used for the penetration into the samples.

Pre-test speed	:	10mm/sec
Test speed	:	2mm/sec
Post speed	:	10mm/sec
Target speed	:	Strain
Strain	:	80%
Time	:	5 sec
Trigger mode	:	Auto
Dimensions of sample	:	25 × 25 × 25 mm

Plate 3.3: Experimental setup for determination of hardness of solid jaggery by using texture analyser

3.5.4 Non-reducing sugars (sucrose)

It was determined according to official method of International commission for uniform method of sugar analysis (ICUMSA, 1964). 32.5 gm of jaggery are weighed and dissolved in about 100 c.c distilled water. The solution is transferred into a 250 c.c measuring flasks and made up the mark (This is N/2 solution). About 150 c.c of the solution are taken in dry beaker and sufficient basic lead acetate is added (Anhydrous 1-2 grams) and stirred well with a glass rod. It is filtered through a dry dry filter paper (Whatman No.3) and collected in a clean dry beaker (rinsed).

(i) The filtrate is taken into a 200 mm polarimeter tube and the reading is noted, after adjusting the instrument so that the polarizing disc of the light is equally illuminated in both the levels. This reading is P_1.

(ii) A hundred c.c of the above filtrate are taken into another clean, dry beaker, sufficient quantity of potassium oxalate (Anhydrous 2-3 g) is added and stirred well with glass rod. The solution is filtered through a dry filter paper (Whatman no.3) and collected in a clean dry beaker. 25 c.c of the deleaded filtrate are pipetted into a 50 c.c of hydrochloric acid (specific gravity 1.1) are added and inversion is carried out at room temperature overnight. Then the solution is made upto the mark, shaken and filtered. The temperature of the solution is noted (T°C). The filtrate is polarized in 200 mm tube and reading noted (P_2).

The percentage of true sucrose in the jaggery is calculated as follows:

$$\text{Sucrose percentage} = \frac{(2 \times P_1 - 4 \times P_2) \times 100}{143 - 0.5T} \qquad (3.5)$$

Where, P_1 is initial polorimeter reading, P_2 is final polorimeter reading and T is the temperature of the inverse sample.

3.5.5 Reducing sugars

It was determined according to Lane and Eynon's volumetric method (Ranganna, 1987).

Reagents

Methylene blue indicator: A 1% of aqueous solution of pure methylene blue.

Fehling's solution (A): A copper sulphate solution containing 69.28 g of $CuSo_4.5H_2O$ per liter.

Standard invert solution

Dissolve 9.5 g of AR sucrose into a 1-litre volumetric flask. Add 5 ml hydrochloric acid and to stand at room temperature for 7 days at 150C for completion of hydrolysis and then make up to mark with water.

Pipette 25 ml of invert solution into a 100 ml volumetric flask and add about 50 ml water. Add a few drops of phenolphthalein indicator and neutralize with 20% NaOH until the solution tums pink. Acidity with 1N HCL adding it drop wise until one drop causes the pink colour to disappear. Make up to the mark with water (1 ml = 2.5 mg of invert sugar).

Standardization of Fehling's solution

Mix equal quantities of Fehling's solution (50 ml of A and 50 ml of B). Accurately pipette out 10 ml of mixed solution into a 250 ml conical flask. Add 25 to 50 ml of water. Take the standard invert sugar solution prepared by inversion of sucrose in a 50 ml burette. Add to the mixed Fehling's solution almost the standard invert sugar solution (18-19 ml) required to effect the reduction of all the copper, so that not more than 1 ml will be required later to complete the titration. Heat the flask and when the liquid begins to boil, add 3 drops of methylene blue indicator solution and complete the titration in a minute. The end point is indicated by the decolourization of the indicator. Note the volume of the sugar solution required for completely reducing 10 ml of Fehling's solution. The equivalent volume should be 20.37±0.05 ml.

Factor for Fehling's solution (g of invert sugar) = $\frac{\text{Time}\times 2.5}{1000}$ (3.6)

Sample preparation

Plane accurately about 50 g of the material in a 500 ml beaker and add 400 ml of water. Neutralize the solution with 1 N NaOH using phenolphthalein indicator. Boil gently for 1 hr with occasional stirring. Add boiling water to maintain the original level. Cool and transfer to 500 ml volumetric flask. Make up to volume and filter through No. 4 Whatman paper. Pipette a 100 ml aliquot into a 500 ml volumetric flask. Add 2 ml of neutral lead acetate solution and about 200 ml of water. Let it stand for 10 minutes, then precipitate the excess of lead with potassium oxalate solution. Make up to and filter.

Method of titration

Pipette 10 ml of the mixed Fehling's solution into a 250 ml flask. Add 50 ml water. Fill the burette with the clarified sugar solution. Add from the burette, sugar solution sufficient to reduce almost completely the Fehling's solution used. Mix the heat to boiling for 15 sec. If the colour remains blue, add further 2-3 ml of the sugar solution. Boil the solution for a few seconds and add few drops of Methylene blue indicator and complete the titration by adding the sugar solution dropwise until the indicator is completely decolourized. Record the volume of solution required.

% reducing sugar = $\frac{\text{mg of Invert sugar} \times \text{dilution} \times 100}{\text{Titre} \times \text{Wt.or volume of sample} \times 100}$ (3.7)

3.5.6 Sensory evaluations of edible coated solid jaggery packed under MAP and Vacuum in LDPE, HDPE and PP

3.5.6.1 Sample preparation

Sugarcane jaggery samples (25 g) were coated with the optimized concentration of edible coating (0.5% WPC and 0.5% gum arabic) and placed in LDPE, HDPE and PP pouches packed the nine pouches (three LDPE pouches, three HDPE and three PP pouches) with MAP machine. Nine pouches (three LDPE pouches, three HDPE pouches and three PP pouches) with 0.5% WPC coated solid jaggery sample placed in the pouches and sealed with the vacuum packaging machine. Nine pouches (three LDPE pouches, three HDPE pouches and three PP pouches) with 0.5% gum arabic coated solid jaggery sample placed in the pouches and sealed with the vacuum packaging machine. Nine pouches (three LDPE pouches, three HDPE pouches and three PP pouches) with 0.5% WPC coated solid jaggery sample placed in the pouches and sealed with the MAP packaging machine. Nine pouches (three LDPE pouches, three HDPE pouches and three PP pouches) with 0.5% gum arabic coated solid jaggery sample placed in the pouches and sealed with the MAP packaging machine. Twelve pouches (0.5% WPC coated jaggery packed in LDPE with vacuum packing; 0.5% gum arabic coated jaggery packed in LDPE with vacuum packing; 0.5% WPC coated jaggery packed in HDPE with vacuum packing; 0.5% gum arabic coated jaggery packed in HDPE with vacuum packing; 0.5% WPC coated jaggery packed in PP with vacuum packing; 0.5% Gum arabic coated jaggery packed in PP with vacuum packing; 0.5% WPC coated jaggery packed in LDPE with MAP packing; 0.5% gum arabic coated jaggery packed in LDPE with MAP packing; 0.5% WPC coated jaggery packed in HDPE with MAP packing; 0.5% gum arabic coated jaggery packed in HDPE with MAP packing; 0.5% WPC coated jaggery packed in PP with MAP packing; 0.5% gum arabic coated jaggery packed in PP with MAP packing) were placed in a desiccator (0.3 m diameter). The desiccator was placed in incubator maintained a temperature of 25°C. At the end of storage studies, the jaggery samples were taken out from the pouches and presented to the panellists.

The resultant samples were designated as follows: 0.5% WPC coated jaggery packed in LDPE with MAP packing (S1); 0.5% WPC coated jaggery packed in LDPE with vacuum packing (S2); 0.5% WPC coated jaggery packed in HDPE with MAP packing (S3); 0.5% WPC coated jaggery packed in HDPE with vacuum packing (S4); 0.5% WPC coated jaggery packed in PP with MAP packing (S5); 0.5% WPC coated jaggery packed in PP with vacuum packing (S6); 0.5% gum arabic coated jaggery packed in LDPE with MAP packing (S7); 0.5% gum arabic coated jaggery packed in LDPE with vacuum packing (S8); 0.5% gum arabic coated jaggery packed in HDPE with MAP packing (S9); 0.5% gum arabic coated jaggery packed in HDPE with vacuum packing (S10); 0.5% gum arabic coated jaggery packed in PP with MAP packing (S11); 0.5% gum arabic coated jaggery packed in PP with vacuum packing (S12). Panelists selected from the scientists and students of the RARS Anakapalle, Vishakhapatnam district, in the age group from 18 to 50 years and conducted sensory evaluation three times. They were trained to evaluate the colour, sweetness, flavour and texture/appearance of the solid jaggery samples. The scale factors *viz*., Excellent (EX), Good (GD), Medium (MD), Fair (FR) and not satisfactory (NS) assigned to the quality factors *viz*., colour, sweetness, flavour and texture/appearance for twelve jaggery samples. The results were analyzed by using Fuzzy comprehensive model to find out the effect of the storage on the quality of jaggery samples.

3.5.6.2 Training of judges and evaluation procedure

Twenty panellists from non-smokers and non-betel leaf chewers were selected based on good health, interests in sensory evaluation, ability to concentrate and learn and familiarity with solid jaggery (Ranganna, 1987). Quality attributes selected for evaluation were colour, sweetness, flavour and texture/appearance. Panellists were familiarized with quality attributes of jaggery before actual sensory evaluation. They were asked to judge the twelve jaggery samples quickly but not in hurry. They were also asked to take two short sniffs of samples before tasting them and give the score for flavour first in score card. They were advised to rinse their mouth with luke warm salt water between testing of consecutive samples. They were instructed to give tick mark (√) in the respective fuzzy scale factor for each of the quality attributes of the sample after evaluation of the sample. The fuzzy scale factors were assigned as Excellent, Good,

Medium, Fair and Not satisfactory. The panellists were asked to give a score in the fuzzy scale based own their own criteria and likings regarding jaggery. The score card was also used to record the weightages given by each judge for the quality attributes of jaggery in general. The sensory score card used for evaluation of jaggery samples (Das, 2005) and sensory score card used for evaluation of sample qualities in general is given in Appendix D3.

3.5.6.3 Fuzzy comprehensive model for sensory score

The Fuzzy model used for the analysis of sensory data was developed by Chen *et al.* (1983). The fuzzy model for the present problem was having three sets:

i) Factor set U_f, ii) Evaluation set V_f and iii) Fuzzy transformation set T_f. The factor set (U_f) includes all of the quality attributes such as colour, sweetness, flavour and texture/appearance of the products. The evaluation set V_f includes the scale factor for each of the quality attributes, such as Excellent, Good, Medium, Fair and Not satisfactory. For the fuzzy transformation (T_f) of the factor set (U_f) into evaluation set (V_f), numerical values assigned to the scale factors were : Excellent =1, Good=0.9, Medium=0.7, Fair=0.4 and Not satisfactory=0.1. The steps involved in this analysis consist of the following evaluations.

i. Fuzzy membership function

ii. Normalized Fuzzy membership function

iii. Normalized Fuzzy membership function matrix

iv. Judgment membership function matrix

v. Judgment subset

vi. Quality-ranking subset

vii. Ranking of the sample

3.5.6.3.1 Fuzzy membership function (FMF)

It was calculated by adding the individual scale factor given to each of the quality attribute of the product and divided by the number of judges who tested the product. As for example, if the number of judges were 20 and the number of scale factor under ‘Excellent’ given by the judges for a particular quality attribute, e.g., ‘colour’ of the first sample is 6, the membership function for the ‘colour’ will be 6/20=0.3. Similarly the membership functions were calculated for the other quality attributes of all the samples.

3.5.6.3.2 Normalized fuzzy membership function (NFMF)

It was calculated by multiplying each of the above MF with the assigned numerical value of the respective ‘scale factors’. As for example, the normalized membership function formed for the membership function under the “Excellent” scale factor of the ‘colour’ quality attribute (since the numerical values assigned to the scale factor for ‘Excellent’=1) will be 1*0.3 = 0.3. Similarly the normalized membership functions were calculated for the other quality attributes of all the samples.

3.5.6.3.3 Normalized fuzzy membership function matrix (NFMFM):

Addition of normalized membership function of individual scale factor of respective quality attributes for each of the products given for sensory evaluation formed the elements of the normalized fuzzy membership function matrix. As for example, if the normalized fuzzy membership functions for the 'colour' of the first sample for the 'Excellent', 'Good', 'Medium', 'Fair' and 'Not satisfactory' were respectively 0.3, 0.495, 0, 0.06 and 0 the element of the normalized fuzzy membership function matrix for the colour will be 0.3+ 0.495+0+0.06+0=0.855. Similarly, all the elements of the normalized matrix was formed and written in the form of a matrix called normalized fuzzy membership function matrix having its row as quality attributes (i.e., 'colour', 'sweetness', 'flavour' and 'texture/appearance' and the column as samples under.

3.5.6.3.4 Judgement membership function matrix (JMFM)

After forming the normalized fuzzy membership function matrix, the column values of a sample were added and the individual values of the same column were divided by the "maximum" of the added value. The values thus obtained formed the elements of the judgment membership function matrix. This matrix was taken for the judgment of rank of the samples.

3.5.6.3.5 Judgement subset (JS)

It was formed by averaging the numerical weightage (as fraction) given by the judges for individual quality attributes, *viz.*, 'colour (C)', 'sweetness(S)', 'flavour (F)' and 'texture/appearance (M)' were respectively 0.21, 0.215, 0.35 and 0.215, the judgment subset 'Y_f' can be represented as Y_f = [0.3444/C 0.1888/S 0.2883/F 0.17864/M]

3.5.6.3.6 Quality-ranking subset (QRS)

Individual elements of the Judgment membership function matrix (X_f) were compared with the respective elements of the judgment subset (Y_f) and minimum of them was taken to form the Quality-ranking subset (Z_f).

3.5.6.3.7 Ranking of the sample

From the values of each element in the Quality-ranking subset (Z_f), the maximum value was taken and assigned as the rank one to the respective sample. Then the quality attribute, which gave this highest value, was considered as the reason for that sample to get the highest rank. Similarly, the rank of all the samples tested was assigned and corresponding quality attribute responsible for the rank was found out.

3.6 Moisture Sorption Isotherms (MSI) of solid jaggery

3.6.1 Samples preparation

Jaggery made from sugarcane (variety 93 A 145), with an initial moisture content of 10% (db.), was taken for this study. The sucrose and reducing sugars (%) in jaggery were determined by the polarimetry and Lane-Eynon method (AOAC, 1984) respectively.

3.6.2 Preparation of different water activity environment

Saturated salt solutions of various inorganic salts Sodium hydroxide (NaOH), Potassium acetate (CH_3COOK), Magnesium chloride ($MgCl_2$), Potassium carbonate (K_2CO3), Magnesium nitrate ($MgNO_3$), Sodium nitrate ($NaNO_3$), Sodium chloride (NaCl), Potassium chloride (KCl) and Potassium nitrate (KNO_3), all reagent grades) were employed to generate controlled humidity environment in a desiccator ranging between 10 and 90% (Greenspan, 1977; Labuza *et al*., 1985). The experimental procedure shown in (Plate 3.4 and 3.5).

The saturated salt solution were prepared by adding inorganic salts listed in the table below to distilled water in small increment and stirred well by a spatula after each addition. This process was continued till the crystals of the salts deposited at the bottom of the container. The solutions were heated to 60°C with the electric heater and more salts were added to it till crystal deposition occurred at the bottom of the container. Crystal deposition at the bottom of the container indicated the attainment of saturation of the solution. The high temperature solutions of each were allowed to cool to the atmospheric temperature and poured into each desiccators to a level just below the platform of the desiccators.

3.6.3 Temperature control

Moisture sorption of solid jaggery samples were determined at 25, 35, and 45°C by static gravimetric technique based on isopiestic vapour transfer technique (Swami *et al*., 2005) with temperature variation ± 1°C of set value was used for the experiment.

3.6.4 Weight recording

Pre-weighed samples of edible coated solid jaggery samples (in triplicate) are taken in respective weighing bottles, and placed them in the desiccators maintaining constant relative humidity with the saturated salt solutions (Table 3.1) as described above. Partial vacuum was created inside each desiccator to accelerate the absorption process (Swami *et al.*, 2005). The desiccators were kept in an incubator maintained at constant temperature with variation ±1°C over the set value. Samples were weighed periodically with an interval of 2 days till constant weights were obtained. It took about 14 days.

3.6.5 Determination of moisture content

The moisture contents of each sample was determined by vacuum oven drying method (AOAC, 1984) and averaged. The results have been expressed as percentage on dry basis.

$$\text{Moisture content, MC \% (db.)} = (W_1 - W_2)/W_2 \quad (3.8)$$

Where,

W_1 is the weight of the sample after attaining equilibrium moisture content.

W_2 is the weight of the material after removing the moisture in the oven.

W_1- W_2 is the weight of the moisture present in W_2 g of bone dry material.

Plate 3.4: Experimental setup for determination of equilibrium moisture content of solid jaggery at temperatures of 25^{0}C, 35^{0}C and 45^{0}C

Plate 3.5: Incubator used for solid jaggery samples in desiccators at different controlled equilibrium relative humidities and at different setup temperatures

Table 3.1: Water Activity of Saturated Salt Solutions at 25, 35 and 45^{0}C

S.No.	Saturated solution	Water activity (a_w)		
		25°C	35°C	45°C
1	Sodium hydroxide	0.0824	0.0692	0.056
2	Potassium acetate	0.2235	0.211	0.198
3	Magnesium chloride	0.3278	0.3205	0.311
4	Potassium carbonate	0.4433	0.4364	0.4299
5	Magnesium nitrate	0.5289	0.4991	0.4693
6	Sodium nitrate	0.7425	0.7206	0.6999
7	Sodium nitrate	0.7529	0.7487	0.7452
8	Potassium chloride	0.8434	0.8295	0.8174
9	Potassium sulphate	0.9780	0.9671	0.9612

(Greenspan, 1977; Labuza *et al.*, 1985)

3.6.6 Sorption models for solid jaggery

The sorption data so obtained were fitted into three MSI models namely, GAB, Iglesias and Chirife, and Halsey (Table 3.2).

Table 3.2: Moisture sorption isotherm models used to analyze EMC - aw data for solid jaggery samples

Model	Mathematical expression	Eq.No.	Reference
GAB	$\frac{M}{M_0} = \frac{CKa_w}{(1-Ka_w)(1-Ka_w+Ca_w)}$	3.9	Van den Berg (1984)
Iglesias and Chirife	$\ln[M+(M^2+M_{0.5})^{1/2}] = ba_w + p$	3.10	Chirife and Iglesias (1978)
Modified Halsey	$\ln M = (1/r)\ln C - (1/r)\ln[\ln(1/ra_w)]$	3.11	Halsey (1948)

Where, M is the equilibrium moisture content; M_O is the monolayer moisture content; aw is the water activity; $M_{0.5}$ is equilibrium moisture content at aw=0.5; C, K, b, p, and r are the constants for respective equations (3.8-3.10).

The parameters Mo, C and K are dependent on temperature as follows:

$$Mo = Mo^1 \exp(Ea/RT) \quad (3.12)$$

$$C = Co \exp\{(\Delta H_c/RT\} \quad (3.13)$$

$$K = Ko \exp\{\Delta H_k)/RT\} \quad (3.14)$$

Where,

C - Guggenheim constant,

K - Molecule multilayer factor,

T - Air temperature,

Ea – Activation energy,

ΔHc -Difference in enthalpy/ heat of sorption between monomolecular layer and Multi-molecular layer of water,

ΔHk -Difference in heat of sorption of multi-molecular layer of water and heat of condensation of water vapor, and Mo^1, Co, Ko are the constants.

From the Mo, C, K data obtained at different temperatures, curves were plotted between **Mo vs. 1/T, C vs. 1/T and K vs. 1/T** individually, that followed the exponential relationship and the values of GAB coefficients **Mo^1, Co, Ko, Ea , ΔH_c, ΔH_k** were evaluated.

3.6.7 Statistical analysis of data

The method of non-linear regression was made with Origin 2017 package (Origin Lab Corporation, Northampton, MA 01060, USA, 2017) to fit equations (3.8 and 3.10) by non-linear curve fitting. Microsoft Excel (Microsoft Corporation, USA, 2010) was used to fit equation (3.9) by linear regression. In ORIGIN, the isotherm curves of solid jaggery were obtained along with the values of parameters Mo, C, K and the regression coefficient R_2 which indicates the closeness or the goodness of fit.

Statistical validity of the fit to the model was evaluated using statistical parameters such as the root mean square error (RMSE) in MS excel that was used to fit GAB equation by linear regression. An RMSE values give a measure of the fitness/efficiency of the model in describing the sorption characteristics of the reported data (Hasan and Nurhan, 2004).

$$\text{RMSE} = [\frac{1}{N} \sum_{i=1}^{N}(M_{\text{exp,i}} - M_{\text{pre,i}})^2]^{\frac{1}{2}} \qquad (3.15)$$

$$\chi^2 = \frac{\sum_{i=1}^{N}(M_{\text{exp,i}} - M_{\text{pre,i}})^2}{N-n} \qquad (3.16)$$

$$\text{EF} = \frac{\sum_{i=1}^{N}(M_{\text{exp,i}} - M_{\text{pre,i}})^2 - \sum_{i=1}^{N}(M_{\text{exp,i}} - M_{\text{pre,i}})^2}{\sum_{i=1}^{N}(M_{\text{exp,i}} - M_{\text{pre,i}})^2} \qquad (3.17)$$

Where,

M_{exp} is the experimental equilibrium moisture content,

M_{pre} is the predicted equilibrium moisture content

$M_{exp,ave}$ is the average value of experimental equilibrium moisture content

N is the number of data points and n is the number of model parameters.

3.6.8 Isosteric heat of sorption

Net isosteric heat of sorption, q_{st} has been estimated at constant moisture contents from the plot of a_W versus 1/T using Clausius Clapeyron Equation (3.18) applicable to sorption process (Rizvi, 1986).

$$\text{Ln } a_w = \frac{-q_{st}}{RT} + Z \qquad (3.18)$$

Where,

q_{st} is net isosteric heat of sorption, kJ mol-1; R is universal gas constant (8.314x 10-3 kJ mol-1 K-1); T is the absolute temperature in K and Z is integral constant.

3.7 Optimization of Process Parameters for Application of Edible Coating over Solid Jaggery

3.7.1 Statistical analysis and experimental design

Four Protein based edible coatings, whey protein concentrate, wheat gluten, corn zein and gelatin, one polysaccharide-based edible coating, gum arabic, were used in these experiments. For each type, Factorial method was applied to study the effect of edible coatings (Protein and Polysaccharide based), concentration of edible coating, Temperature, and water activity as independent variables on equilibrium moisture content (% db.). Multi-level categorical design was used for optimization of process parameters for application of edible coating over solid jaggery. The multilevel categoric (general factorial) design allows researchers to have factors that each have a different number of levels. It will create an experiment that includes all possible combinations of your factor levels. In this design all factors are categoric. Table 3.3. Represents the levels of independent variables used in the experimental design. Difference between the variables were tested for significance using the one-way ANOVA analysis procedure. The statistical software package Design Expert 9.0' (Version 9.0.6.2, Stat – Ease, Minneapolis, MN) was used for regression analysis of the data and estimation of regression equation coefficients. A second order polynomial equation was used to express the Equilibrium moisture content (Y) as function of the independent variable,

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_3X_3 + \beta_{11}X_{12} + \beta_{22}X_2^2 + \beta_{33}X_3^2 + \beta_{12}X_1X_2 + \beta_{13}X_1X_3 + \beta_{23}X_2X_3 + \beta_{24}X_2X_4 + \beta_{14}X_1X_4 + \beta_{34}X_3X_4 \quad (3.19)$$

Table 3.3: Levels of independent variables used in the multi-level factorial design

Factor	Name	Units	Type	Subtype	Minimum	Maximum	Levels
A	Temperature	^{0}C	Categoric	Nominal	25	45	3
B	Concentration	%	Categoric	Nominal	0.5	2.5	3
C	Water activity	%	Categoric	Nominal	0.1	0.9	8
D	Edible coating		Categoric	Nominal	1	5	5

3.8 Permeability Test for Packaging Material

Determination of water vapour permeability is gravimetric analysis. Dry silica gel in in the packaging material cap from packaging material changes own weight, because silica gel receive water vapour through packaging material in environment with known relative humidity and temperature. Water vapour Permeability of Low-density polyethylene (LDPE), High density polyethylene (HDPE) and Polypropylene (PP) pouches were investigated. The thickness and area of the pouches were shown in the table 3.4.

Table 3.4: The thickness and area of the packaging materials

S.No	Material	Thickness (micron)	Area (m^2)
1	LDPE	87.5	0.03375
2	HDPE	40.0	0.03375
3	PP	37.5	0.03225

Method

All three packaging material pouches (triplicate) were filled with approximately equal weight of desiccants (Silica gel). After filling with desiccant pouches were properly sealed on heat sealing machine. Then all three pouches with desiccants kept in BOD Incubator at 38±2^{0}C temperature and 90±1% relative humidity (plate 3.6). After that weight change reading was taken every day all three pouches. Day by day we noticed that weight of pouches is increasing in some cases its slightly decreasing. After thirteen days we noticed that there was no weight change of pouches. The cumulative moisture gain with time by silica gel kept in three pouches (LDPE, HDPE and PP) was noted down. The analytical data kept in the following equations and we calculated the water vapour transmission rate and water vapour permeability of the three pouches. The saturated vapour pressure (P) of water at 40^{0}C is 7375.02 Pa.

$$\text{Water vapour Transmission Rate (Kg/day*m}^2\text{)} = \frac{\text{weight gain (kg/day)}}{\text{Area of (m}^2\text{)} \times 2\ \text{(sides)} \times \text{No.of days}} \tag{3.20}$$

$$\text{Permeance (Kg/day*m}^2\text{*Pa)} = \frac{\text{Water vapour Transmission Rate ((Kg/day*m2)}}{\text{saturated vapour pressure (P)of water(Pa)}} \tag{3.21}$$

$$\text{Water vapour permeability (Kg*micron/day*m}^2\text{*Pa)} = \text{Permeance} \times \text{Thickness (mi)} \tag{3.22}$$

Plate 3.6. Experimental setup for determination of water vapour permeability for packaging material

3.9 Storage Studies of Edible Coated Solid Jaggery Packed under MAP and Vacuum in LDPE, HDPE and PP at Temperatures of 25^{0}C

3.9.1 Sample preparation

Sugarcane solid jaggery samples (25 g) were coated with optimized concentration of edible coating (0.5% concentration of both protein (WPC) and polysaccharide (gum arabic) based) placed in LDPE (9×6 inch size, thickness 87.5 micron, Permeability 1.352×10^{-8} kg water/day $\times m^2 \times$pa), HDPE (9×6 inch size, thickness 40 micron, Permeability 3.708×10^{-8} kg water/day$\times m^2\times$pa) and PP (8×6 inch size, thickness 37.5 micron, Permeability 3.032×10^{-8} kg water/day$\times m^2\times$pa) pouches. The packing materials, packaging methods and optimized edible coatings serving as the treatments in the experiment were:

T1= 0.5% WPC coated jaggery packed in LDPE with MAP packing
T2= 0.5% WPC coated jaggery packed in LDPE with vacuum packing
T3= 0.5% WPC coated jaggery packed in HDPE with MAP packing
T4= 0.5% WPC coated jaggery packed in HDPE with vacuum packing
T5= 0.5% WPC coated jaggery packed in PP with MAP packing
T6= 0.5% WPC coated jaggery packed in PP with vacuum packing
T7= 0.5% gum arabic coated jaggery packed in LDPE with MAP packing
T8= 0.5% gum arabic coated jaggery packed in LDPE with vacuum packing
T9= 0.5% gum arabic coated jaggery packed in HDPE with MAP packing
T10= 0.5% gum arabic coated jaggery packed in HDPE with vacuum packing
T11= 0.5% gum arabic coated jaggery packed in PP with MAP packing
T12= 0.5% gum arabic coated jaggery packed in PP with vacuum packing

All these pouches were placed in incubator maintained a temperature of 25°C. Before taking out the pouches from the incubator, pouches were placed in the desiccator for 5 minutes to cool down, and the physico-chemical analysis of samples were done with three replication at the interval of seven days for the end of storage period and taken the average value of three replication. The resultant samples were designated as show in Appendix C1 to C6.

3.10 Accelerated Storage of Edible Coated Solid Jaggery

Accelerated shelf life studies were conducted by changing the storage conditions to fasten the deteriorative processes that occur during storage. In confections, elevated temperatures and humidities are often used to enhance product degradation in accelerated shelf life tests. A product with a one-year shelf life may be evaluated under accelerated storage conditions within perhaps a month in certain circumstances (Ergun *et al.,* 2010). Twenty five grams of edible coated (0.5% concentration of WPC and gum arabic) solid jaggery with an initial moisture content Xi= 0.010 kg water/kg dry solids was packed in 9×6 inches (LDPE, HDPE) pouches, 8×6 inches PP pouches and placed in an environment maintained at 90% RH and 38 ± 2^{0}C. Nine pouches (three LDPE, three HDPE and three PP pouches) were filled with 0.5% concentration of WPC coated solid jaggery and packed with modified atmosphere packaging machine. Nine pouches (three LDPE, three HDPE and three PP pouches) were filled with 0.5% concentration of WPC coated solid jaggery and packed with vacuum packaging machine. Nine pouches (three LDPE, three HDPE and three PP pouches) were filled with 0.5% concentration of gum arabic coated solid jaggery and packed with modified atmosphere packaging machine. Nine pouches (three LDPE, three HDPE and three PP pouches) were filled with 0.5% concentration of gum arabic coated solid jaggery and packed with vacuum packaging machine. Total thirty six such Pouches were prepared, and after intervals of 10 days, one of the pouches was removed from the control environment and its contents analysed for moisture content X (kg water/kg dry solids).

3.10.1 Moisture gain and storage life prediction

The rate of change of moisture content *dX/d*q of the powder with storage time ϴ is expressed as:

$$X_S \frac{dx}{d\theta} = KA_P\ (Rhp^* - a_w p^*) \qquad (3.23)$$

Where, Xs (kg) is the dry weight of the edible coated solid jaggery inside the pouch; p^* (Pa) is the saturation vapour pressure of water at the temperature T (^{0}C) of storage; Rh is the relative humidity of the storage environment; K (kg water/m^2/day/Pa) is the permeability of the packaging material; A_p (m^2) is the surface area of the packaging material through which water vapour permeates; aw is the water activity of the edible coated jaggery at T (^{0}C) and X (kg water/kg·dry·solids) is the moisture content of the edible coated jaggery after Ɵ days of storage time. The integration of Eq. (3.22) with initial and critical moisture content value is used to predict the shelf-life of the edible coated jaggery. On integration of Eq. (3.22) from initial moisture content X_i to critical moisture content X_c, the storage-life can be expressed as:

$$\Theta = X_s (X_c - X_i) / KA_P (Rhp^* - a_w p^*) \quad (3.24)$$

3.11 Cost-economics of the Edible Coating over Jaggery

After conducting detailed studies on edible coatings and packaging methods and materials, Techno-economic analysis of the protein and polysaccharide based edible coated jaggery studied to transfer the technology to the jaggery farmers. For estimation of cost-economics of edible coating over solid jaggery, the following cost elements were used.

3.11.1 Fixed cost

Fixed cost included cost items like taxes, insurance and rent for jaggery crusher and jaggery furnace etc.

3.11.2 Variable cost

Variable cost include cost of raw material, labour charges other actual cost incurred during solid jaggery production, chemicals required for the preparation of edible coating and packaging material for packing the edible coated jaggery.

3.11.3 Total cost

Total cost included total fixed cost as well as total variable cost.

$$(TC=TFC+TVC) \quad (3.25)$$

3.11.4 Estimation of benefit-cost ratio

Benefit-cost ratio =total returns/ total cost

CHAPTER –IV

RESULTS AND DISCUSSION

The present investigation was conducted to study the effect of edible coatings, packaging methods and materials on shelf life of sugarcane solid jaggery. This chapter deals with the determination of equilibrium moisture content (EMC) characteristics of edible coated solid jaggery cubes, analysis of the data, modelling and optimization of process parameters for application of edible coating on solid jaggery based on EMC and selection of suitable packaging materials and methods, permeability of packaging materials, determination of physico-chemical properties of the edible coated solid jaggery packed in LDPE, HDPE and in PP at 650 mm of Hg vacuum and modified atmosphere packing (MAP) and Techno-economic analysis of edible coated solid jaggery. The data was subjected to statistical analysis and the results obtained are presented in this chapter.

4.1 Moisture Sorption Isotherm Solid Jaggery at Temperature of 25, 35 and 45°C

4.1.1 Nature of isotherms

Average equilibrium moisture contents (EMC, %db.) for solid sugarcane jaggery cubes with different edible coatings namely, whey protein concentrate, gelatin, gluten, zein and gum arabic with different concentrations (0.5%, 1.5% and 2.5%) at different temperatures i.e. 25, 35, and 45°C are given in Appendix-(A1-A3). Typical MSI of the jaggery sample without edible coating and edible coated solid jaggery samples with different edible coatings are respectively for 25°C, 35°C and 45°C are shown in Figure 4.1-4.16. Each data point on this curve represents the mean value of three replications. The MSI of all five edible coated solid jaggery samples shows the similar decreasing trend with increasing of temperature. This also show no apparent difference among the EMC values of the three jaggery samples over the entire range of water activity. As the concentration of edible coating increases, the equilibrium moisture content decreased for all edible coated jaggery sample. Keeping the trends presented in Figure 4.1-4.16, the characteristic parameters M_0, C and K display the concurrent decrease with increasing temperature. In particular, the downward trend M_0 with respect to increasing temperature reflects the anticipated reduction in hygroscopicity, which accompanies temperature elevation. This may be ascribed to a reduction in a total sorption ability of the material, which may in turn reflect temperature induced physical and chemical variations (McMinn and Magee, 1999). Several researches (Hossain *et al.*, 2001; McLaughlin and Magge 1998; Hossain and Bala 2010; Shivhare *et al*., 2004) have reported similar trends for food materials.

At lower a_w values, water might have been adsorbed only to the surface –OH sites of the crystalline sugar, thus showing very low moisture content. At higher a_w values, dissolution of sugar occurs, and a crystalline sugar gets converted to amorphous state, resulting higher absorption of moisture to the newly opened up active adsorption sites (Ayranci *et al.*, 1990).

4.1.2 Effect of temperature on moisture sorption of jaggery samples

All the MSI for each of the edible coated solid jaggery samples (Figure 4.2-4.16) shows no significant effect of temperature on the respective EMC values upto a water activity values 0.3 – 0.5. However, beyond this value, at any particular value of $a_{w,}$ EMC increased as the temperature increased. This kind of temperature effect on isotherms at higher level of water activity has been reported by many workers for high sugar foods like, fresh and dried fruits (Saravacos *et al.*, 1986; Tsunmi *et al*., 1990; Manuel and Narain, 1990; Ayranci *et al*., 1990) which has been termed as crossing over behaviour for this group of foods. This phenomenon is attributable to dissolution of more sugar at higher temperature and higher humidity (water activity) environment resulting more water is held by the sugar in those foods giving high EMC values.

4.1.3 Fitting sorption data to various models

Appendix-A4 shows estimated Parameter of GAB, lglesias and Chirife and Modified Halsey at Temperatures of 25^{0}C, 35^{0}C and 45^{0}C of solid jaggery samples without edible coating. Appendix-(A5-A9) shows the estimated Parameter of GAB, lglesias and Chirife and Modified Halsey at temperatures of 25^{0}C, 35^{0}C and 45^{0}C of solid jaggery samples coated with whey protein concentrate, gluten, gelatin, zein and gum arabic edible coatings respectively. Comparing all these three models on the basis of good fit of sorption data, GAB model appears to be best with lowest values of RMSE and Chi-square values compared to those with the other two models. The model efficiency was highest for GAB followed by Halsey, and Iglesias and Chirife. Although Iglesias and Chirife model was well applied to nine high sugar fresh fruits with sugars mostly in dissolved form, but it gave lowest model efficiency for jaggery samples; possibly due to presence of high amount of crystalline non-reducing sugars in the jaggery samples.

The monolayer moisture content (M_o) of the solid jaggery samples was varied from maximum of 4.368% (db.) at 25°C to minimum of 3.7402% (db.) at 45°C. A decreasing trend of monolayer moisture content (M_0) values of the solid jaggery samples coated with whey protein concentrate, wheat gluten, zein, gelatine and gum arabic edible coatings with increase of coating concentration (0.5% to 2.5%) and temperature (25°C to 45°C). The highest monolayer moisture content (M_0), 4.8861% (db.) was obtained with 0.5% concentration of wheat gluten edible coating at 25°C temperature. The lowest monolayer moisture content (M_0), 3.3629% (db.) was obtained with 2.5% concentration of whey protein concentrate edible coating at 45°C temperature. Although a decreasing trend of M_o values was obtained for solid jaggery with the increase in temperature. However, monolayer moisture content (M_o) and C values of jaggery samples, evaluated for GAB model, were found to be lower than that of date paste (Alhamdan and Hassan, 1999) and dried fruits (Ayranci *et al.*, 1990).

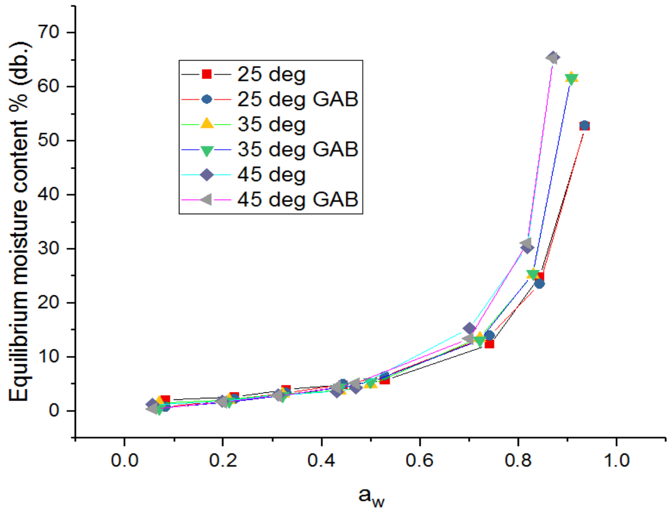


Fig. 4.1: Sorption isotherms of jaggery samples at 25, 35 and 45°C

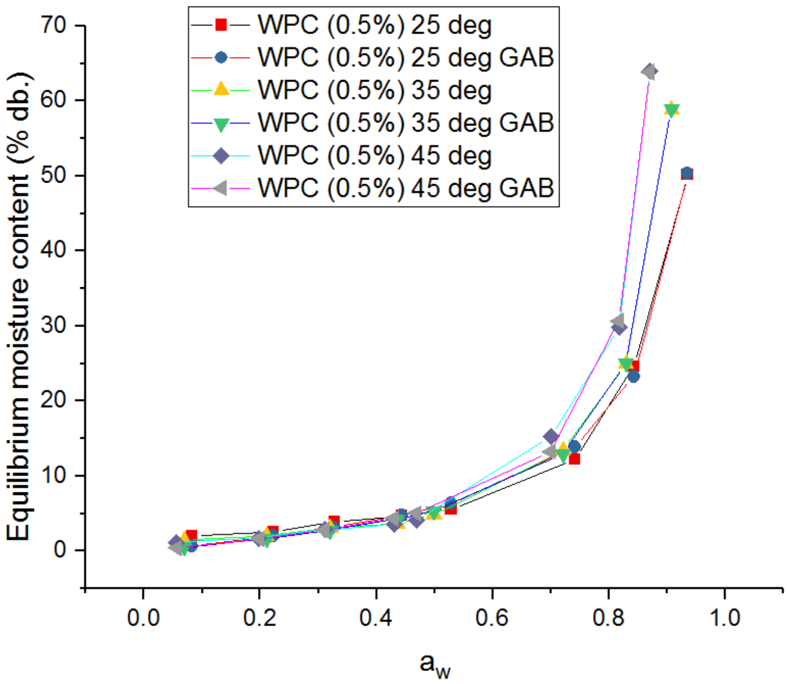


Fig. 4.2: Sorption isotherms of whey protein concentrate coated (0.5% concentration) jaggery samples at 25, 35 and 45°C

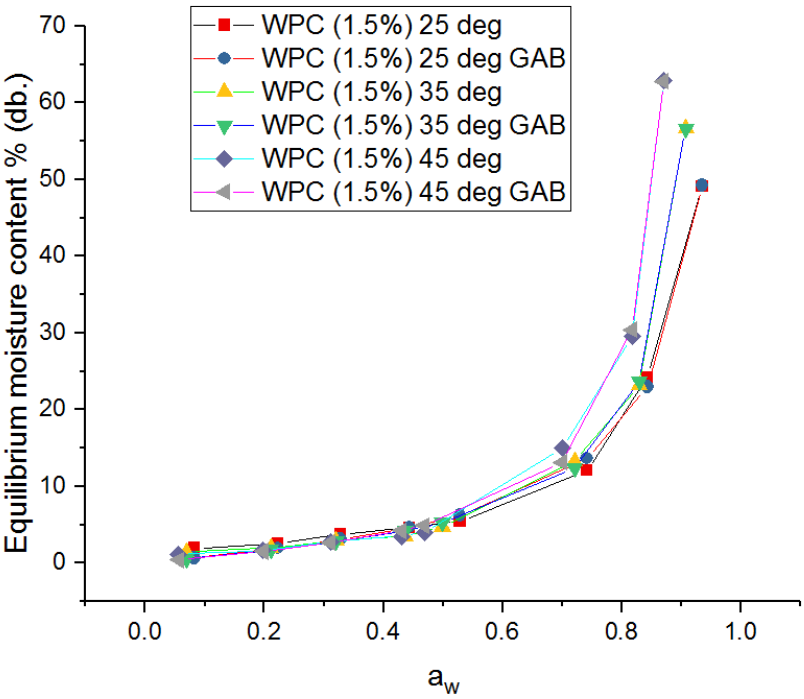


Fig. 4.3: Sorption isotherms of whey protein concentrate coated (1.5% conc.) jaggery samples at 25, 35 and 45°C

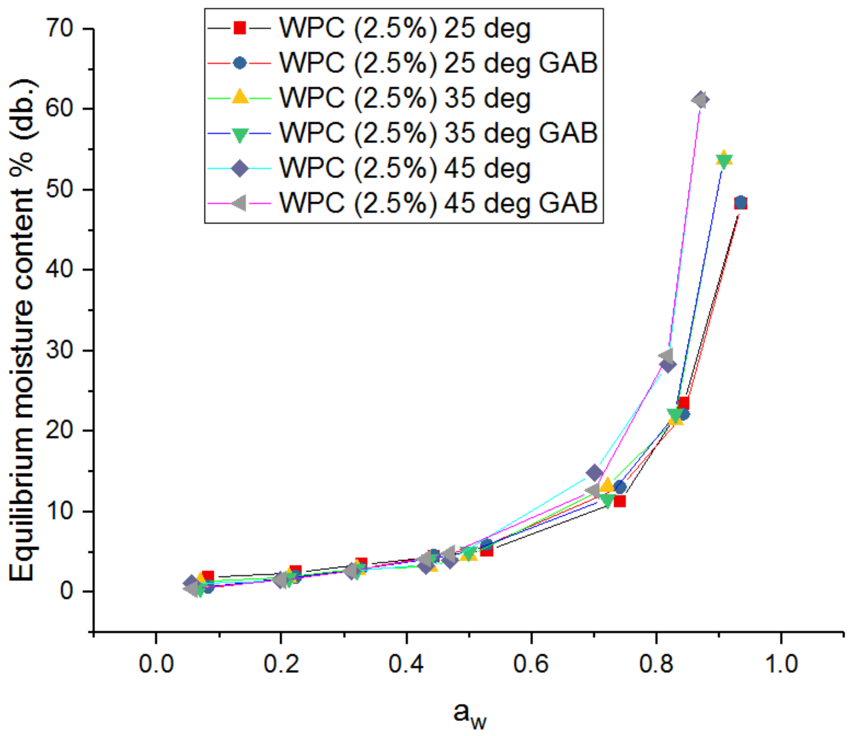


Fig. 4.4: Sorption isotherms of whey protein concentrate coated (2.5% conc.) jaggery samples at 25, 35 and 45°C

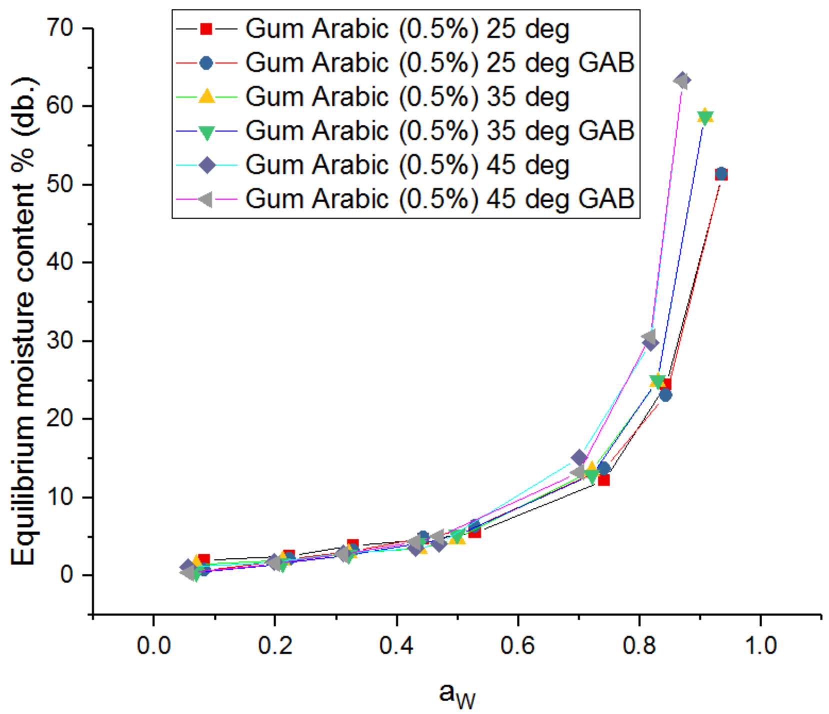


Fig. 4.5: Sorption isotherms of gum arabic coated (0.5% concentration) jaggery samples at 25, 35 and 45°C

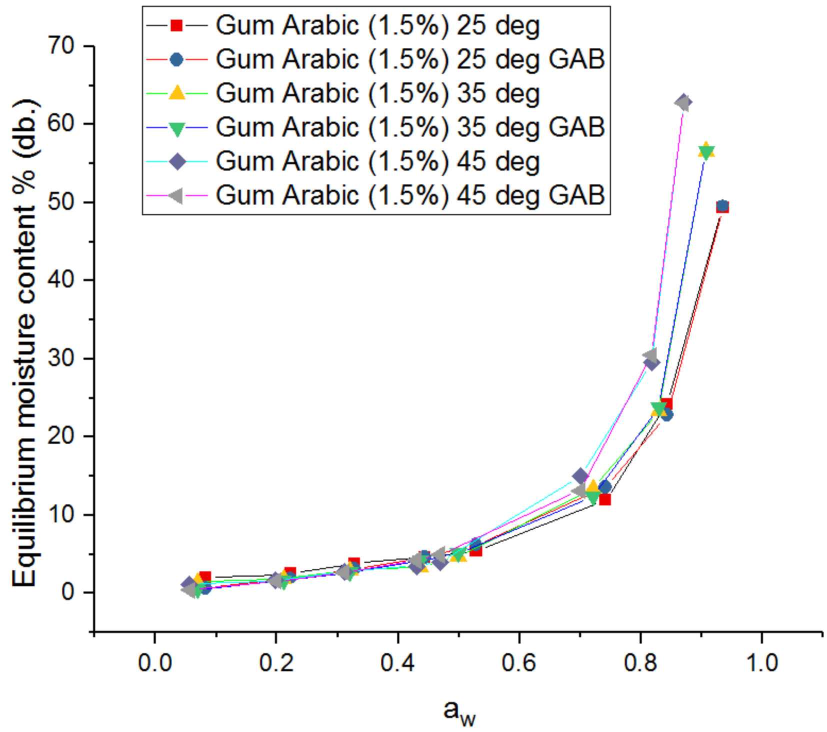


Fig. 4.6: Sorption isotherms of gum arabic coated (1.5% concentration) jaggery samples at 25, 35 and 45°c

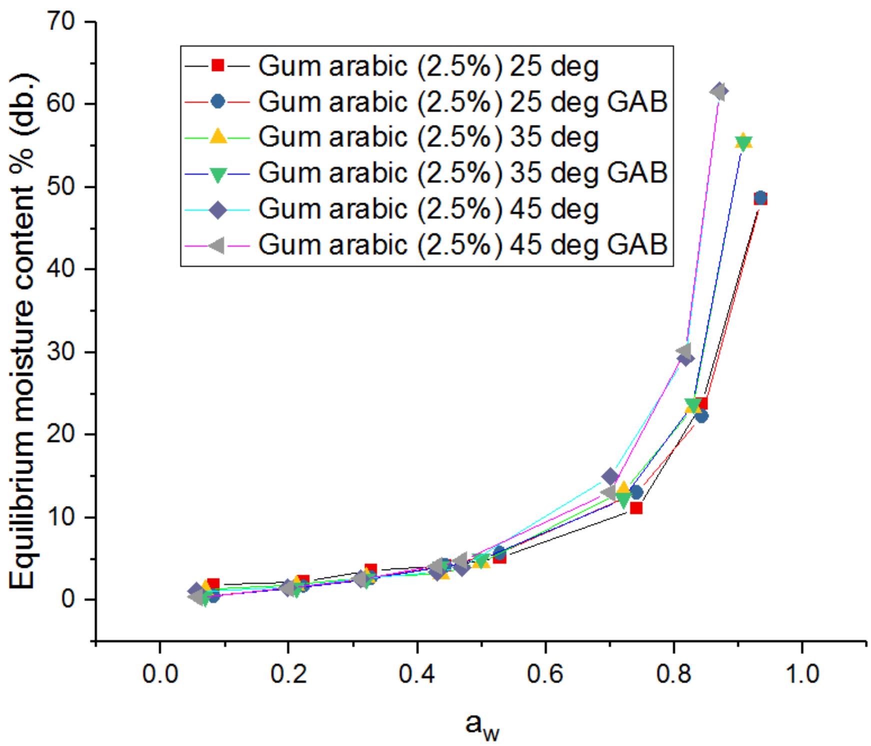


Fig. 4.7: Sorption isotherms of gum arabic coated (2.5% concentration) jaggery samples at 25, 35 and 45°C

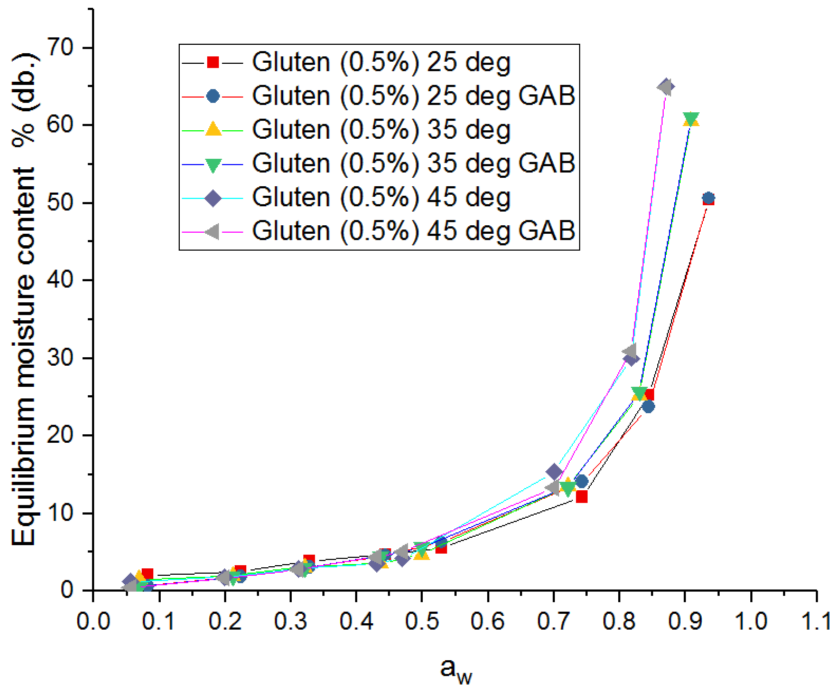


Fig. 4.8: Sorption isotherms of gluten coated (0.5% concentration) jaggery samples at 25, 35 and 45°C

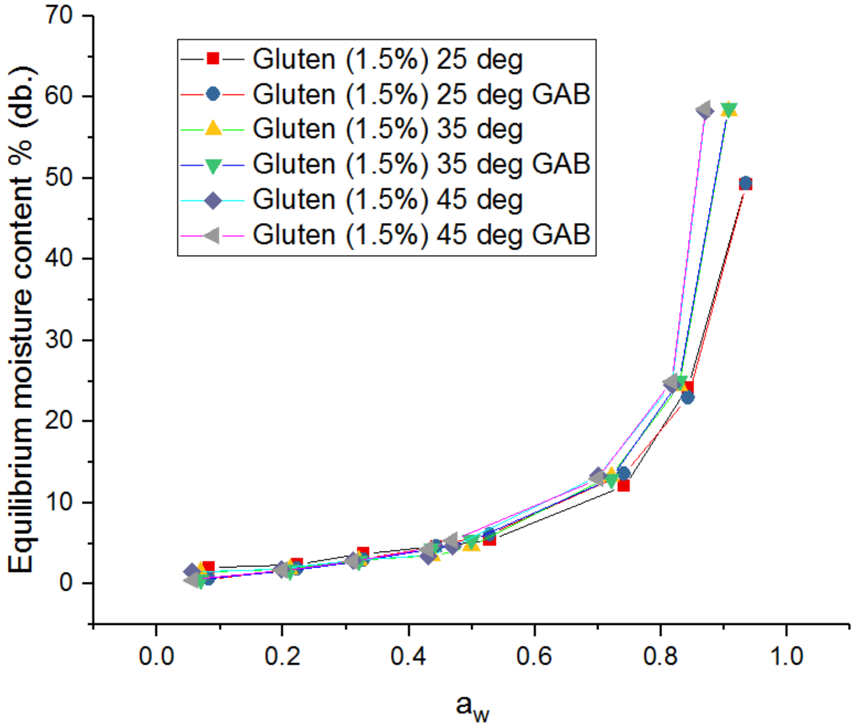


Fig. 4.9: Sorption isotherms of gluten coated (1.5% concentration) jaggery samples at 25, 35 and 45°C

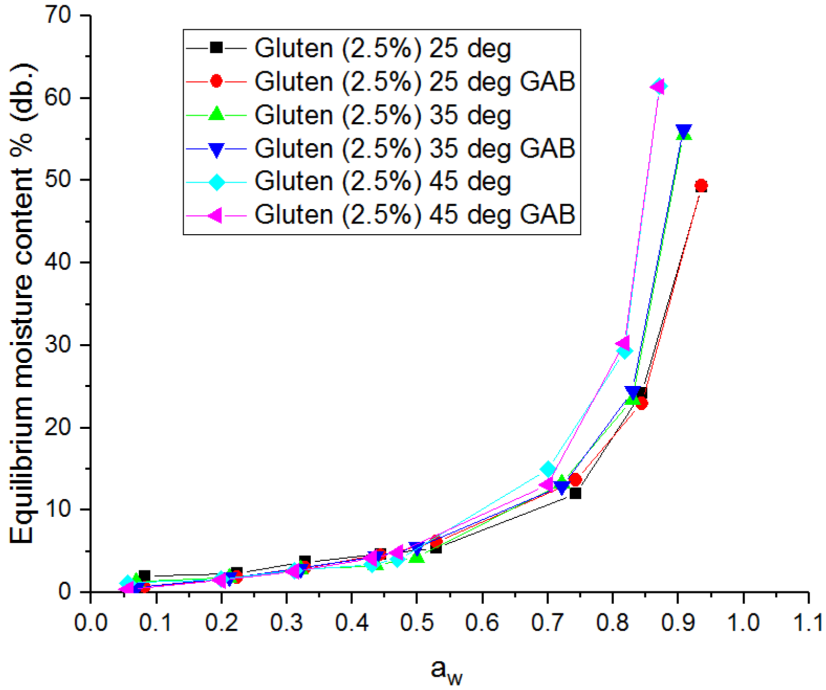


Fig. 4.10: Sorption isotherms of gluten coated (2.5% concentration) jaggery samples at 25, 35 and 45°C

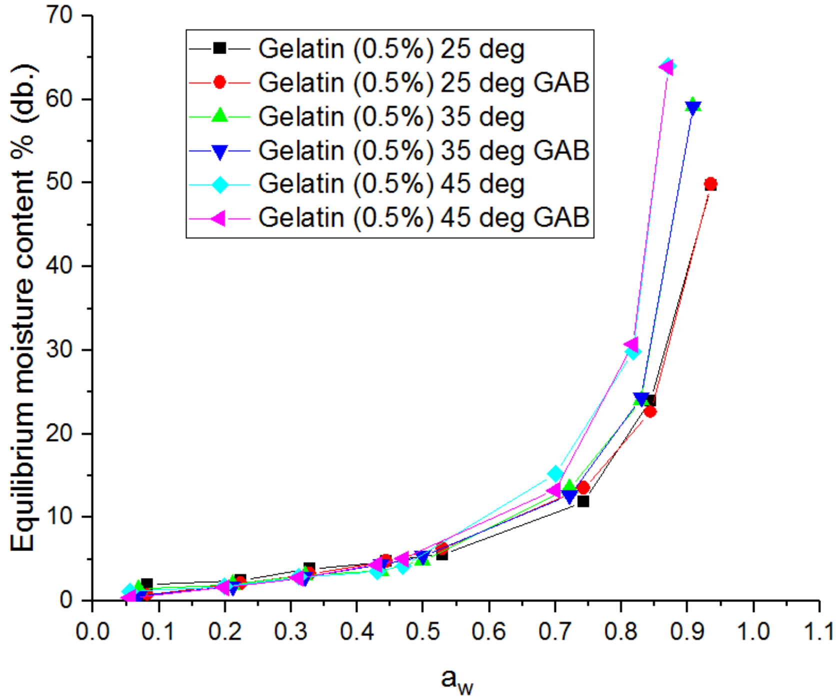


Fig. 4.11: Sorption isotherms of gelatin coated (0.5% concentration) jaggery samples at 25, 35 and 45°c

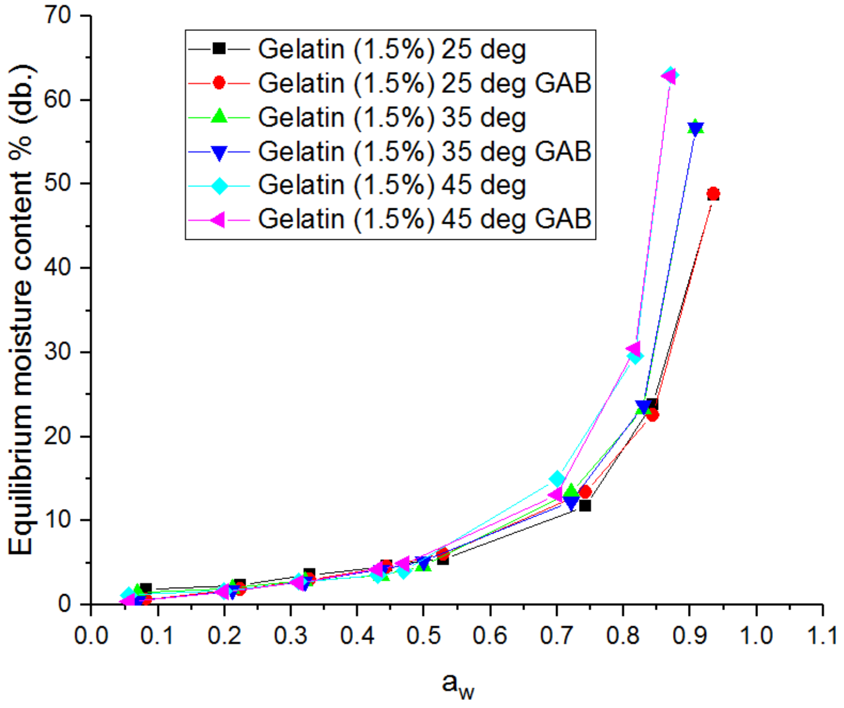


Fig. 4.12: Sorption isotherms of gelatin coated 1.5% concentration) jaggery samples at 25, 35 and 45°C

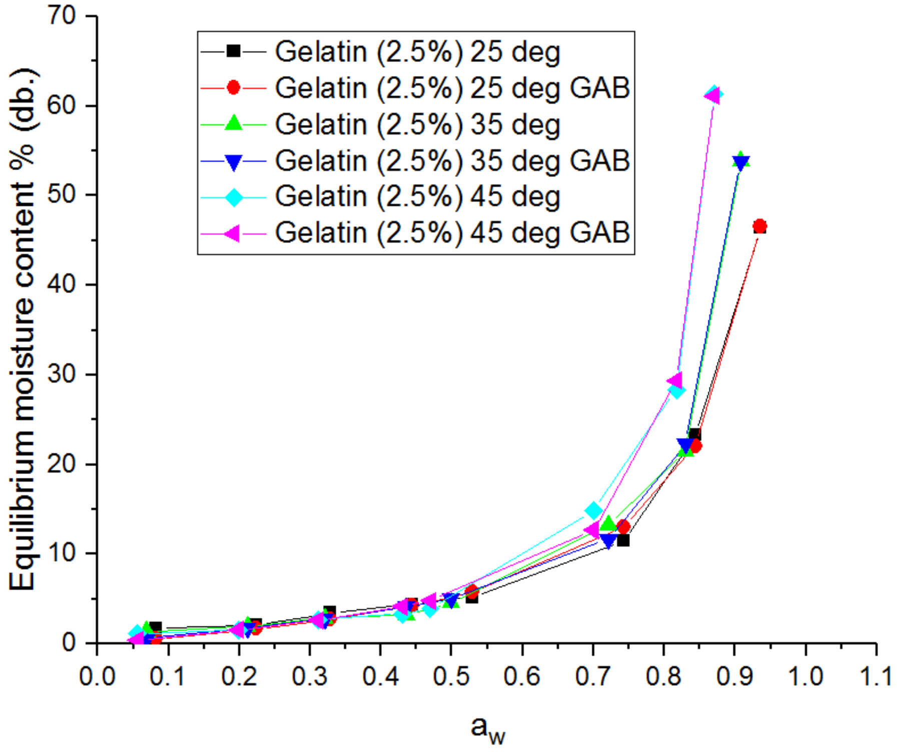


Fig. 4.13: Sorption isotherms of gelatin coated (2.5% concentration) jaggery samples at 25, 35 and 45°C

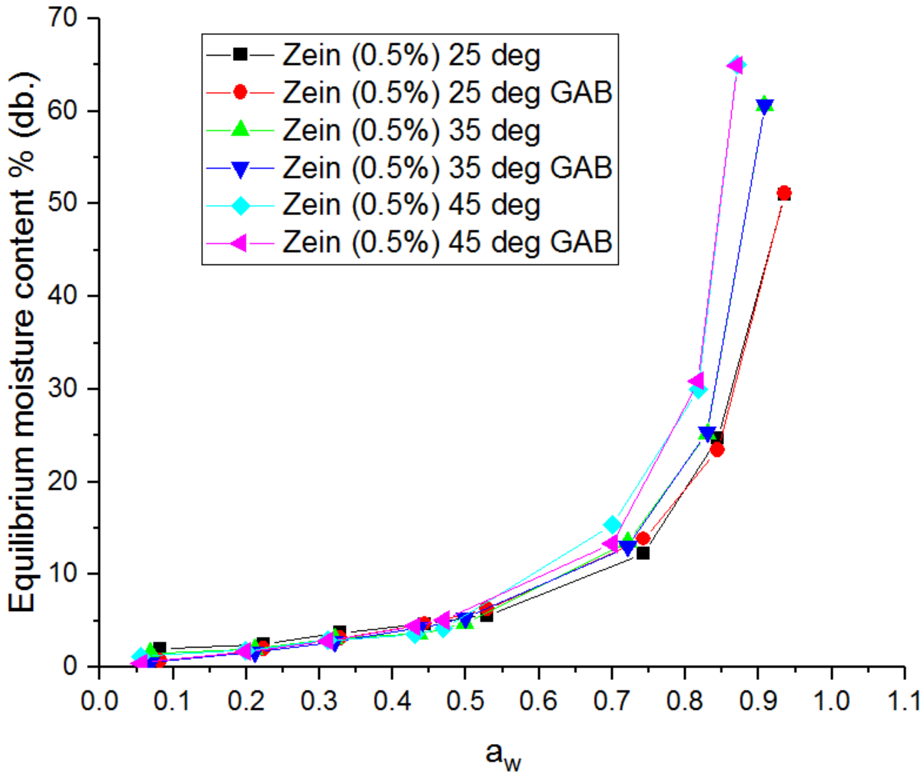


Fig. 4.14: Sorption isotherms of zein coated (0.5% concentration) jaggery samples at 25, 35 and 45°C

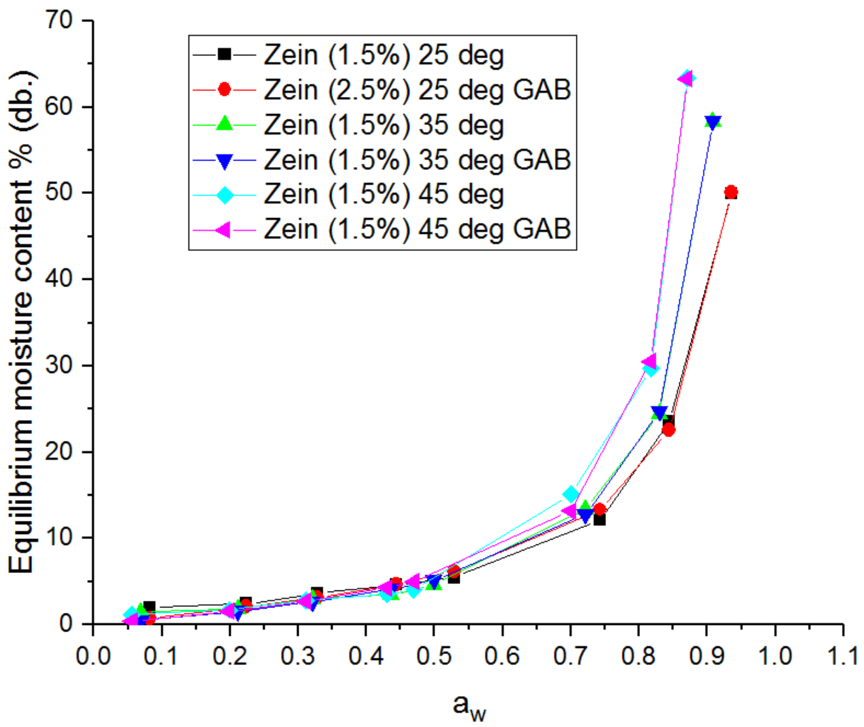


Fig. 4.15: Sorption isotherms of zein coated (1.5% concentration) jaggery samples at 25, 35 and 45°C

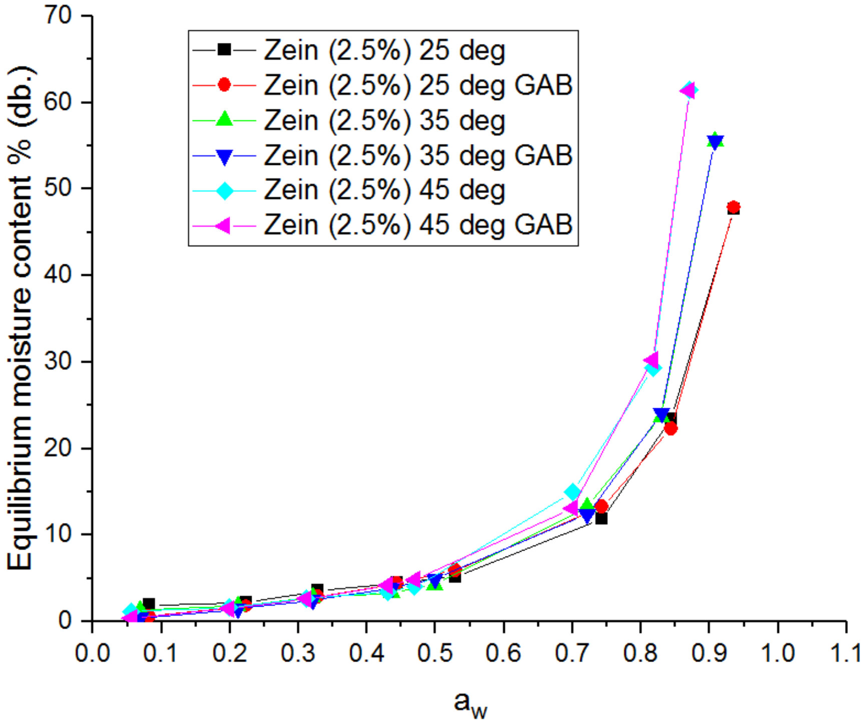


Fig. 4.16: Sorption isotherms of zein coated (2.5% concentration) jaggery samples at 25, 35 and 45°C

4.1.4 Heat of sorption

The net isosteric heat of sorption for solid jaggery samples coated with whey protein concentrate, gluten, gelatin, zein and gum arabic edible coatings at different moisture contents obtained from respective isotherms are shown in Figure (17-21) respectively. All the samples show similar trends. The net isosteric heat of solid jaggery without edible coating decreased from 3.257 kJ/mol to 2.667 kJ/mol with increased in moisture content from 5 to 45 % (db.). A similar decreasing trend of net isosteric heat of sorption to the solid jaggery with whey protein concentrate, wheat gluten, zein, gelatine and gum arabic edible coatings with increase of temperature and increased with increase of temperature for moisture content from 5 to 45% (db.). This trend is similar to those reported by other researchers for agricultural, food, and medicinal and aromatic plants (Hossain *et al.*, 2001; Iglesias and Chirife 1976).

Isosteric heat of sorption was large at low moisture content and was found to be decrease exponentially with the increase in moisture content. The net isosteric heat of sorption is defined as the amount of energy by which the heat of vaporization of moisture in a product exceeds the latent heat of pure water (Labuza, 1968). It gives a measure of the water-solid binding strength. The isosteric heat is strongly dependent on moisture content. Isosteric heat of sorption provides information of the state of sorbed water and thus a measure of physical, chemical and microbiological stability of food material under a given storage condition can be known. An attempt to evaluate relationship between net isosteric heat of sorption (q_{st}) and moisture content (M), Tsami *et al*., (1990) proposed an empirical exponential correlation (equation 4.1) as:

$$q_{st} = q_o e^{-\alpha M} \tag{4.1}$$

Where α and (q_o) are the characteristics parameters.

An attempt to evaluate relationship between net isosteric heat of sorption (q_{st}) and moisture content (M) proposed an empirical exponential correlation as shown in Table 4.1.

Table 4.1: Exponential relationship between isosteric heat of sorption and moisture content for adsorption process

S.No	Solid jaggery Sample	Exponential equation	Correlation coefficient, R
1	Uncoated jaggery	$y = 3.3399e^{-0.005x}$	0.930
2	0.5% WPC	$y = 3.322e^{-0.005x}$	0.985
3	1.5% WPC	$y = 3.3513e^{-0.005x}$	0.987
4	2.5% WPC	$y = 3.3714e^{-0.005x}$	0.988
5	0.5% gluten	$y = 3.3856e^{-0.006x}$	0.970
6	1.5% gluten	$y = 3.3787e^{-0.006x}$	0.978
7	2.5% gluten	$y = 3.4103e^{-0.006x}$	0.982
8	0.5% gelatin	$y = 3.3935e^{-0.006x}$	0.956
9	1.5% gelatin	$y = 3.3831e^{-0.006x}$	0.976
10	2.5% gelatin	$y = 3.3876e^{-0.005x}$	0.982
11	0.5% zein	$y = 3.3186e^{-0.005x}$	0.979
12	1.5% zein	$y = 3.3536e^{-0.005x}$	0.983
13	2.5% zein	$y = 3.3815e^{-0.005x}$	0.989
14	0.5% gum arabic	$y = 3.3257e^{-0.005x}$	0.992
15	1.5% gum arabic	$y = 3.3473e^{-0.005x}$	0.990
16	2.5% gum arabic	$y = 3.3751e^{-0.005x}$	0.992

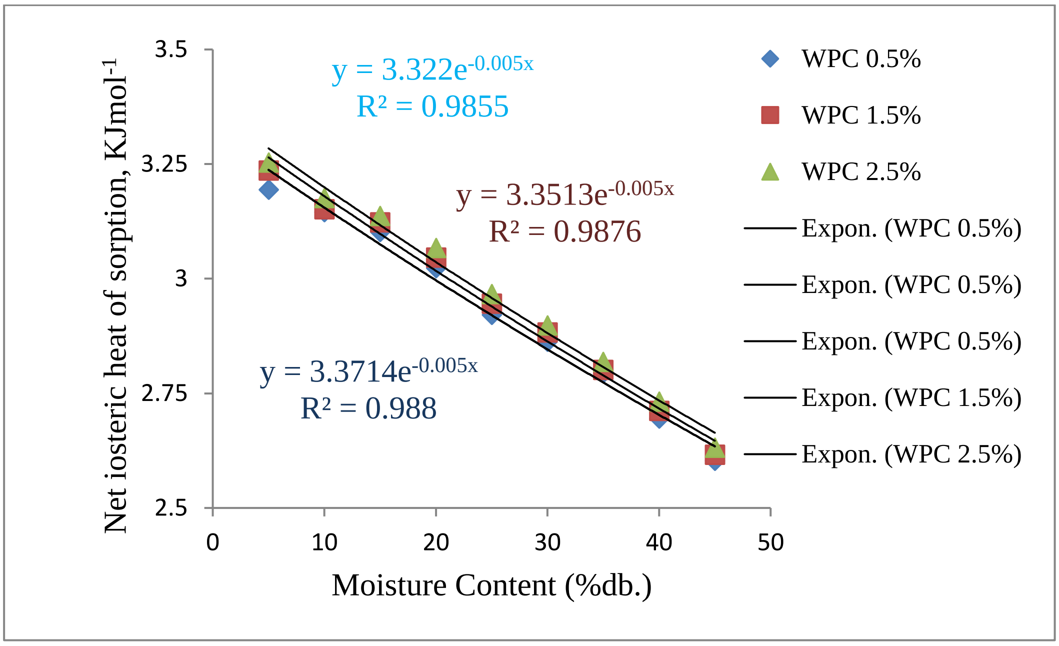


Fig. 4.17: Net isosteric heat of sorption of whey protein concentrate (0.5%, 1.5% and 2.5%) coated solid jaggery sample

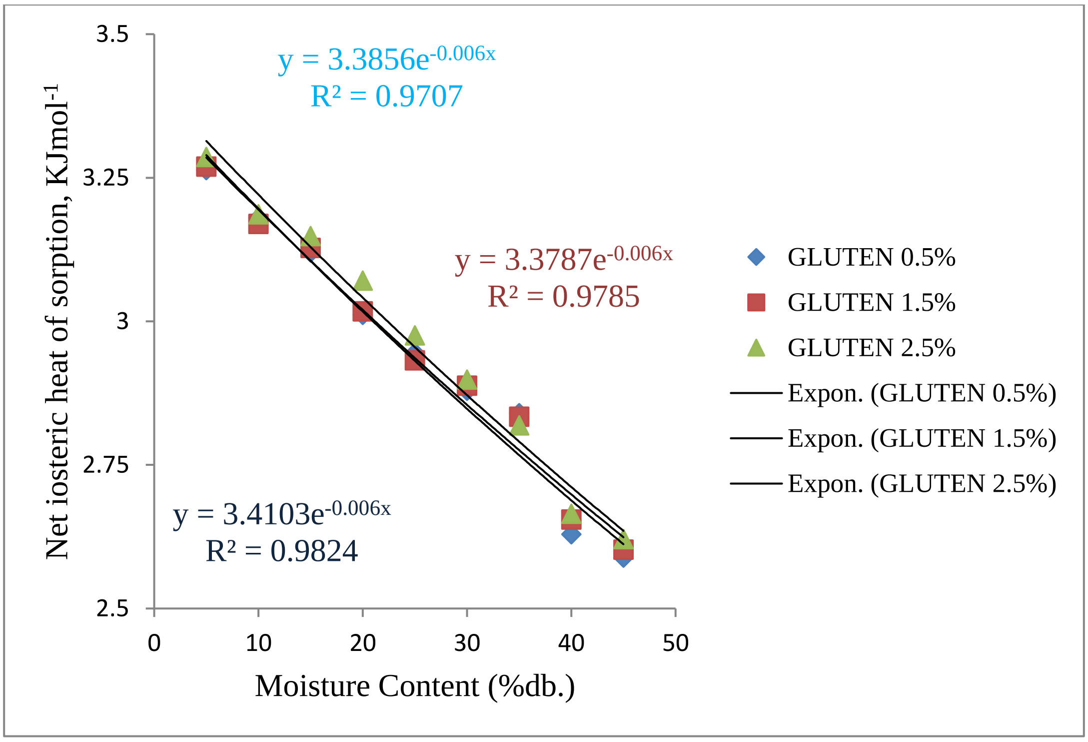


Fig. 4.18: Net isosteric heat of sorption of gluten (0.5%, 1.5% and 2.5%) coated solid jaggery sample

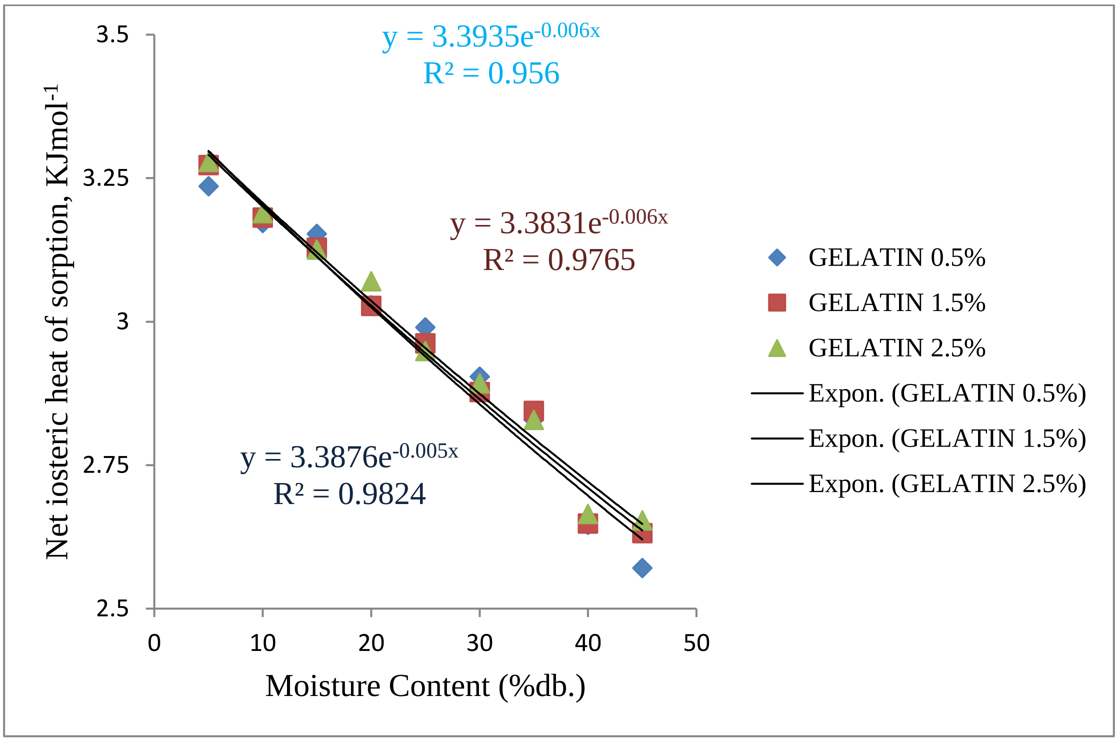


Fig. 4.19: Net isosteric heat of sorption of gelatin (0.5%, 1.5% and 2.5%) coated solid jaggery sample

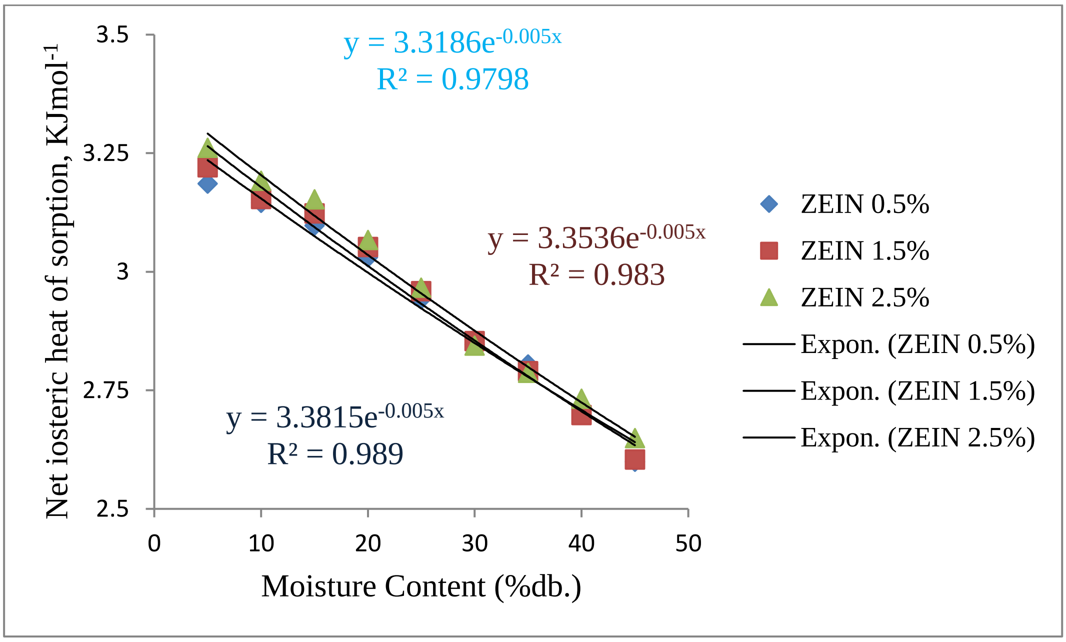


Fig. 4.20: Net isosteric heat of sorption of zein (0.5%, 1.5% and 2.5%) coated solid jaggery sample

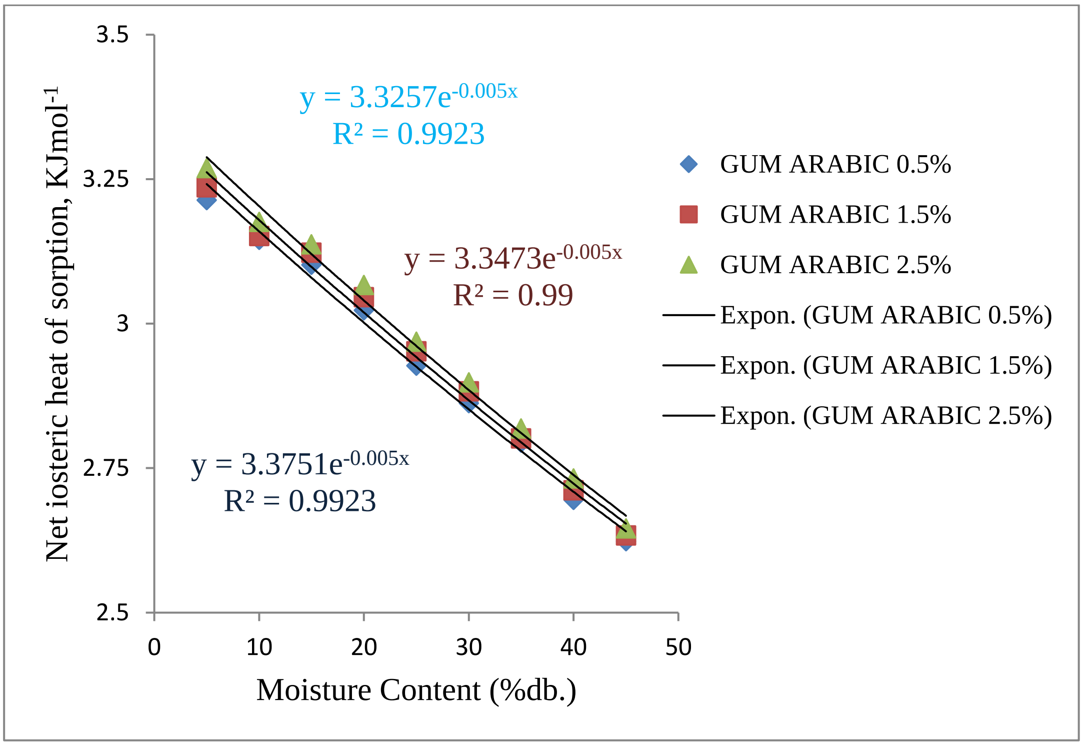


Fig. 4.21: Net isosteric heat of sorption of gum arabic (0.5%, 1.5% and 2.5%) coated solid jaggery sample

4.2 Optimization of Process Parameters for Application of Edible Coating over Solid Jaggery

4.2.1 Fitting the model

Multilevel factorial method was used to optimize the process conditions for the application of edible coating on the solid jaggery to increase the storage period of the solid jaggery. In order to study the effects of the three independent variables viz, A Temperature (T, 35-45^{0}C), B concentration of edible coating (0.5-1.5%), C water activity ($a_{w,\%}$) and five edible coatings on Equilibrium moisture content of the solid jaggery, Multi-level factorial methodology was applied. Table 2 represents the coefficients R^2, adjusted R^2, standard deviation (SD), mean and CV %. The results revealed that the Equilibrium moisture content (% db.) was in the range of 1.16% to 65.053 % under experimental conditions. The highest equilibrium moisture content 65.053% was observed at temperature, water activity, concentration of edible coating and type of edible coating of 45^{0}C, 0.9%, 0.5% and edible coating 4 (i.e. corn zein) respectively. The lowest equilibrium moisture content 1.16% was observed at temperature, water activity, concentration of edible coating and type of edible coating of 45^{0}C, 0.1%, 2.5% and edible coating 1 (i.e. whey protein concentrate) respectively (Appendix-B).

Analysis of variance (ANOVA) showed that the resultant second order polynomial model adequately represented the experimental data with the coefficient of multiple determinations (R^2) and adjusted R2 for the equilibrium moisture content (EMC), being 0. 9998 and 0.9998, respectively (Table.4.2).

Table 4.2: Analysis of variance (ANOVA)

S.No		EMC (% db.)
1	Std. Dev.	0.28
2	Mean	13.87
3	C.V. %	2.05
4	R-Squared	0.9998
5	Adj R-Squared	0.9997

4.2.3 Analysis of variance for selected models

The Model F-value of 17355.77 implies the model was significant. There was only a 0.01% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms were significant. In this case A, B, C, D, AB, AC, AD, BC, CD were significant model terms. Values greater than 0.1000 indicate the model terms were not significant.

Table 4.3: ANOVA showing the coefficient quadratic model for equilibrium moisture content

Source	Sum of Squares	df	Mean Square	F Value	p-value
Model	1.168E+005	83	1406.82	17355.77	< 0.0001
A-Temp	300.25	2	150.13	1852.08	< 0.0001
B-Conce	37.81	2	18.90	233.21	< 0.0001
C-Aw	1.148E+005	7	16395.96	2.023E+005	< 0.0001
D-Edible Coating	3.73	4	0.93	11.49	< 0.0001
AB	2.09	4	0.52	6.43	< 0.0001
AC	1570.00	14	112.14	1383.49	< 0.0001
AD	1.32	8	0.16	2.03	0.0428
BC	69.51	14	4.97	61.25	< 0.0001
CD	9.68	28	0.35	4.27	< 0.0001
Residual	22.37	276	0.081		
Cor Total	1.168E+005	359			

4.2.4 Normal plot of residuals

The fig. 4.22 shows the normal plot of residuals was plotted between the externally studentized residuals and normal % probability. The normal probability plot indicates whether the residuals follow a normal distribution, in this figure the EMC points will follow a straight line. Expect some moderate scatter even with normal data. Look only for definite patterns like an "S-shaped" curve, which indicates that a transformation of the response may provide a better analysis.

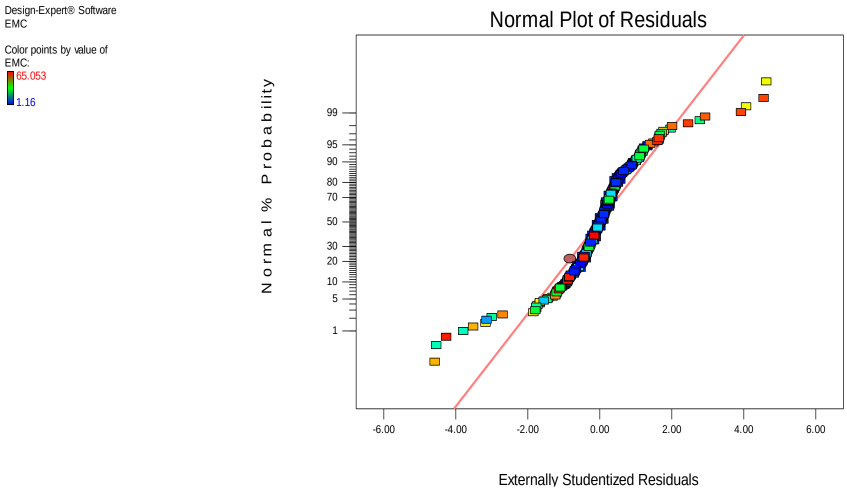


Fig. 4.22: Normal plot of residuals

Fig. 4.23 shows 3D- surface plot of the equilibrium moisture content as a function of water activity and storage temperature and revealed that the water activity showed a positive linear effect on equilibrium moisture content. At very low water activity, the equilibrium moisture content was less and increased significantly with an increase in the water activity.

Fig. 4.24 is a response surface plot showing the effect of different edible coatings and water activity on the equilibrium moisture content. For all edible coatings, the equilibrium moisture content increased linearly with the increase in water activity. An increase in the water activity increases the equilibrium relative humidity.

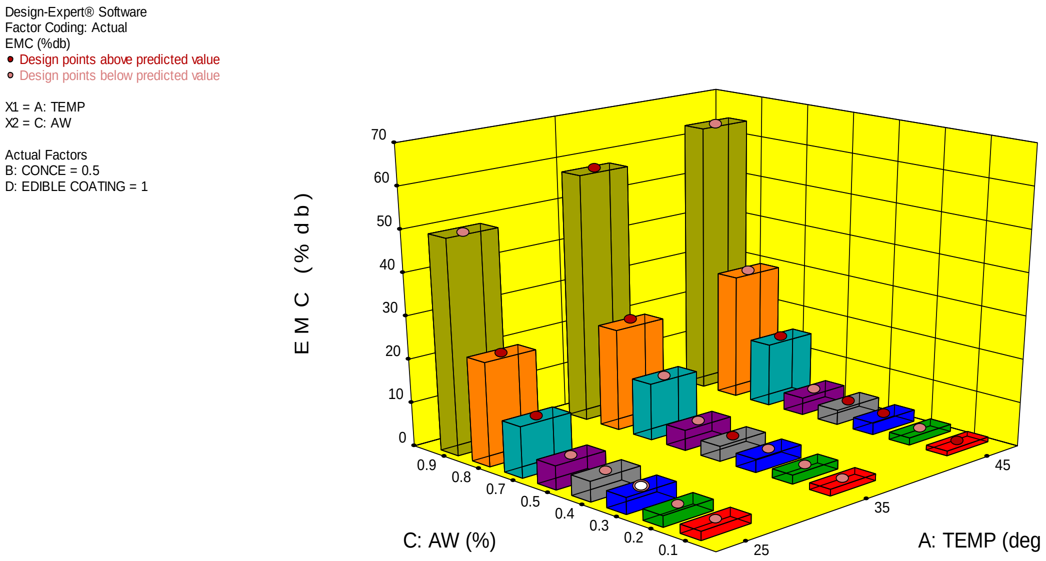


Fig. 4.23: 3D- Surface plot of the equilibrium moisture content as a function of water activity and storage temperature

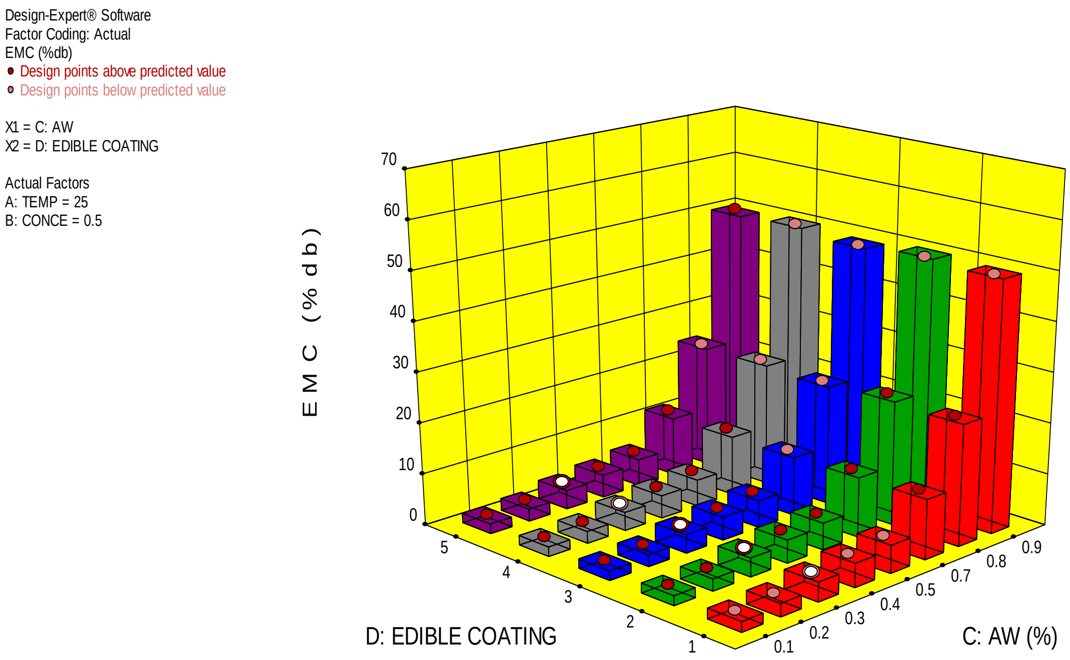


Fig. 4.24: 3D- Surface plot of the equilibrium moisture content as a function of different edible coatings and water activity

4.2.5 Optimization of process parameters for application of edible coating over solid jaggery

Response optimization was conducted to predict the optimum levels of independent variables leading to the desired response goal. In order to check the optimized conditions, a numerical optimization was employed. Temperature, equilibrium moisture content, water activity and concentration of edible coating kept minimum, edible coating was within the range. The numerical optimization results showed that the overall optimum area was predicted to be obtained by the application of edible coating over solid jaggery at the combined level of 25^{0}C, 0.1%, 0.5% and whey protein concentrate (i.e. edible coating 1) for temperature, water activity, coating concentration and edible coating, respectively with desirability of 0.884% by response surface plots and response optimizer. The corresponding predicted values based on the final reduced model for equilibrium moisture content were 5.649% (db.)

Table 4.4: Optimization criteria for different factors and responses

Constraints name	Goal	Lower limit	Upper limit	Lower weight	Upper weight	Importance
Temperature	minimize	25	45	1	1	3
Concentration	in range	0.5	2.5	1	1	3
Water activity	minimize	0.1	0.9	1	1	3
Edible coating	in range	1	5	1	1	3
EMC	minimize	4	20	1	1	3

4.3 Properties of Packaging Materials

Fig. 4.24 showed Cumulative moisture gain with time by silica gel kept in three pouches (LDPE, HDPE and pp) at 38±2^{0}C temperature and 90±1% relative humidity. Calculated value of slope of the best fit straight lines of LDPE, HDPE and PP were 0.0001 kg.day^{-1}, 0.0005 kg.day^{-1} and 0.0006 kg.day^{-1} respectively. The surface area (A) for LDPE and HDPE was 0.03375m^2 and for PP 0.03225 m^2. The saturated vapour pressure (P) of water at 40^{0}C is 7375.02 Pa. by putting these values in the equation 3.22. We determined the values of water vapour transmission rates and permeability of selected three packaging materials and were presented in the Table 4.5. Table.4.5 reveals that Low density polyethylene (LDPE) had lowest permeability followed by polypropylene (PP) and high density poly ethylene (HDPE).

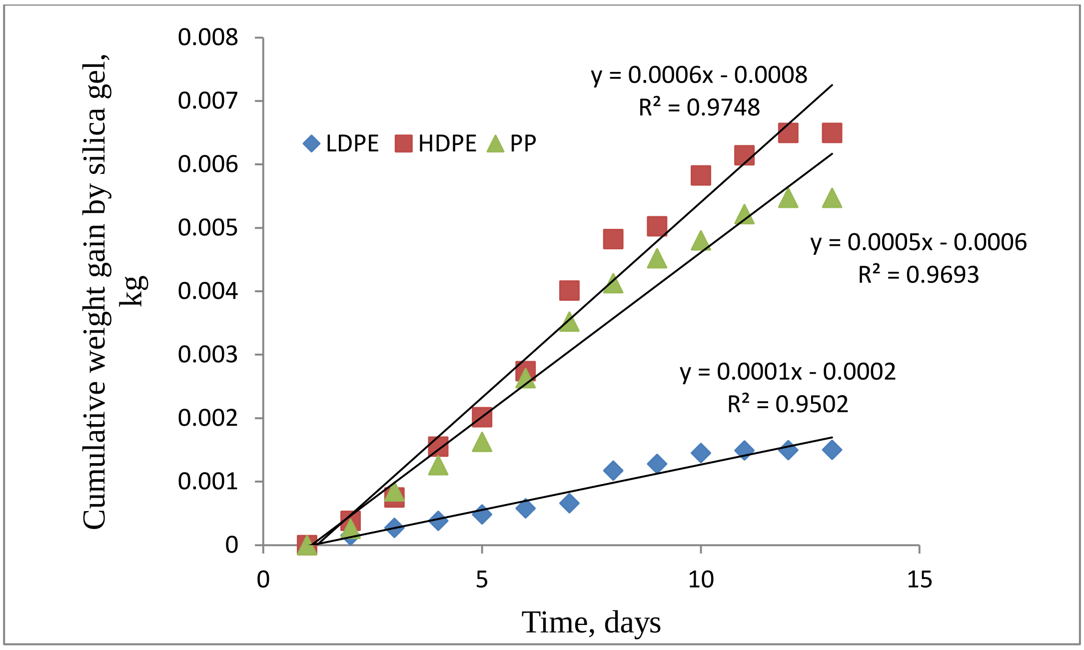


Fig. 4.25: Cumulative moisture gain by silica gel through different packaging materials with time of storage in controlled environment

Table 4.5: Specifications of packaging materials used in the storage study

S.No	Material	Thickness (micron)	Area (m^2)	WVTR (kg water/day×m^2)	Permeability (kg water/day×m^2×pa)
1	LDPE	87.5	0.03375	0.00011396	0.000001352
2	HDPE	40	0.03375	0.00068376	3.7085E-06
3	PP	37.5	0.03225	0.0005963	3.03204E-06

4.4 Determination of Shelf-Life of Edible Coated Jaggery during Accelerated Storage

The initial moisture contents Xi of the 0.5% concentrated WPC and gum arabic edible coated solid jaggery were 0.00964 and 0.00967 kg water/kg dry solids respectively and the critical moisture content Xc of the 0.5% concentrated WPC and gum arabic edible coated solid jaggery placed in the different packaging material when stickiness started were given in the Table 4.6. Substituting saturation vapour pressure of water at 40°C from steam table as 7.37502 kPa, the relative humidity

(Rh) of the storage environment as 0.9, The surface area (A) for LDPE and HDPE was 0.03375m^2 and for PP 0.03225 m^2 and water vapour permeability of the pouch material as LDPE, HDPE and PP were 1.352×10^{-8} kg water/day ×m^2×pa, 3.708×10^{-8} kg water/day×m^2×pa and 3.032×10^{-8} kg water/day×m^2×pa and the amount of dry solids in 50 gm of both WPC and gum arabic edible coated solid jaggery presented in table 4.6 in Eq. (10), the numerical solution of Eq. (4) resulted in the graphical relationship between the time of storage and the moisture content of the honey powder (Fig. 4).. These findings are in similar line with various previous research outcomes. It was observed that mango and watermelon juice powder showed stickiness and significant caking at 8.9 %(db) and 5 %(db) moisture content respectively (Jaya and Das 2005; Arya *et al*. 1986). Experiments also revealed higher storage life of vacuum puffed honey powder in compared to 2 months and 105 days experimental shelf life of watermelon and mango juice powder respectively (Jaya and Das 2005; Arya *et al.* 1986).

Table 4.6: Shelf-life of edible coated jaggery during accelerated storage

S.NO	Treatment	Initial weight gms	Dry weight, kg	$X_{i,}$ (kg water/kg dry solids)	X_c (Kg water/kg dry solids)	Predicted storage life, days
1	T1	49.625	0.04914	0.00964	0.01814	237.022
2	T2	50.234	0.04974	0.00964	0.01869	255.443
3	T3	49.547	0.04906	0.00964	0.02588	164.729
4	T4	50.008	0.04952	0.00964	0.02683	175.968
5	T5	47.128	0.04667	0.00964	0.02502	189.961
6	T6	49.269	0.04879	0.00964	0.02461	193.326
7	T7	50.274	0.04970	0.00967	0.0177	231.202
8	T8	50.048	0.04956	0.00967	0.01828	245.823
9	T9	49.974	0.04949	0.00967	0.02472	156.376
10	T10	48.634	0.04816	0.00967	0.02627	167.843
11	T11	47.857	0.04739	0.00967	0.02451	188.960
12	T12	49.028	0.04855	0.00967	0.02429	190.707

The predicted storage life of solid jaggery with edible coating packed under MAP and Vacuum condition in LDPE, HDPE and PP packets were presented in the table 4.6. The minimum predicted storage life i.e. 156.37 days was observed in the 0.5% concentrated gum arabic edible coated solid jaggery packed in HDPE with MAP packaging machine and the maximum predicted storage life i.e. 255.44 days was obtained in the 0.5% WPC edible coated solid jaggery packed in LDPE with vacuum packaging machine. The storage life of edible coated jaggery was maximum in LDPE with vacuum packing followed by PP and HDPE.

4.5 Physico-chemical Characteristics of Solid Jaggery

4.5.1 Physico-chemical characteristics of solid jaggery without and with edible coating at temperatures of 25°C during storage period under MAP and Vacuum packed LDPE, HDPE and PP packets.

The freshly prepared solid jaggery cubes (25 gms) without edible coating and with edible coating (0.5% concentration of whey protein concentrate and 0.5% concentration gum arabic) samples packed in LDPE, HDPE and PP with MAP and Vacuum packaging machine was analyzed for its physicochemical characteristics i.e., Moisture content, water activity, hardness, colour, sucrose and reducing sugars and the data is shown in Appendix C1 to C6, with respect to storage period, temperature and packaging material.

4.5.1.1 Water activity

The changes in the water activity of solid jaggery without and with edible coating at temperatures of 25°C during storage period under MAP and Vacuum packed LDPE, HDPE and PP packets are shown in the fig. 4.27. It was found that there was significant differences of a_w for all the samples. The experimental data revealed that the initial water activity of the jaggery samples ranges from 0.373 to 0.384. Water activity of the jaggery samples follows increasing trend as storage period increases. After completion of storage period, the highest value of water activity i.e. 0.421 was found in the solid jaggery sample without edible coating (control) and the lowest value of water activity i.e. 0.387 was found in the solid jaggery sample coated with 0.5% concentration WPC packed in PP pouch with vacuum condition. Comparing the a_w values to the moisture values, it was found that the greater the moisture, the higher the a_w, which agrees with what was reported by Verma and Maharaj (1990) for block panela.

4.5.1.2 Sucrose

The experimental changes in non-reducing sugar (sucrose) content of solid jaggery without and with edible coating at temperatures of 25°C during storage period under MAP and Vacuum packed LDPE, HDPE and PP packets are shown in the Fig. 4.28. The initial sucrose contents of the jaggery sample without coating and with WPC, gum arabic coated jaggery samples were 82.40, 82.29 and 82.25 respectively. There was no significant changes in the sucrose content of the jaggery samples throughout the storage period. It was observed that in the vacuum packed jaggery sample there was less decrease in the sucrose content as compare to the MAP packaging and the WPC coated solid jaggery sample in PP pouch packed with vacuum packing shows the better result as compared to the other samples. Shinde *et al.* (1981) opined that polyethylene of any form and colour prevented inversion of non-reducing sugar. According to the findings of Uppal and Sharma (1999), there was no difference in sucrose content of jaggery of glass and plastic containers. Singh (1998) reported less reduction in sucrose content of jaggery (3.2%-3.6%) kept in plastic containers.

4.5.1.3 Reducing sugars

The changes in reducing sugar content of solid jaggery without and with edible coating at temperatures of 25°C during storage period under MAP and Vacuum packed LDPE, HDPE and PP packets are shown in the Fig. 4.29. It was observed that reducing sugar increased as the storage period increased, but there was least increasing in coated samples as compared to uncoated samples. In the solid jaggery sample without edible coating, there was significant increase in the reducing sugars from 6.84 to 7.11 for the storage period. The data revealed that there was less increase in the reducing sugars in the 0.5% concentration of WPC coated solid jaggery samples packed in PP pouches with vacuum packing throughout storage period from 6.87 to 7.00 as compared to the other samples. The data also revealed that jaggery sample coated with 0.5% WPC gives less increase in the reducing sugar as compared to 0.5% gum arabic coated sample and there was less increasing in the reducing sugars packed in PP pouches followed by LDPE and HDPE. The increase in reducing sugar content in jaggery may be due to inversion of sucrose into glucose and fructose. Shinde *et al.,* (1983) reported that jaggery wrapped in polyethene film showed no inversion of non-reducing sugars during storage and there was almost no change in the reducing sugar values. The decrease in sucrose or the increase in reducing sugars was more or less in accordance with the increase in moisture and it can be inferred that high absorption of moisture creates conditions for inversion (Mandal *et al.*, 2006).

4.5.1.4 Colour

The changes in colour of solid jaggery without and with edible coating at temperatures of 25°C during storage period under MAP and vacuum packed LDPE, HDPE and PP packets are shown in the Fig. 4.31. The results revealed that there was a significant changes in the colour of the uncoated jaggery and there was no significant difference in the colour of the coated jaggery. 0.5% WPC coated jaggery cubes packed in HDPE pouches with vacuum condition shows less change in the colour followed by 0.5% WPC coated jaggery cubes packed in LDPE pouches with MAP packing and 0.5% gum arabic coated jaggery cubes packed in HDPE pouches with MAP packing throughout the storage period. Uppal and Sharma (1999) observed that there was no difference in quality parameters of jaggery stored in airtight glass and plastic containers except the colour, which was better in airtight glass containers.

4.5.1.5 Hardness

The changes in Hardness of solid jaggery without and with edible coating at temperatures of 25°C during storage period under MAP and Vacuum packed LDPE, HDPE and PP packets are shown in the fig. 4.30. The initial hardness in terms of force required in Newton (N) to compress the sample completely was in the range of 14.627 to 17.269 in all the treatment. The data revealed that the hardness of the uncoated, WPC coated and gum arabic coated solid jaggery samples ranges from 14.627 to 12.965N, 17.269 to 14.875 and 16.578 to 14.971 respectively. It was observed from the storage study that hardness followed the decreasing trend throughout the storage period. This can be observed that coating of jaggery samples could have helped in retaining the desirable moisture up to an extent for soft texture while in control lead to an excessive moisture loss from leading to undesirable dry, brittle and hard texture. WPC coated and packed in PP pouch with vacuum package gives the less decrease in the hardness as compared to the other samples. The highest decrease in the hardness was observed in the jaggery sample without coating. This can be observed coating of jaggery samples could help up to some extent in retaining the texture of jaggery.

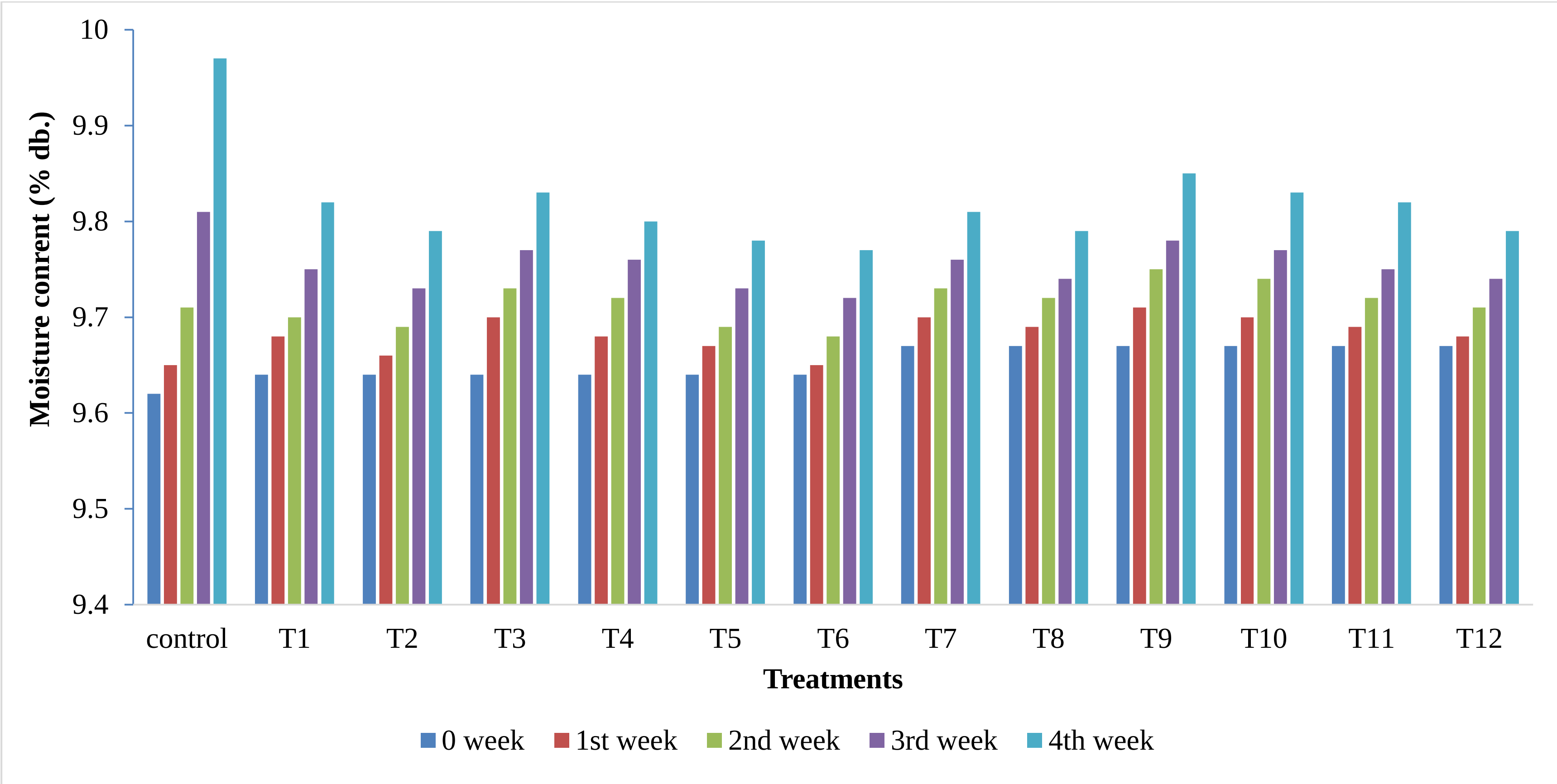


Fig. 4.26: Changes in moisture content of edible coated jaggery stored in different packaging material at 25^{0}C temperature

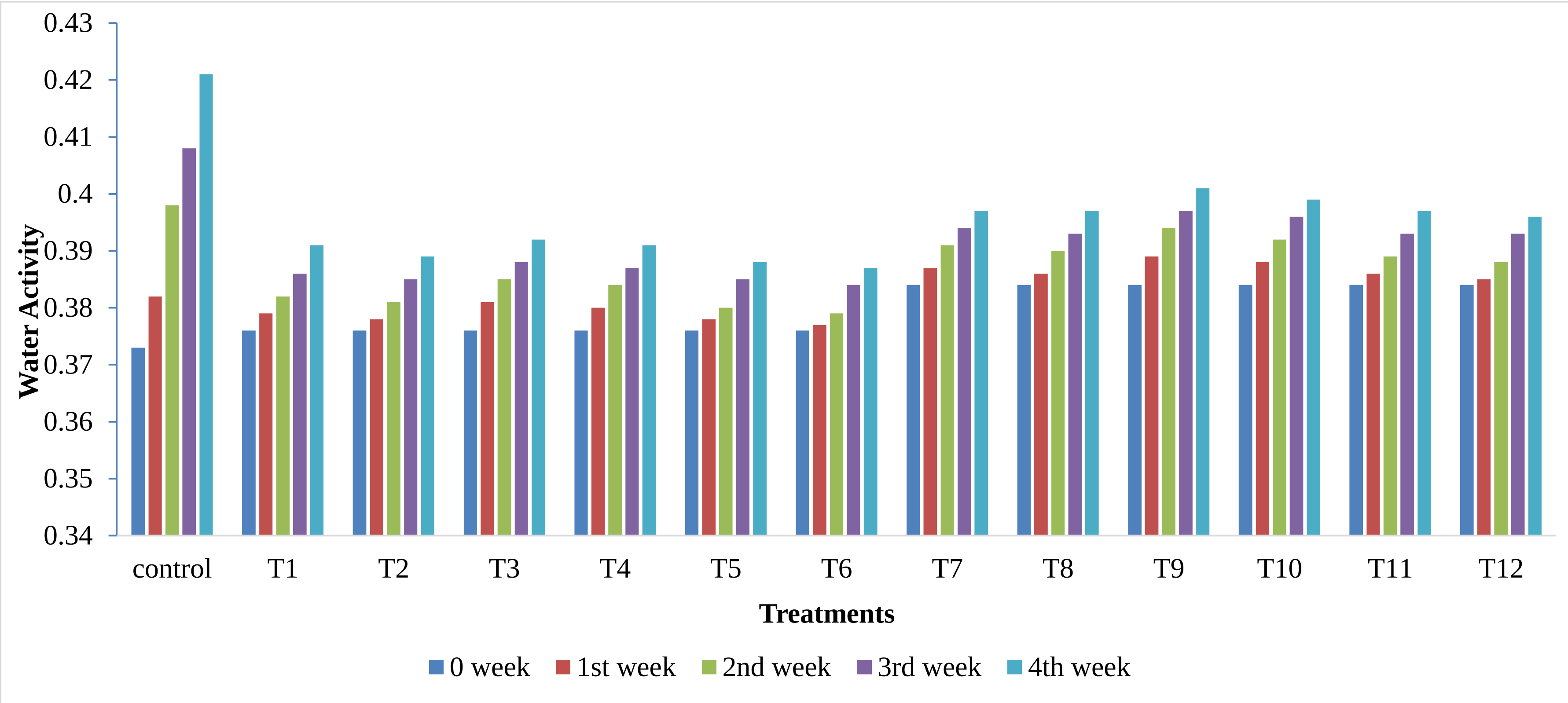


Fig. 4.27: Changes in water activity of edible coated jaggery stored in different packaging material at 25^{0}C temperature

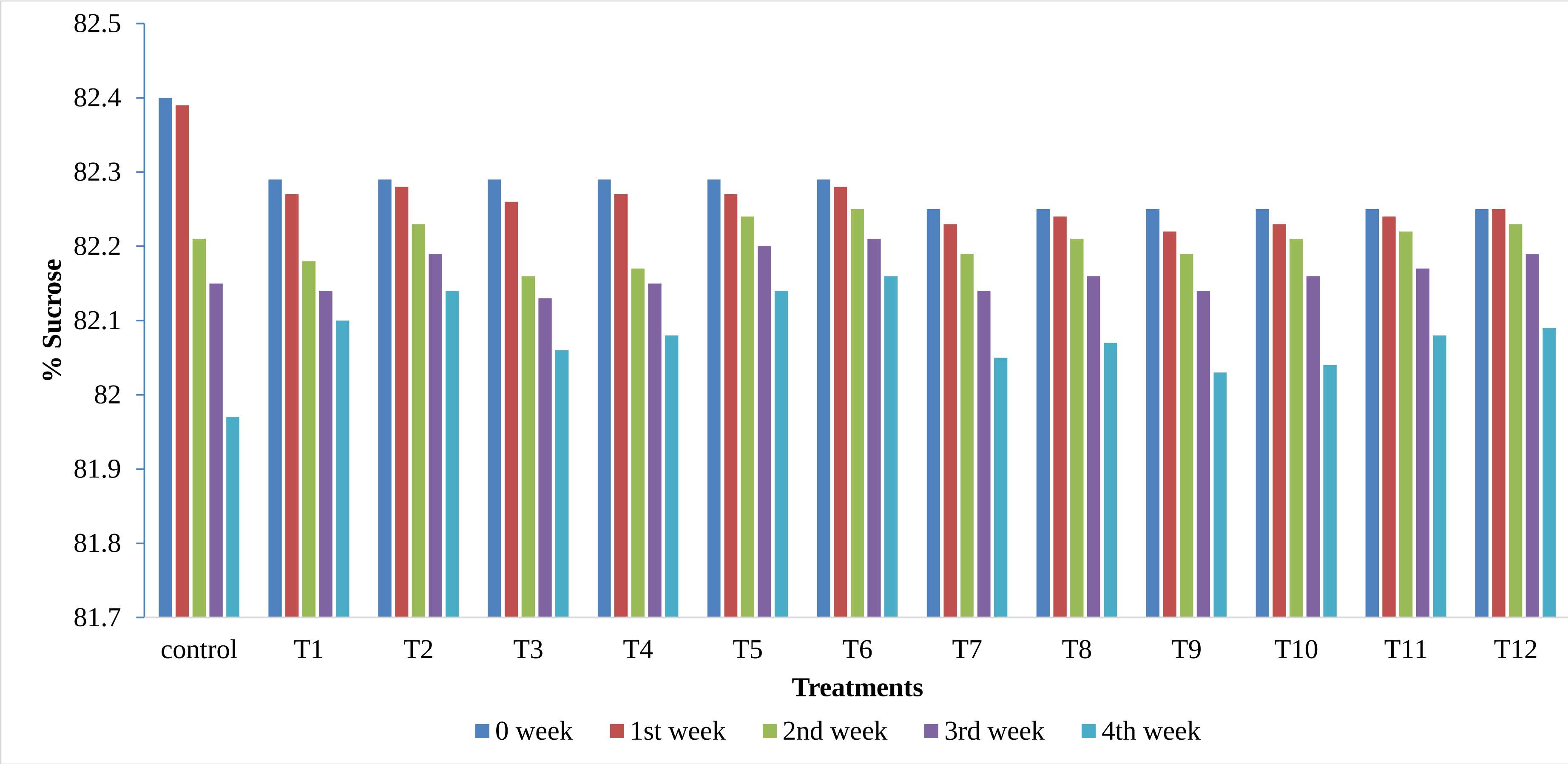


Fig. 4.28: Changes in sucrose (% db.) of edible coated jaggery stored in different packaging material at 25^{0}C temperature

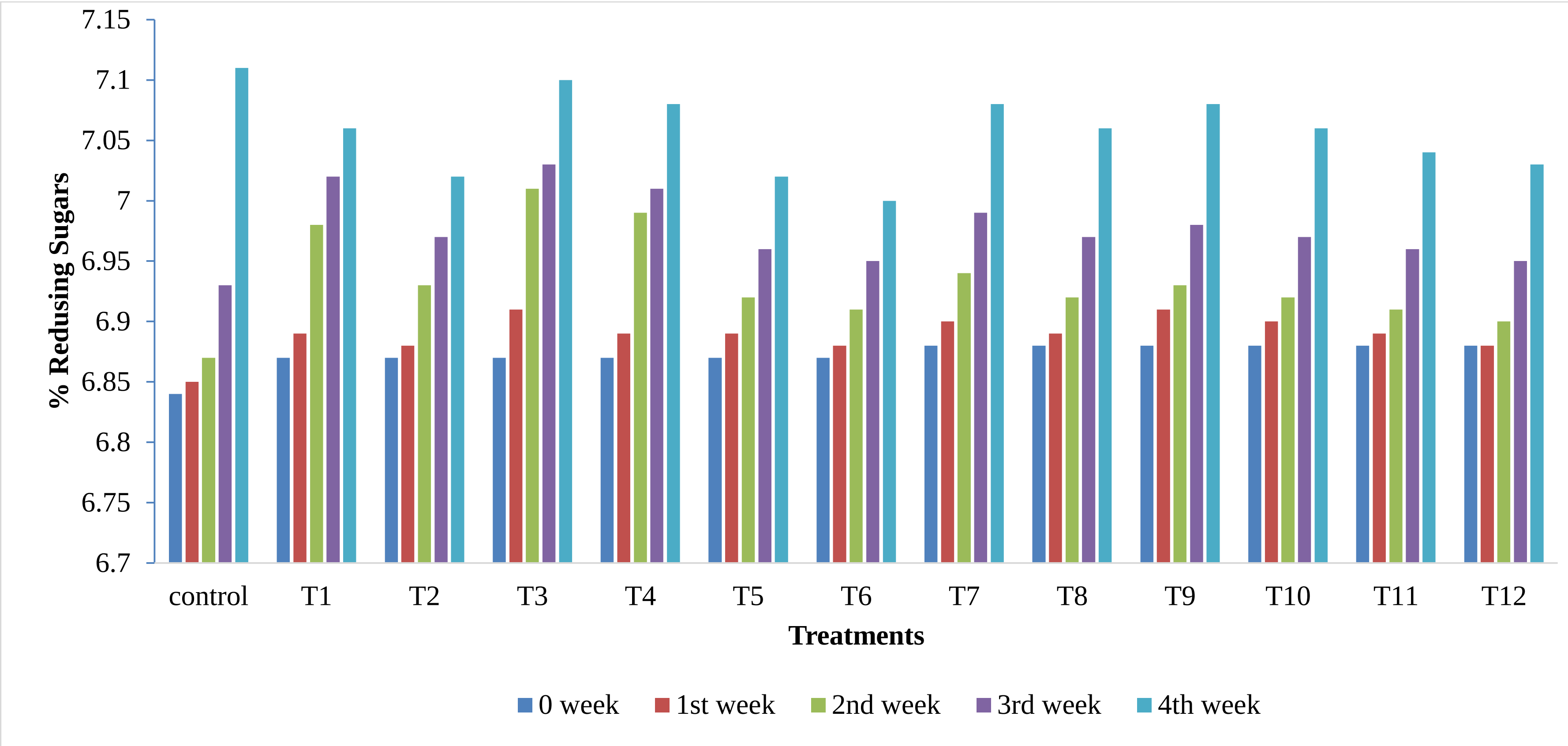


Fig. 4.29: Changes in reducing sugar of edible coated jaggery stored in different packaging material at 25^{0}C temperature

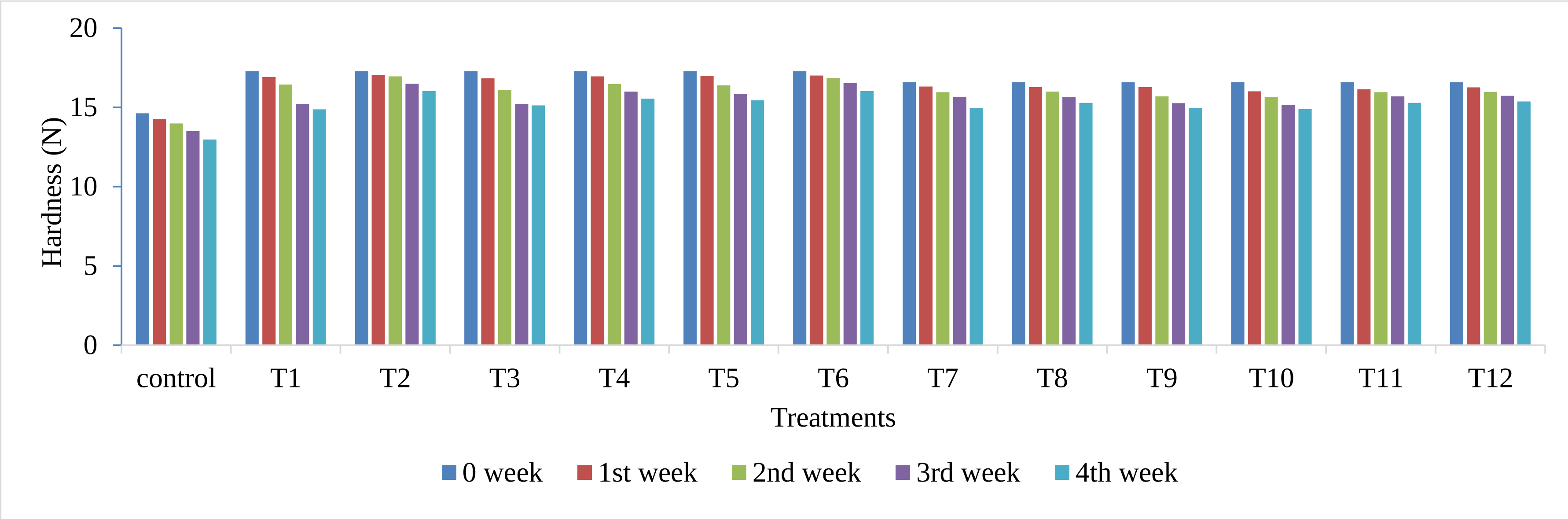


Fig. 4.30: Changes in hardness of edible coated jaggery stored in different packaging material at 25^{0}C temperature

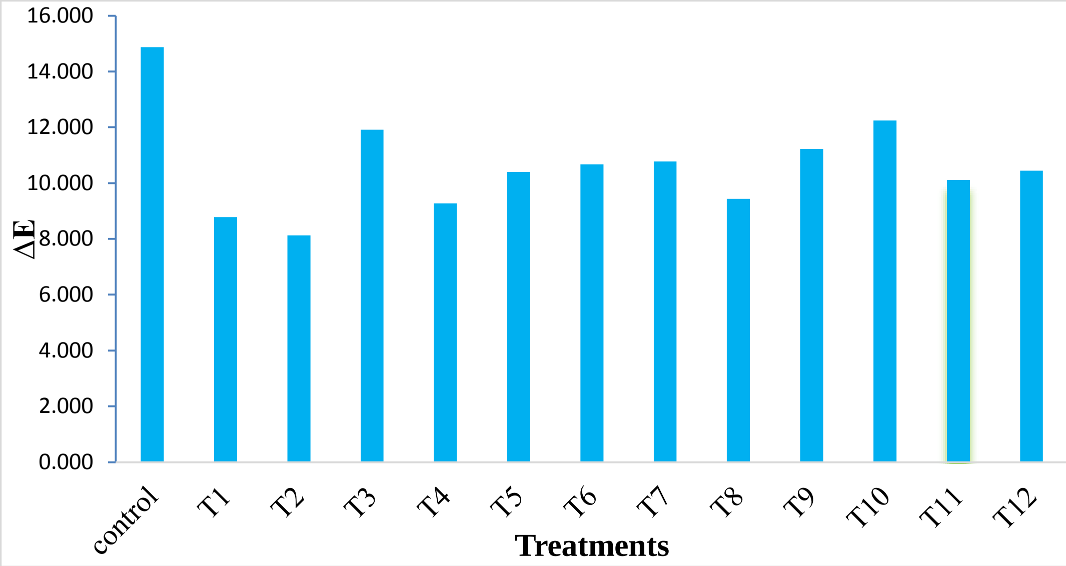


Fig. 4.31: Changes in colour of edible coated jaggery stored in different packaging material at 25^{0}C temperature

4.6 Sensory Evaluation of Quality Parameter of Edible Coated Solid Jaggery

The sensory scores of edible coated Solid jaggery were analysed as described under section 3.5.6 of materials and methods.

4.6.1 Sensory evaluation of edible coated solid jaggery sample using fuzzy logic

Results of sensory scores of twelve edible coated Solid jaggery samples were presented in (Table 4.7 to 4.10) in terms of quality attributes namely, colour, sweetness, flavour and texture/ appearance. The samples S4, S6, S7, S10 and S11 had higher scores for colour; S4, S6, S7, S8, S10 and S11 for sweetness; samples S4, S7, S8, S10 and S11 flavour; and samples S7, S8, S9, S10 and S11 for texture / appearance. Fuzzy membership function (FMF) and normalized fuzzy membership function (NFMF) were the calculated.

As for example, the 'colour' scores of S1 sample were: EX=0, GD=1, MD=3, FR=10 and NS=6 (Table 4.6(a), column 2 and 3). The number of judges was 20. Fuzzy membership function for these scores were calculated as EX (=0/20)=0, GD (=1/20)=0.05, MD (=3/20)=0.15, FR (=10/20)=0.5 and NS (=6/20)=0.03 (Table 4.7, column 4). Similarly the membership functions were calculated for the other quality attributes of all the samples. Normalized fuzzy membership function was then calculated as 0*1+0.05*0.9+0.15*0.7+0.5*0.4+0.03*0.1=0.38 and mentioned in (Table 4.7, column 5). Similarly the membership functions and normalized fuzzy membership function were calculated for the other quality attributes of other two samples (Table 4.7, columns 6-11). The same procedure was repeated for the samples S4, S5 and S6 and was presented in (Tables 4.8, 4.9 and 4.10 respectively. The total of the normalized fuzzy membership function for all the samples are given in row 28 of (Table 4.7). As for example, for S1 sample, the value is 0.38+0.42+0.405+0.395=1.6. Similarly for S2 =2.965, S3=2.96 (Table 4.6); S4=2.3, S5=1.6, S6=3.165 (Table 4.8). From this, it was found that, the maximum of the total of normalized fuzzy membership function for the S1 sample is 1.6. All the normalized fuzzy membership function of the samples was then divided by this value (i.e., 1.6) to find the 'Judgement membership function (JMF)' (Table 4.11 a-d)). As for example, for the sample S1, the value of JMF for colour: 0.38/1.6=0.238; sweetness: 0.42/1.6 =0.263; flavour: 0.405/1.6 =0.253 and texture / appearance: 0.395/1.6 =0.247. The JMF values for sample S1 are given in Table (4.10 (a) (column 2 and 3)). Similarly for other samples S2 (column 4 and 5) and S3 (column 6 and 7) are given in (Table 4.11 (a)). The same procedure was repeated for the samples S4, S5 and S6) and was presented in (Tables 4.11 (b-d) respectively.

The values of judgement membership function were then compared with the average of weightage given by the panelist for each of the quality attributes. The weightage average values for each of the quality attribute were calculated (Tables 4.12 and Table 4.13) as described in the above Para and is given in Table 4.11 (column 2).

The weightage average values for colour, sweetness, flavour and texture / appearance are 0.260, 0.284, 0.230 and 0.225 respectively (Table 4.14, column 2). A comparison of preference of quality attributes for solid jaggery samples showed that weightage average value for Sweetness. (0.284) is the highest followed by Colour (0.260). This is followed by flavour (0.230) and then texture / appearance (Important, 0.225). (Table 4.13). The order of preference of quality attributes for solid jaggery samples in general is as follows: Sweetness > Colour > Flavour > Texture / Appearance. Comparing the weightage average of quality attributes and judgement membership function formed, the minimum of these two was assigned as the quality ranking subset value. As for example, weightage average of colour was

0.260 (Table 4.14, column 2 and row 2) and judgement membership function of the colour of the sample S1 was 0.238(Table 4.14, column 3 and row 1), the minimum of the two values were 0.238 and it was assigned as the quality ranking subset value for the colour of the sample S1 (Table 4.14, column 3 and row 2). Similarly all the quality ranking subset values were assigned to each of the samples for all the quality attributes and are given in Table 4.14.

The rank of a sample was assigned from the maximum of quality ranking subset value of the samples. As for the sample S1, the maximum value of the quality ranking subset values (*viz*., 0.238, 0.264, 0.230 and 0.225) is 0.264. Similarly, quality ranking values for S2, S3, S4, S5 and S6 are 0.264, 0.277, 0.260, 0.272, 0.273 and 0.284 respectively.

Comparing the quality ranking, it was found that score of the sample S6 (edible coated solid jaggery packed in PP pouch with vacuum package, stored at 25^{o}C) is the highest (0.284) based on the score obtained for the quality attribute Sweetness' , followed by S2 (edible coated solid jaggery packed in LDPE pouch with vacuum package, stored at 25^{o}C), S5 (jaggery packed in PP pouch with MAP packaging, stored at 25^{o}C), and S4 (edible coated solid jaggery packed in HDPE pouch with vacuum package, stored at 25^{o}C). Above samples are followed by control samples S1 (edible coated solid jaggery packed in LDPE pouch MAP packaging, stored at 25^{o}C) and S3 (edible coated solid jaggery packed in HDPE pouch with MAP packaging, stored at 25^{o}C).

It was observed that, flavour and texture / appearance score values of all the samples (MAP and Vacuum packaging) was the same as weightage average of the quality attributes of 'flavour' and 'texture / appearance', but it was differed in terms of Colour. It may be concluded that, jaggery samples stored under vacuum in PP and LDPE pouches at temperature of 25^{o}C does not alter the quality attributes of flavour and texture / appearance, but there are variations in quality attributes of Colour and Sweetness.

S.No	Quality attribute	Scale factor	S1	S1: FMF	S1: (NFMF)	S2	S2: FMF	S2: (NFMF)	S3	S3: FMF	S3: (NFMF)
1	COLOUR	EX	0	0	0	2	0.1	0.1	3	0.15	0.15
2		GD	1	0.05	0.045	7	0.35	0.315	10	0.5	0.45
3		MD	3	0.15	0.105	5	0.25	0.175	0	0	0
4		FR	10	0.5	0.2	5	0.25	0.1	6	0.3	0.12
5		NS	6	0.3	0.03	1	0.05	0.005	1	0.05	0.005
6		Total	**20**		**0.38**	**20**		**0.695**	**20**		**0.725**
7											
8	SWEETNESS	EX	0	0	0	7	0.35	0.35	7	0.35	0.35
9		GD	2	0.05	0.09	9	0.45	0.405	7	0.35	0.315
10		MD	5	0.15	0.175	0	0	0	0	0	0
11		FR	6	0.5	0.12	3	0.15	0.06	5	0.25	0.1
12		NS	7	0.3	0.035	1	0.05	0.005	1	0.05	0.005
13		Total	**20**		**0.42**	**20**		**0.82**	**20**		**0.77**
14											
15	FLAVOUR	EX	0	0	0	3	0.15	0.15	4	0.2	0.2
16		GD	2	0.1	0.09	4	0.2	0.18	10	0.5	0.45
17		MD	4	0.25	0.14	9	0.45	0.315	0	0	0
18		FR	7	0.3	0.14	3	0.15	0.06	5	0.25	0.1
19		NS	7	0.35	0.035	1	0.05	0.005	1	0.05	0.005
20		Total	**20**		**0.405**	**20**		**0.71**	**20**		**0.755**
21											
22	TEXURE /APPEARANCE	EX	0	0	0	5	0.25	0.25	4	0.2	0.2
23		GD	1	0.1	0.05	4	0.2	0.18	4	0.2	0.18
24		MD	4	0.2	0.2	7	0.35	0.245	7	0.35	0.245
25		FR	9	0.35	0.45	3	0.15	0.06	4	0.2	0.08
26		NS	6	0.35	0.3	1	0.05	0.005	1	0.05	0.005
27		Total	**20**		**0.395**	**20**		**0.74**	**20**		**0.71**
28	**Total of NFMF :**				**1.6**			**2.965**			**2.96**

Table 4.7: Scale factor, fuzzy membership (FMF) and normalized membership functions (NFMF) for quality attributes of jaggery samples (S1, S2 and S3)

S.No	Quality attribute	Scale factor	S4	S4: FMF	S4:(NFMF)	S5	S5: FMF	S5:(NFMF)	S6	S6: FMF	S6:(NFMF)
1	COLOUR	EX	1	0.05	0.05	1	0.05	0.05	10	0.5	0.5
2		GD	3	0.15	0.135	2	0.1	0.09	2	0.1	0.09
3		MD	7	0.35	0.245	4	0.2	0.14	4	0.2	0.14
4		FR	8	0.4	0.16	5	0.25	0.1	4	0.2	0.08
5		NS	1	0.05	0.005	8	0.4	0.04	0	0	0
6		Total	**20**		**0.595**	**20**		**0.42**			**0.81**
7											
8	SWEETNESS	EX	1	0.05	0.05	1	0.05	0.05	4	0.2	0.2
9		GD	3	0.15	0.135	2	0.1	0.09	14	0.7	0.63
10		MD	9	0.45	0.315	4	0.2	0.14	2	0.1	0.07
11		FR	6	0.3	0.12	6	0.3	0.12	0	0	0
12		NS	1	0.05	0.005	7	0.35	0.035	0	0	0
13		Total	**20**		**0.625**	**20**		**0.435**	**20**		**0.9**
14											
15	FLAVOUR	EX	0	0	0	1	0.05	0.05	9	0.45	0.45
16		GD	1	0.05	0.045	1	0.05	0.045	7	0.35	0.315
17		MD	6	0.3	0.21	4	0.2	0.14	4	0.2	0.14
18		FR	9	0.45	0.18	6	0.3	0.12	0	0	0
19		NS	4	0.2	0.02	8	0.4	0.04	0	0	0
20		Total	**20**		**0.455**	**20**		**0.395**	**20**		**0.905**
21											
22	TEXURE /APPEARANCE	EX	3	0.15	0.15	0	0	0	2	0.1	0.1
23		GD	3	0.15	0.135	1	0.05	0.045	3	0.15	0.135
24		MD	6	0.3	0.21	3	0.15	0.105	5	0.25	0.175
25		FR	6	0.3	0.12	8	0.4	0.16	6	0.3	0.12
26		NS	2	0.1	0.01	8	0.4	0.04	4	0.2	0.02
27		Total	**20**		**0.625**	**20**		**0.35**	**20**		**0.55**
28	**Total of NFMF :**				**2.3**			**1.6**			**3.165**

Table 4.8: Scale Factor, fuzzy membership (FMF) and normalized membership functions (NFMF) for quality attributes of jaggery samples (S4, S5, and S6)

S.No	Quality attribute	Scale factor	S7	S7: FMF	S7: (NFMF)	S8	S8: FMF	S8: (NFMF)	S9	S9: FMF	S9: (NFMF)
1	COLOUR	EX	1	0.05	0.05	5	0.25	0.25	6	0.3	0.3
2		GD	1	0.05	0.045	7	0.35	0.315	12	0.6	0.54
3		MD	5	0.25	0.175	4	0.2	0.14	2	0.1	0.07
4		FR	7	0.35	0.14	4	0.2	0.08	0	0	0
5		NS	6	0.3	0.03	0	0	0	0	0	0
6		Total	**20**		**0.44**	**20**		**0.785**	**20**		**0.91**
7											
8	SWEETNESS	EX	0	0	0	2	0.1	0.35	11	0.55	0.55
9		GD	1	0.05	0.045	13	0.65	0.405	7	0.35	0.315
10		MD	5	0.25	0.175	4	0.2	0.14	2	0.1	0.07
11		FR	7	0.35	0.14	1	0.05	0	0	0	0
12		NS	7	0.35	0.035	0	0	0	0	0	0
13		Total	**20**		**0.395**	**20**		**0.845**	**20**		**0.935**
14											
15	FLAVOUR	EX	1	0.05	0.05	7	0.35	0.35	9	0.45	0.45
16		GD	1	0.05	0.045	9	0.45	0.405	9	0.45	0.405
17		MD	7	0.35	0.245	4	0.2	0.14	2	0.1	0.07
18		FR	3	0.15	0.06	0	0	0	0	0	0
19		NS	8	0.4	0.04	0	0	0	0	0	0
20		Total	**20**		**0.44**	**20**			**20**		**0.925**
21											
22	TEXURE /APPEARANCE	EX	0	0	0		0.2	0.2	10	0.5	0.5
23		GD	2	0.1	0.09		0.45	0.405	7	0.35	0.315
24		MD	5	0.25	0.175		0.35	0.245	3	0.15	0.105
25		FR	5	0.25	0.1		0	0	0	0	0
26		NS	8	0.4	0.04		0	0	0	0	0
27		Total	**20**		**0.405**			**0.85**	**20**		**0.92**
28	**Total of NFMF :**				**1.68**			**3.375**			**3.69**

Table 4.9: Scale Factor, fuzzy membership (FMF) and normalized membership functions (NFMF) for quality attributes of jaggery samples (S7, S8 and S9)

S.No	Quality attribute	Scale factor	S10	S10: FMF	S10: (NFMF)	S11	S11: FMF	S11: (NFMF)	S12	S12: FMF	S12: (NFMF)
1	COLOUR	EX	1	0.05	0.05	5	0.25	0.25	1	0.05	0.05
2		GD	3	0.15	0.135	10	0.5	0.45	12	0.6	0.54
3		MD	8	0.4	0.28	3	0.15	0.105	4	0.2	0.14
4		FR	4	0.2	0.08	2	0.1	0.04	3	0.15	0.06
5		NS	4	0.2	0.02	0	0	0	0	0	0
6		Total	**20**		**0.565**	**20**		**0.845**	**20**		**0.79**
7											
8	SWEETNESS	EX	1	0.05	0.05	9	0.45	0.45	8	0.4	0.4
9		GD	2	0.1	0.09	5	0.25	0.225	5	0.25	0.225
10		MD	6	0.3	0.21	4	0.2	0.14	4	0.2	0.14
11		FR	4	0.2	0.08	2	0.1	0.04	3	0.15	0.06
12		NS	7	0.35	0.035	0	0	0	0	0	0
13		Total	**20**		**0.465**	**20**		**0.855**	**20**		**0.825**
14											
15	FLAVOUR	EX	1	0.05	0	7	0.35	0.35	3	0.15	0.15
16		GD	1	0.05	0.045	7	0.35	0.315	4	0.2	0.18
17		MD	5	0.25	0.175	3	0.15	0.105	7	0.35	0.245
18		FR	6	0.3	0.12	3	0.15	0.06	2	0.1	0.04
19		NS	7	0.35	0.035	0	0	0	4	0.2	0.02
20		Total	**20**		**0.425**	**20**		**0.83**	**20**		**0.635**
21											
22	TEXURE /APPEARANCE	EX	1	0.05	0.05	9	0.45	0.45	3	0.15	0.15
23		GD	2	0.1	0.09	7	0.35	0.315	4	0.2	0.18
24		MD	5	0.25	0.175	3	0.15	0.105	8	0.4	0.28
25		FR	6	3	0.12	1	0.15	0.02	5	0.25	0.1
26		NS	6	0.3	0.03	0	0	0	0	0	0
27		Total	**20**		**0.465**	**20**		**0.89**	**20**		**0.71**
28	**Total of NFMF :**				**1.92**			**3.42**			**2.69**

Table 4.10: Scale Factor, fuzzy membership (FMF) and normalized membership functions (NFMF) for quality attributes of jaggery samples (S10, S11 and S12)

S.No.	Quality attribute	S1	JMF	S2	JMF	S3	JMF
1	COLOUR	0.38	0.238	0.42	0.263	0.44	0.262
2	SWEETNESS	0.42	0.263	0.435	0.273	0.395	0.235
3	FLAVOUR	0.405	0.253	0.395	0.247	0.44	0.262
4	TEXTURE /APPEARANCE	0.395	0.247	0.35	0.219	0.405	0.241

Table 4.11(a)

S.No.	Quality attribute	S4	JMF	S5	JMF	S6	JMF
1	COLOUR	0.910	0.247	0.565	0.294	0.81	0.256
2	SWEETNESS	0.935	0.253	0.465	0.242	0.9	0.284
3	FLAVOUR	0.925	0.251	0.425	0.221	0.905	0.286
4	TEXTURE /APPEARANCE	0.920	0.249	0.465	0.242	0.55	0.174

Table 4.11(b)

S.No.	Quality attribute	S7	JMF	S8	JMF	S9	JMF
1	COLOUR	0.785	0.225	0.725	0.245	0.595	0.259
2	SWEETNESS	0.845	0.242	0.77	0.26	0.625	0.272
3	FLAVOUR	0.895	0.526	0.755	0.255	0.455	0.198
4	TEXTURE /APPEARANCE	0.85	0.243	0.71	0.24	0.625	0.272

Table 4.11(c)

S.No.	Quality attribute	S10	JMF	S11	JMF	S12	JMF
1	COLOUR	0.845	0.247	0.79	0.226	0.595	0.259
2	SWEETNESS	0.855	0.25	0.825	0.236	0.625	0.272
3	FLAVOUR	0.83	0.243	0.635	0.182	0.455	0.198
4	TEXTURE /APPEARANCE	0.89	0.26	0.71	0.203	0.625	0.272

Table 4.11(d)

Table 4.11: Judgement membership functions (JMF) of edible coated sugarcane jaggery packed in different packaging material with different packaging methods

S.No.	Quality attribute	Scale factor	S1	S1:FMF	S1:(NFMF)
1	COLOUR	EIMP	7	0.35	0.35
2		HIMP	5	0.25	0.225
3		IMP	6	0.3	0.21
4		SIMP	2	0.1	0.04
5		NIMP	0	0	0
6		Total	20		0.825
1	SWEETNESS	EIMP	8	0.4	0.4
2		HIMP	8	0.4	0.36
3		IMP	4	0.2	0.14
4		SIMP	0	0	0
5		NIMP	0	0	0
6		Total	20		0.9
1	FLAVOUR	EIMP	3	0.15	0.15
2		HIMP	6	0.3	0.27
3		IMP	7	0.35	0.245
4		SIMP	3	0.15	0.06
5		NIMP	1	0.05	0.005
6		Total	20		0.73
1	TEXTURE /APPEARANCE	EIMP	4	0.2	0.2
2		HIMP	6	0.3	0.27
3		IMP	5	0.25	0.175
4		SIMP	3	0.15	0.06
5		NIMP	2	0.1	0.01
6		Total	20		0.715
		Maximum of the total of NFMF = 3.170			

Table 4.12: Scale factor, fuzzy membership (FMF) and normalized membership functions (NFMF) for quality attributes of edible coated sugarcane jaggery in general

S.No.	Quality attribute	S1	JMF
1	COLOUR	0.825	0.26
2	SWEETNESS	0.9	0.284
3	FLAVOUR	0.73	0.23
4	TEXTURE /APPEARANCE	0.715	0.225

Table 4.13: Judgement membership functions (JMF) of edible coated sugarcane jaggery in General

S.No.	Quality attribute	Weightage average	S1:QR	S2:QR	S3:QR	S4:QR	S5:QR	S6:QR	S7:QR	S8:QR	S9:QR	S10:QR	S11:QR	S12:QR
1	COLOUR	0.26	0.234	0.26	0.26	0.238	0.260	0.256	0.225	0.245	0.247	0.247	0.226	0.259
2	SWEETNESS	0.284	0.277	0.273	**0.235**	0.264	0.242	0.284	0.242	0.26	0.250	0.253	0.236	0.272
3	FLAVOUR	0.23	0.23	0.23	0.230	0.23	0.221	0.23	0.230	0.23	0.230	0.230	0.182	0.198
4	TEXTURE /APPEARANCE	0.225	0.225	0.219	0.225	0.225	0.225	0.174	0.225	0.225	0.225	0.225	0.203	0.225
		Ranking	II	III	X	V	IX	I	XI	VI	VIII	VII	XII	IV

Table 4.14: Quality ranking subset values of edible coated sugarcane jaggery packed in different packaging material

4.7 Cost-Economics of the Solid Jaggery with Edible Coating and Without Edible Coating

In order to determine cost economics of the edible coated solid jaggery process, the cost operation was determined. The cost of operation for making jaggery from one tonne of sugarcane was calculated considering fixed cost and variable cost taking the price of raw sugarcane, bagasse, additives, edible coating, chemicals, packaging material, rent and labour charge. The procedure for calculation of cost of edible coated solid jaggery is presented in the Table 4.15.

S.No	Description	With edible coating	Without edible coating
		Cost (Rupees)	Cost (Rupees)
I	**Variable cost**		
	Cane cost (1 tonne @Rs.2300/- per tonne)	2300-00	2300-00
	Additives (lime and oil)	35-00	35.00
	Labour charges (2 men@350/- & 2 women@200/-	1100-00	1100-00
	Bagasse (150kg @800/- per tonne)	120-00	120-00
	Polythene bags (1kg @ 170/- per kg)	170-00	170-00
	Edible coating (50gm)	140-00	
	Glycerol (250ml)	250-00	
	Packing charges	300-00	300-00
	Total Cost (I)	**4115-00**	**3725-00**
II.	**Fixed cost**		
	Rent	300-00	300-00
	Total Cost (II)	**300-00**	**300-0000**
	Total (I+II)	**4415-00**	**4025-00**
III	**Output**		
	Jaggery (110 kg@Rs.45/- with coating and @40 without coating)	4950-00	4400-00
	Bagasse (250 kg @Rs.900/- per tonne	200-00	200.00
	Total returns	**5150-00**	**4600-00**
IV	**BC Ratio (TR/TC) on total cost**	**1.17**	**1.14**

Table 4.15: Cost-economics of the solid jaggery with edible coating and without edible coating

CHAPTER-V

SUMMARY AND CONCLUSIONS

Jaggery is a traditional unrefined non-centrifugal sugar consumed in Asia, Africa, Latin America and the Caribbean. India is the largest producer and consumer of jaggery. Out of total world production, more than 70% is produced in India. It is consumed in almost all sections of the society as a sweetener, and as a source of energy. It is also used in animal feed mixtures. Jaggery is among major agro processing industries in India. Nearly 20-30% of total sugarcane produced in the country is used for manufacture of about 7 million tonnes jaggery, which is known as most nutritious agent among all sweeteners.

Jaggery is packaged traditionally under different packaging materials like paddy straw, banana leaves, gunny bag, polythene sheet, etc., which possess poor barrier properties against moisture, light, air, etc., leading to spoilage or deterioration of jaggery quality. It has been reported that more than 10% of jaggery produced in the country, worth Rs. 40 crore, is lost every year due to product deterioration. However none of these are completely satisfactory for preserving jaggery in good conditions particularly during the wet and humid monsoon conditions. Application of edible films on the food products could also be used as a protective coating to extend the shelf life. Edible films and coatings may extend the shelf life of jaggery by providing a semi-permeable barrier to gases and water vapor. This barrier would reduce diffusion of gases, enzymatic browning and the loss of water from the product.

In this present study edible coatings prepared with protein based (whey protein concentrate, gelatin, gluten and zein) and polysaccharide based edible coating (gum arabic) with different concentrations (0.5%, 1.5% and 2.5%) were investigated for their capacity to preserve the quality of jaggery. The moisture sorption isotherms (MSI) of solid jaggery, coated with different edible coatings, was determined by the static gravimetric technique based on isopiestic vapour transfer technique using saturated salt solutions at three temperatures of 25, 35, and 45°C. The process parameters for the optimization of the application of edible coating over solid jaggery were determined by using Design Expert 9.0 software. The optimized concentration of edible coating was applied on the solid jaggery and storage studies were conducted.

Sugarcane jaggery samples (25 g) were coated with the optimized concentration of edible coating (0.5% WPC and 0.5% Gum Arabic) and placed in LDPE, HDPE and PP pouches packed the nine pouches (three LDPE pouches, three HDPE and three PP pouches) with MAP machine. Nine pouches (three LDPE pouches, three HDPE pouches and three PP pouches) with 0.5% WPC coated solid jaggery sample placed in the pouches and sealed with the vacuum packaging machine. Nine pouches (three LDPE pouches, three HDPE pouches and three PP pouches) with 0.5% gum arabic coated solid jaggery sample placed in the pouches and sealed with the vacuum packaging machine. Nine pouches (three LDPE pouches, three HDPE pouches and three PP pouches) with 0.5% WPC coated solid jaggery sample placed in the pouches and sealed with the MAP packaging machine. Nine pouches (three LDPE pouches, three HDPE pouches and three PP pouches) with 0.5% Gum Arabic coated solid jaggery sample placed in the pouches and sealed with the MAP packaging machine. Twelve pouches (0.5% WPC coated jaggery packed in LDPE with vacuum packing; 0.5% gum arabic coated jaggery packed in LDPE with vacuum packing; 0.5% WPC coated jaggery packed in HDPE with vacuum packing; 0.5% gum arabic coated jaggery packed in HDPE with vacuum packing; 0.5% WPC coated jaggery packed in PP with vacuum packing; 0.5% gum arabic coated jaggery packed in PP with vacuum packing; 0.5% WPC coated jaggery packed in LDPE with MAP packing; 0.5% gum arabic coated jaggery packed in LDPE with MAP packing; 0.5% WPC coated jaggery packed in HDPE with MAP packing; 0.5% gum arabic coated jaggery packed in HDPE with MAP packing; 0.5% WPC coated jaggery packed in PP with MAP packing; 0.5% gum arabic coated jaggery packed in PP with MAP packing) were placed in a desiccator (0.3 m diameter). The desiccator was placed in incubator maintained a temperature of 25°C. At the end of storage studies, the jaggery samples were taken out from the pouches and presented to the panelists.

The resultant samples were designated as follows: 0.5% WPC coated jaggery packed in LDPE with MAP packing (S1); 0.5% WPC coated jaggery packed in LDPE with vacuum packing (S2); 0.5% WPC coated jaggery packed in HDPE with MAP packing (S3); 0.5% WPC coated jaggery packed in HDPE with vacuum packing (S4); 0.5% WPC coated jaggery packed in PP with MAP packing (S5); 0.5% WPC coated jaggery packed in PP with vacuum packing (S6); 0.5% gum arabic coated jaggery packed in LDPE with MAP packing (S7); 0.5% gum arabic coated jaggery packed in LDPE with vacuum packing (S8); 0.5% gum arabic coated jaggery packed in HDPE with MAP packing (S9); 0.5% gum arabic coated jaggery packed in HDPE with vacuum packing (S10); 0.5% gum arabic coated jaggery packed in PP with MAP packing (S11); 0.5% gum arabic coated jaggery packed in PP with vacuum packing (S12).

Accelerated storage studies were conducted for the sugarcane solid jaggery samples (50 g) coated with optimized concentration of edible coating (0.5% concentration of both protein (WPC) and polysaccharide (gum arabic) based) placed in LDPE, HDPE and PP pouches with vacuum and MAP packing and all these pouches were placed in the desiccator at 90% RH and this desiccator was placed in incubator at 45^{o}C. Techno-economic analysis of the protein and polysaccharide based edible coated jaggery studied to transfer the technology to the jaggery farmers. Based on the work done, the following conclusions were drawn.

1. The typical MSI of solid jaggery shown that EMC increased with increased in water activity and decreased with increased in temperature. The monolayer moisture content (M_0) of the solid jaggery samples without edible coating varied from a maximum of 4.368 % (db.) at 25°C and minimum 3.7402% (db.) at 45°C. The highest monolayer moisture content (M_0), 4.8861% (db.) was obtained with 0.5% concentration of wheat gluten edible coating at 25°C temperature. The lowest monolayer moisture content (M_0), 3.3629% (db.) was obtained with 2.5% concentration of whey protein concentrate edible coating at 45°C temperature.
2. The moisture sorption isotherms for all three jaggery samples are Type-III isotherms. GAB equation was found to be best fit model compared to Iglesias and Chirife and modified Halsey equations.
3. The net isosteric heat of sorption estimated from the Clausius – Clapeyron equation for solid jaggery without edible coating decreased from 3.257 kJ/mol to 2.667 kJ/mol with increased in moisture content from 5 to 45 % (db.). A similar decreasing trend of net isosteric heat of sorption to the solid jaggery with whey protein concentrate, wheat gluten, zein, gelatine and gum arabic edible coatings with increase of temperature and increased with increase of temperature for moisture content from 5 to 45% (db.).
4. The numerical optimization results showed that the overall optimum area was predicted to be obtained by the application of edible coating over solid jaggery at the combined level of 25^{o}C, 0.1%, 0.5% and whey protein concentrate (i.e. edible coating 1) for temperature, water activity, coating concentration and edible coating, respectively with desirability of 0.884% by response surface plots and response optimizer.
5. The water vapour permeability of LDPE, HDPE and PP pouches was determined and the values were 1.352×10^{-8}, 3.708×10^{-8} and 3.032×10^{-8} kg water/day×m^2×pa

respectively. The data revealed that the low density polyethylene (LDPE) had lowest permeability followed by polypropylene (PP) and high density poly ethylene (HDPE).

6. The minimum predicted storage life i.e. 156.37 days was observed in the 0.5% concentrated gum arabic edible coated solid jaggery packed in HDPE with MAP packaging machine and the maximum predicted storage life i.e. 255.44 days was obtained in the 0.5% WPC edible coated solid jaggery packed in LDPE with vacuum packaging machine. The storage life of edible coated jaggery was maximum in LDPE with vacuum packing followed by PP and HDPE.
7. The experimental data revealed that the initial water activity of the jaggery samples ranges from 0.373 to 0.384. Water activity of the jaggery samples follows increasing trend as storage period increases. After completion of storage period, the highest value of water activity i.e. 0.421 was found in the solid jaggery sample without edible coating (control) and the lowest value of water activity i.e. 0.387 was found in the solid jaggery sample coated with 0.5% concentration WPC packed in PP pouch with vacuum condition.
8. The initial sucrose contents of the jaggery sample without coating and with WPC, gum arabic coated jaggery samples were 82.40, 82.29 and 82.25 respectively. There was no significant changes in the sucrose content of the jaggery samples throughout the storage period. It was observed that in the vacuum packed jaggery sample there was less decrease in the sucrose content as compare to the MAP packaging and the WPC coated solid jaggery sample in PP pouch packed with vacuum packing shows the better result as compared to the other samples.
9. It was observed that reducing sugar increased as the storage period increased, but there was least increasing in coated samples as compared to uncoated samples. In the solid jaggery sample without edible coating, there was significant increase in the reducing sugars from 6.84 to 7.11 for the storage period. The data revealed that there was less increase in the reducing sugars in the 0.5% concentration of WPC coated solid jaggery samples packed in PP pouches with vacuum packing throughout storage period from 6.87 to 7.00 as compared to the other samples.
10. 0.5% WPC coated jaggery cubes packed in HDPE pouches with vacuum condition shows less change in the colour followed by 0.5% WPC coated jaggery cubes packed in LDPE pouches with MAP packing and 0.5% gum arabic coated

jaggery cubes packed in HDPE pouches with MAP packing throughout the storage period.

11. The initial hardness in terms of force required in Newton (N) to compress the sample completely was in the range of 14.627 to 17.269 in all the treatment. The data revealed that the hardness of the uncoated, WPC coated and gum arabic coated solid jaggery samples ranges from 14.627 to 12.965 N, 17.269 to 14.875 N and 16.578 to 14.971 N respectively.
12. It was observed that, smell and texture / appearance score values of all the samples (MAP and Vacuum packaging) was the same as weightage average of the quality attributes of 'flavour' and 'texture / appearance', but it was differed in terms of colour. It may be concluded that, jaggery samples stored under vacuum in PP and LDPE pouches at temperature of 25°C does not alter the quality attributes of flavour and texture / appearance, but there are variations in quality attributes of colour and sweetness.

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APPENDIX-A

S.NO	25^0C	Control	Whey protein concentrate			Gluten			Gum arabic			Zelatine			Zein		
	a_w		0.50%	1.50%	2.50%	0.50%	1.50%	2.50%	0.50%	1.50%	2.50%	0.50%	1.50%	2.50%	0.50%	1.50%	2.50%
1	0.0824	2.067	2.067	1.9494	1.88	2.065	2.005	1.963	2.05	1.972	1.87	2.016	1.875	1.722	2.026	1.964	1.913
2	0.2235	2.682	2.541	2.5466	2.497	2.563	2.359	2.195	2.606	2.503	2.238	2.5	2.296	2.083	2.508	2.43	2.264
3	0.3278	3.995	3.88	3.7270	3.497	3.847	3.748	3.736	3.898	3.817	3.7	3.851	3.613	3.45	3.727	3.638	3.569
4	0.4433	4.827	4.693	4.6497	4.46	4.723	4.664	4.522	4.706	4.665	4.423	4.765	4.649	4.566	4.696	4.614	4.496
5	0.5289	5.67	5.607	5.475	5.224	5.522	5.401	5.073	5.591	5.411	5.172	5.61	5.419	5.174	5.603	5.482	5.162
6	0.7425	12.342	12.286	12.0954	11.317	12.129	12.056	11.93	12.236	11.927	11.088	11.9	11.77	11.47	12.31	12.17	11.85
7	0.8434	24.86	24.631	24.213	23.455	25.239	24.248	23.747	24.439	24.231	23.796	23.97	23.87	23.28	24.68	23.54	23.48
8	0.9358	52.73	50.178	49.1313	48.234	50.453	49.257	47.85	51.255	49.405	48.576	49.74	48.68	46.4	50.98	49.96	47.75

Appendix-A1: Estimated average equilibrium moisture content % (db.) values of coated solid jaggery samples at 25^0C temperature

	35^0C	Control	Whey protein concentrate			Gluten			Gum arabic			Gelatine			Zein		
S.NO	a_w		0.50%	1.50%	2.50%	0.50%	1.50%	2.50%	0.50%	1.50%	2.50%	0.50%	1.50%	2.50%	0.50%	1.50%	2.50%
1	0.0692	1.5396	1.497	1.4529	1.3771	1.5253	1.5087	1.3452	1.5266	1.4481	1.3643	1.4977	1.4537	1.3856	1.5297	1.5131	1.3493
2	0.211	2.0538	2.015	1.9858	1.9066	1.9969	1.8751	1.7928	1.9751	1.871	1.8994	2.0122	1.9925	1.9131	2.0011	1.8794	1.7972
3	0.3205	3.1764	3.135	2.9855	2.8781	3.0989	2.9449	2.8151	2.98	2.957	2.8146	3.1352	2.8943	2.8968	3.1031	2.9492	2.8416
4	0.4364	3.7697	3.642	3.4812	3.2333	3.6059	3.453	3.3106	3.4882	3.4013	3.1898	3.6581	3.4905	3.2365	3.6104	3.4575	3.3149
5	0.4991	4.8831	4.817	4.747	4.5748	4.735	4.6499	4.3037	4.7562	4.6842	4.5714	4.849	4.6272	4.5846	4.7396	4.6541	4.3085
6	0.721	13.541	13.403	13.331	13.121	13.537	13.332	13.280	13.488	13.417	13.264	13.487	13.374	13.288	13.503	13.434	13.252
7	0.8295	25.292	24.95	23.267	21.506	25.218	24.494	23.442	24.863	23.387	23.389	24.108	23.279	21.513	25.224	24.501	23.71
8	0.9079	61.669	58.917	56.693	53.821	60.681	58.354	55.577	58.771	56.623	55.501	59.21	56.742	53.865	60.692	58.366	55.589

Appendix-A2: Estimated average equilibrium moisture content % (db.) values of coated solid jaggery samples at 35^0C temperature

	45^0C	Control	Whey protein concentrate			Gluten			Gum arabic			Gelatine			Zein		
S.NO	a_w		0.50%	1.50%	2.50%	0.50%	1.50%	2.50%	0.50%	1.50%	2.50%	0.50%	1.50%	2.50%	0.50%	1.50%	2.50%
1	0.056	1.2002	1.191	1.179	1.16	1.1951	1.1838	1.1735	1.1929	1.1759	1.1621	1.1951	1.1835	1.1647	1.1998	1.1874	1.1777
2	0.198	1.805	1.739	1.6583	1.515	1.7995	1.7132	1.6471	1.8025	1.6555	1.602	1.7428	1.6627	1.5198	1.8043	1.7179	1.6522
3	0.311	2.972	2.88	2.7453	2.643	2.8909	2.7934	2.6668	2.9644	2.7894	2.6946	2.8849	2.7507	2.6482	2.8954	2.7979	2.6713
4	0.4299	3.598	3.54	3.5068	3.367	3.5478	3.515	3.4333	3.5335	3.4864	3.4382	3.5454	3.5063	3.3719	3.5529	3.5202	3.438
5	0.4693	4.27	4.16	4.0124	3.944	4.1945	4.0394	4.0244	4.1398	4.0412	3.9812	4.1643	4.017	3.9486	4.2086	4.0438	4.0294
6	0.6999	15.389	15.277	15.036	14.892	15.367	15.107	14.986	15.119	15.057	14.987	15.283	15.042	14.898	15.345	15.112	14.992
7	0.8174	30.242	29.806	29.592	28.377	30.009	29.674	29.404	29.812	29.624	29.375	29.813	29.598	28.383	30.016	29.681	29.378
8	0.8703	65.504	64.004	62.979	61.287	65.042	63.388	61.513	63.421	62.874	61.743	64.015	62.99	61.297	65.053	63.399	61.522

Appendix-A3: Estimated average equilibrium moisture content % (db.) values of coated solid jaggery samples at 45^0C temperature

	CONTROL															
Temp.^{0}C	GAB parameters						lglesias and Chirife					Modified Halsey				
	Mo	C	K	RMSE	χ2	EF	B	p	RMSE	χ2	EF	r	c	RMSE	χ2	EF
25^{0}C	4.368	2.288	0.9835	0.12	0.0008	0.9803	3.4421	0.6802	0.023	0.0023	0.9624	1.1015	2.978	0.032	0.0018	0.8864
35^{0}C	3.9485	1.8819	1.0333	0.013	0.0009	0.9774	3.7412	0.548	0.037	0.0028	0.9504	0.8688	2.4215	0.039	0.0014	0.8721
45^{0}C	3.7402	1.9913	1.0852	0.11	0.0008	0.9761	4.2921	0.23	0.042	0.0018	0.9073	0.56	1.7601	0.042	0.0012	0.8559

Appendix-A4: Estimated parameter of GAB, lglesias and Chirife and Modified Halsey at temperatures of 25^{0}C, 35^{0}C and 45^{0}C of solid jaggery samples

Model	Whey protein concentrate								
	25^0C			35^0C			45^0C		
	0.50%	1.50%	2.50%	0.50%	1.50%	2.50%	0.50%	1.50%	2.50%
GAB									
Mo									
(%db)	4.5963	4.5665	4.344	4.0321	3.6723	3.3628	3.7423	3.7689	3.5886
C	2.1922	2.1241	2.5015	1.7231	1.7359	1.866	1.61	1.7133	1.5468
K	0.972	0.974	0.971	1.029	1.0322	1.0343	1.0465	1.0825	1.0837
RMSE	0.12	0.011	0.09	0.016	0.013	0.01	0.014	0.021	0.008
$\chi2$	0.0002	0.0003	0.0002	0.0005	0.0001	0.0005	0.0004	0.0002	0.0002
EF	0.9834	0.983	0.9837	0.9789	0.9767	0.9748	0.9714	0.9775	0.9768
Iglesias and Chirife									
B	3.441	3.33	3.245	3.842	3.814	3.79	4.378	4.317	4.322
P	0.846	0.831	0.825	0.748	0.732	0.7	0.695	0.547	0.515
RMSE	0.0425	0.0125	0.0124	0.0246	0.0356	0.0345	0.0256	0.0287	0.0326
$\chi2$	0.0052	0.0012	0.0045	0.0043	0.0016	0.0018	0.0019	0.003	0.002
EF	0.968	0.967	0.968	0.958	0.957	0.956	0.948	0.94	0.937
Halsey									
R	0.966	0.948	0.914	0.744	0.732	0.711	0.744	0.646	0.628
C	3.666	3.573	3.399	2.97	2.902	2.799	2.974	2.777	2.703
RMSE	0.009	0.011	0.017	0.014	0.011	0.013	0.01	0.012	0.011
$\chi2$	0.086	0.017	0.079	0.053	0.049	0.045	0.014	0.029	0.025
EF	0.886	0.881	0.882	0.872	0.871	0.87	0.856	0.885	0.886

Appendix-A5: Estimated parameter of GAB, lglesias and Chirife and Modified Halsey at temperatures of 25^0C, 35^0C and 45^0C of whey protein concentrate coated solid jaggery samples

Model	Gluten								
	25^0C			35^0C			45^0C		
	0.50%	1.50%	2.50%	0.50%	1.50%	2.50%	0.50%	1.50%	2.50%
GAB									
Mo									
(%db)	4.8861	4.6152	4.6743	4.048	4.012	3.927	3.726	3.757	3.835
C	2.283	2.153	2.414	1.955	1.79	2.054	1.659	1.586	1.84
K	0.98	0.975	0.968	1.031	1.029	1.027	1.085	1.083	1.08
RMSE	0.015	0.018	0.012	0.021	0.022	0.014	0.023	0.021	0.016
$\chi2$	4E-04	6E-04	2E-04	6E-04	7E-04	9E-04	7E-04	8E-04	7E-04
EF	0.981	0.983	0.984	0.979	0.98	0.98	0.976	0.977	0.978
Iglesias and Chirife									
B	3.488	3.476	3.453	3.874	3.872	3.907	4.298	4.307	4.309
P	0.876	0.865	0.859	0.733	0.705	0.64	0.587	0.56	0.542
RMSE	0.0546	0.0623	0.0365	0.0364	0.0548	0.0698	0.0522	0.0321	0.0327
$\chi2$	0.006	0.007	0.009	0.007	0.008	0.007	0.004	0.006	0.002
EF	0.967	0.967	0.967	0.957	0.955	0.952	0.943	0.941	0.939
Halsey									
R	0.961	0.933	0.904	0.732	0.711	0.683	0.667	0.653	0.642
C	3.649	3.513	3.375	2.938	2.847	2.732	2.862	2.802	2.755
RMSE	0.011	0.015	0.017	0.018	0.009	0.088	0.009	0.015	0.018
$\chi2$	0.088	0.08	0.08	0.056	0.056	0.05	0.036	0.031	0.025
EF	0.884	0.886	0.881	0.872	0.872	0.872	0.885	0.885	0.886

Appendix-A6: Estimated parameter of GAB, lglesias and Chirife and Modified Halsey at temperatures of 25^0C, 35^0C and 45^0C of gluten coated solid jaggery samples

Model	Gelatin								
	25^0C			35^0C			45^0C		
	0.50%	1.50%	2.50%	0.50%	1.50%	2.50%	0.50%	1.50%	2.50%
GAB									
Mo									
(%db)	4.276	4.506	4.687	3.747	3.87	3.587	3.742	3.769	3.376
C	2.283	2.029	2.528	2.146	1.753	1.873	1.907	1.74	1.414
K	0.98	0.975	0.968	1.034	1.032	1.034	1.084	1.082	1.084
RMSE	0.025	0.018	0.013	0.021	0.019	0.015	0.018	0.014	0.012
$\chi2$	6E-04	7E-04	9E-04	7E-04	8E-04	7E-04	4E-04	6E-04	2E-04
EF	0.981	0.983	0.984	0.976	0.977	0.975	0.977	0.978	0.977
Iglesias and Chirife									
B	3.42	3.354	3.225	3.828	3.828	3.79	4.295	4.315	4.32
P	0.875	0.865	0.852	0.754	0.718	0.704	0.581	0.549	0.518
RMSE	0.0256	0.0287	0.0326	0.0425	0.0125	0.0124	0.0246	0.0356	0.0345
$\chi2$	0.0043	0.0016	0.0018	0.0019	0.003	0.002	0.0052	0.0012	0.0045
EF	0.968	0.968	0.969	0.958	0.956	0.956	0.942	0.94	0.937
Halsey									
R	0.965	0.913	0.864	0.747	0.723	0.714	0.664	0.647	0.629
C	3.643	3.423	3.21	2.977	2.873	2.81	2.846	2.78	2.706
RMSE	0.009	0.009	0.012	0.015	0.009	0.017	0.018	0.019	0.008
$\chi2$	0.083	0.07	0.057	0.037	0.054	0.048	0.034	0.029	0.026
EF	0.885	0.882	0.886	0.872	0.871	0.872	0.884	0.885	0.885

Appendix-A7: Estimated parameter of GAB, lglesias and Chirife and Modified Halsey at temperatures of 25^0C, 35^0C and 45^0C of gelatin coated solid jaggery samples

Model	Zein								
	25⁰C			35⁰C			45⁰C		
	0.50%	1.50%	2.50%	0.50%	1.50%	2.50%	0.50%	1.50%	**2.50%**
GAB									
Mo									
(%db)	4.617	4.25	4.551	4.044	4.023	4.022	3.723	3.757	3.825
C	1.962	2.156	1.921	1.794	1.795	1.758	1.662	1.589	1.656
K	0.977	0.981	0.973	1.031	1.029	1.026	1.085	1.083	1.08
RMSE	0.024	0.023	0.016	0.21	0.018	0.015	0.028	0.021	0.017
$\chi 2$	4E-04	6E-04	2E-04	4E-04	6E-04	2E-04	0.0006	0.0006	0.0006
EF	0.983	0.981	0.983	0.979	0.98	0.981	0.976	0.977	0.978
Iglesias and Chirife									
B	3.525	3.458	3.413	3.871	3.872	3.908	4.294	4.305	4.305
P	0.887	0.875	0.823	0.735	0.706	0.642	0.59	0.562	0.544
RMSE	0.0425	0.0125	0.0124	0.0246	0.0356	0.0345	0.0256	0.0287	0.0326
$\chi 2$	0.006	0.007	0.009	0.007	0.008	0.007	0.004	0.006	0.002
EF	0.967	0.968	0.966	0.957	0.956	0.952	0.943	0.941	0.94
Halsey									
R	0.946	0.93	0.9	0.733	0.712	0.684	0.668	0.654	0.643
C	3.59	3.5	3.356	2.942	2.853	2.739	2.866	2.805	2.758
RMSE	0.014	0.015	0.008	0.009	0.007	0.009	0.012	0.015	0.011
$\chi 2$	0.082	0.077	0.073	0.046	0.057	0.05	0.04	0.032	0.026
EF	0.886	0.884	0.885	0.872	0.872	0.872	0.884	0.885	0.885

Appendix-A8: Estimated parameter of GAB, lglesias and Chirife and Modified Halsey at temperatures of 25⁰C, 35⁰C and 45⁰C of zein coated solid jaggery samples

Model	Gum arabic								
	25^{0}C			35^{0}C			45^{0}C		
	0.50%	1.50%	2.50%	0.50%	1.50%	2.50%	0.50%	1.50%	2.50%
GAB									
Mo (%db)	4.377	4.507	4.565	4.08	3.866	3.878	3.758	3.783	3.824
C	2.166	1.995	2.455	1.882	1.896	1.943	1.598	1.741	1.614
K	0.981	0.976	0.975	1.028	1.031	1.028	1.083	1.082	1.08
RMSE	0.014	0.012	0.011	0.013	0.011	0.009	0.012	0.011	0.008
$\chi 2$	0.0001	0.0005	0.0004	0.0003	0.0002	0.0005	0.0002	0.0005	0.0001
EF	0.981	0.982	0.984	0.98	0.978	0.979	0.977	0.9775	0.978
Iglesias and Chirife									
B	3.579	3.458	3.325	3.858	3.845	3.869	4.271	4.314	4.323
P	0.848	0.84	0.825	0.727	0.707	0.672	0.594	0.551	0.531
RMSE	0.021	0.019	0.015	0.025	0.018	0.013	0.018	0.014	0.012
$\chi 2$	0.002	0.001	0.002	0.002	0.002	0.003	0.001	0.002	0.002
EF	0.966	0.966	0.967	0.957	0.956	0.954	0.933	0.94	0.938
Halsey									
R	0.969	0.949	0.885	0.724	0.715	0.694	0.671	0.648	0.638
C	3.68	3.575	3.295	2.9	2.848	2.769	2.868	2.785	2.744
RMSE	0.007	0.009	0.012	0.008	0.009	0.011	0.001	0.019	0.011
$\chi 2$	0.089	0.082	0.082	0.052	0.046	0.041	0.037	0.029	0.026
EF	0.887	0.886	0.887	0.872	0.872	0.872	0.886	0.886	0.887

Appendix-A9: Estimated parameter of GAB, lglesias and Chirife and Modified Halsey at temperatures of 25^{0}C, 35^{0}C and 45^{0}C of gum arabic coated solid jaggery samples

M.C (%db.)	ISOSTERIC HEAT (q_{st})															
		WPC			GLUTEN			GELATIN			ZEIN			GUM ARABIC		
	Control	0.5%	1.5%	2.5%	0.5%	1.5%	2.5%	0.5%	1.5%	2.5%	0.5%	1.5%	2.5%	0.5%	1.5%	2.5%
5	3.257	3.240	3.269	3.288	3.286	3.279	3.310	3.293	3.283	3.304	3.237	3.190	3.298	3.244	3.265	3.292
10	3.177	3.160	3.188	3.207	3.188	3.182	3.212	3.196	3.186	3.222	3.157	3.111	3.217	3.164	3.184	3.210
15	3.099	3.082	3.109	3.128	3.094	3.088	3.117	3.101	3.092	3.143	3.079	3.034	3.137	3.085	3.105	3.131
20	3.022	3.006	3.032	3.051	3.003	2.997	3.025	3.010	3.001	3.065	3.003	2.960	3.060	3.009	3.029	3.054
25	2.947	2.932	2.958	2.975	2.914	2.908	2.935	2.921	2.912	2.990	2.929	2.886	2.984	2.935	2.954	2.978
30	2.875	2.859	2.884	2.902	2.828	2.822	2.849	2.834	2.826	2.916	2.856	2.815	2.910	2.862	2.881	2.905
35	2.804	2.789	2.813	2.830	2.744	2.739	2.764	2.751	2.742	2.844	2.786	2.746	2.839	2.792	2.810	2.833
40	2.734	2.720	2.744	2.760	2.663	2.658	2.683	2.669	2.661	2.774	2.717	2.678	2.769	2.723	2.741	2.763
45	2.667	2.653	2.676	2.692	2.584	2.579	2.603	2.591	2.583	2.705	2.650	3.354	2.700	2.656	2.673	2.695

Appendix-A10: Isosteric heat of sorption at different level of moisture content for edible coated jaggery

APPENDIX-B

	Factor 1	Factor 2	Factor 3	Factor 4	Response
Run	Temperature, ^0C	Concentration, %	Water activity	Edible coating	EMC, % (db.)
1	35	2.5	0.2	2	1.7928
2	35	0.5	0.5	2	4.7350
3	35	2.5	0.4	1	3.2333
4	35	2.5	0.1	4	1.3493
5	35	0.5	0.2	2	1.9969
6	35	2.5	0.3	1	2.8781
7	35	0.5	0.3	5	2.9800
8	35	2.5	0.4	3	3.2365
9	35	1.5	0.4	4	3.4575
10	35	1.5	0.9	4	58.366
11	35	2.5	0.4	4	3.3149
12	35	1.5	0.4	1	3.4812
13	35	0.5	0.4	5	3.4882
14	35	2.5	0.1	2	1.3452
15	35	1.5	0.8	2	24.4949
16	35	2.5	0.8	1	21.5067
17	35	0.5	0.1	2	1.5253
18	35	0.5	0.2	3	2.0122
19	35	1.5	0.2	1	1.9858
20	35	1.5	0.5	3	4.6272
21	35	0.5	0.8	1	24.9500
22	35	1.5	0.2	3	1.9925
23	35	1.5	0.5	1	4.7470
24	35	1.5	0.7	1	13.3312
25	35	1.5	0.3	4	2.9492
26	35	2.5	0.3	4	2.8416
27	35	2.5	0.7	1	13.1216
28	35	0.5	0.3	1	3.1350
29	35	0.5	0.9	3	59.2100
30	35	1.5	0.4	3	3.4905
31	35	0.5	0.9	1	58.9170
32	35	2.5	0.8	2	23.4421
33	35	2.5	0.3	5	2.8146
34	35	2.5	0.2	4	1.7972
35	35	0.5	0.9	2	60.6812
36	35	2.5	0.5	1	4.5748
37	35	2.5	0.7	5	13.2640
38	35	2.5	0.9	1	53.8219
39	35	2.5	0.9	4	55.5890
40	35	2.5	0.1	1	1.3771
41	35	0.5	0.1	4	1.5297

42	35	1.5	0.2	5	1.8710
43	35	2.5	0.9	5	55.5013
44	35	1.5	0.7	5	13.4172
45	35	2.5	0.8	4	23.7100
46	35	2.5	0.7	4	13.2519
47	35	0.5	0.8	2	25.2181
48	35	0.5	0.2	5	1.9751
49	35	2.5	0.3	3	2.8968
50	35	1.5	0.3	3	2.8943
51	35	1.5	0.1	5	1.4481
52	35	0.5	0.9	5	58.7712
53	35	1.5	0.3	5	2.9570
54	35	2.5	0.8	3	21.5131
55	35	0.5	0.8	3	24.1080
56	35	0.5	0.3	4	3.1031
57	35	1.5	0.8	1	23.2676
58	35	0.5	0.5	5	4.7562
59	35	0.5	0.4	2	3.6059
60	35	1.5	0.7	2	13.3323
61	35	1.5	0.1	1	1.4529
62	35	2.5	0.1	3	1.3856
63	35	0.5	0.5	4	4.7396
64	35	0.5	0.5	3	4.8490
65	35	0.5	0.4	4	3.6104
66	35	2.5	0.1	5	1.3643
67	35	2.5	0.4	5	3.1898
68	35	2.5	0.8	5	23.3892
69	35	1.5	0.9	1	56.6932
70	35	0.5	0.7	3	13.4870
71	35	1.5	0.8	4	24.5010
72	35	1.5	0.1	4	1.5131
73	35	0.5	0.2	4	2.0011
74	35	1.5	0.2	4	1.8794
75	35	2.5	0.9	3	53.8651
76	35	1.5	0.4	2	3.4530
77	35	0.5	0.8	5	24.8639
78	35	0.5	0.3	3	3.1352
79	35	1.5	0.5	4	4.6541
80	35	1.5	0.9	5	56.6234
81	35	0.5	0.9	4	60.6920
82	35	1.5	0.4	5	3.4013
83	35	1.5	0.1	2	1.5087
84	35	2.5	0.5	4	4.3085
85	35	0.5	0.7	4	13.5030
86	35	0.5	0.1	5	1.5266
87	35	1.5	0.9	3	56.7420
88	35	1.5	0.5	5	4.6842
89	35	2.5	0.3	2	2.8151

90	35	2.5	0.5	5	4.5714
91	35	2.5	0.5	3	4.5846
92	35	2.5	0.7	3	13.288
93	35	2.5	0.7	2	13.2809
94	35	0.5	0.1	3	1.4977
95	35	1.5	0.3	1	2.9855
96	35	0.5	0.7	2	13.5376
97	35	2.5	0.2	3	1.9131
98	35	0.5	0.4	3	3.6581
99	35	2.5	0.2	5	1.8994
100	35	1.5	0.5	2	4.6499
101	35	2.5	0.2	1	1.9066
102	35	1.5	0.3	2	2.9449
103	35	1.5	0.7	3	13.3740
104	35	0.5	0.7	5	13.4887
105	35	1.5	0.2	2	1.8751
106	35	0.5	0.8	4	25.2240
107	35	0.5	0.2	1	2.0150
108	35	1.5	0.9	2	58.3544
109	35	0.5	0.3	2	3.0989
110	35	1.5	0.1	3	1.4537
111	35	1.5	0.7	4	13.4339
112	35	2.5	0.4	2	3.3106
113	35	1.5	0.8	3	23.2790
114	35	2.5	0.5	2	4.3037
115	35	0.5	0.1	1	1.4970
116	35	0.5	0.7	1	13.4030
117	35	2.5	0.9	2	55.5779
118	35	1.5	0.8	5	23.3870
119	35	0.5	0.4	1	3.6420
120	35	0.5	0.5	1	4.8170
121	45	2.5	0.5	3	3.9486
122	45	1.5	0.8	4	29.6810
123	45	0.5	0.2	1	1.7390
124	45	2.5	0.7	2	14.9860
125	45	0.5	0.9	3	64.0150
126	45	1.5	0.8	3	29.5980
127	45	1.5	0.7	1	15.0360
128	45	1.5	0.1	1	1.1790
129	45	2.5	0.7	3	14.8980
130	45	0.5	0.5	4	4.2086
131	45	1.5	0.3	5	2.7894
132	45	1.5	0.1	4	1.1874
133	45	1.5	0.4	2	3.5150
134	45	0.5	0.7	4	15.3450
135	45	1.5	0.9	1	62.9790
136	45	2.5	0.7	5	14.9870
137	45	0.5	0.2	3	1.7428

138	45	2.5	0.3	2	2.6668
139	45	0.5	0.5	2	4.1945
140	45	0.5	0.1	2	1.1951
141	45	2.5	0.3	1	2.6430
142	45	0.5	0.9	4	65.0530
143	45	1.5	0.7	5	15.0570
144	45	2.5	0.1	1	1.1600
145	45	2.5	0.8	5	29.3750
146	45	2.5	0.1	5	1.1621
147	45	2.5	0.2	1	1.5150
148	45	1.5	0.5	5	4.0412
149	45	1.5	0.4	5	3.4864
150	45	0.5	0.5	3	4.1643
151	45	2.5	0.9	5	61.7430
152	45	0.5	0.9	1	34.0040
153	45	2.5	0.2	2	1.6471
154	45	2.5	0.3	3	2.6482
155	45	1.5	0.2	5	1.6555
156	45	1.5	0.9	2	63.3880
157	45	1.5	0.2	2	1.7132
158	45	2.5	0.1	3	1.1647
159	45	0.5	0.3	3	2.8849
160	45	2.5	0.4	4	3.4380
161	45	1.5	0.3	4	2.7979
162	45	0.5	0.9	5	63.4210
163	45	0.5	0.8	4	30.0160
164	45	1.5	0.2	3	1.6627
165	45	0.5	0.3	1	2.8800
166	45	1.5	0.7	3	15.0420
167	45	2.5	0.5	2	4.0244
168	45	0.5	0.4	1	3.5400
169	45	2.5	0.4	3	3.3719
170	45	1.5	0.7	2	15.1070
171	45	2.5	0.2	5	1.6020
172	45	2.5	0.7	4	14.9920
173	45	0.5	0.2	2	1.7995
174	45	0.5	0.1	4	1.1998
175	45	2.5	0.7	1	14.8920
176	45	0.5	0.8	2	30.0090
177	45	0.5	0.3	4	2.8954
178	45	0.5	0.9	2	65.0420
179	45	0.5	0.4	5	3.5335
180	45	0.5	0.5	1	4.1600
181	45	2.5	0.9	2	61.5130
182	45	0.5	0.5	5	4.1398
183	45	2.5	0.8	2	29.4040
184	45	2.5	0.5	1	3.9440
185	45	1.5	0.5	4	4.0438

186	45	2.5	0.5	4	4.0294
187	45	1.5	0.1	5	1.1759
188	45	0.5	0.3	2	2.8909
189	45	0.5	0.7	3	15.2830
190	45	1.5	0.8	2	29.6740
191	45	2.5	0.2	4	1.6522
192	45	1.5	0.9	3	62.9900
193	45	1.5	0.1	3	1.1835
194	45	2.5	0.1	2	1.1735
195	45	0.5	0.8	5	29.8120
196	45	2.5	0.8	4	29.3780
197	45	2.5	0.4	1	3.3670
198	45	1.5	0.4	1	3.5068
199	45	2.5	0.3	5	2.6946
200	45	2.5	0.5	5	3.9812
201	45	0.5	0.7	2	15.3670
202	45	1.5	0.5	3	4.0170
203	45	2.5	0.1	4	1.1777
204	45	0.5	0.8	1	29.8060
205	45	1.5	0.9	4	63.3990
206	45	1.5	0.5	1	4.0124
207	45	1.5	0.4	4	3.5202
208	45	2.5	0.2	3	1.5198
209	45	1.5	0.4	3	3.5063
210	45	0.5	0.1	1	1.1910
211	45	1.5	0.8	5	29.624
212	45	0.5	0.7	1	15.2770
213	45	0.5	0.4	3	3.5454
214	45	0.5	0.2	4	1.8043
215	45	0.5	0.1	5	1.1929
216	45	1.5	0.8	1	29.5920
217	45	1.5	0.3	1	2.7453
218	45	0.5	0.7	5	15.1190
219	45	2.5	0.4	2	3.4333
220	45	0.5	0.4	2	3.5478
221	45	2.5	0.9	3	61.2970
222	45	2.5	0.9	4	61.5220
223	45	0.5	0.8	3	29.8130
224	45	0.5	0.2	5	1.8025
225	45	1.5	0.1	2	1.1838
226	45	2.5	0.4	5	3.4382
227	45	0.5	0.3	5	2.9644
228	45	0.5	0.1	3	1.1951
229	45	2.5	0.3	4	2.6713
230	45	1.5	0.3	2	2.7934
231	45	1.5	0.3	3	2.7507
232	45	1.5	0.7	4	15.1120
233	45	2.5	0.8	1	28.377

234	45	0.5	0.4	4	3.5529
235	45	2.5	0.8	3	28.3830
236	45	1.5	0.9	5	62.8740
237	45	1.5	0.5	2	4.0394
238	45	1.5	0.2	1	1.6583
239	45	1.5	0.2	4	1.7179
240	45	2.5	0.9	1	61.287
241	25	2.5	0.7	3	11.4700
242	25	2.5	0.3	2	3.7360
243	25	1.5	0.2	1	2.5466
244	25	2.5	0.9	2	47.8500
245	25	0.5	0.9	4	50.9800
246	25	0.5	0.1	5	2.0500
247	25	0.5	0.7	4	12.3100
248	25	2.5	0.2	5	2.2380
249	25	2.5	0.1	3	1.7220
250	25	1.5	0.2	4	2.4300
251	25	2.5	0.3	1	3.4970
252	25	0.5	0.9	3	49.7400
253	25	0.5	0.2	2	2.5630
254	25	0.5	0.1	2	2.0650
255	25	2.5	0.1	4	1.9130
256	25	2.5	0.5	2	5.0730
257	25	1.5	0.7	3	11.7700
258	25	0.5	0.7	3	11.9000
259	25	1.5	0.5	3	5.4190
260	25	2.5	0.2	1	2.4970
261	25	2.5	0.7	1	11.3170
262	25	1.5	0.3	1	3.7270
263	25	2.5	0.5	1	5.2240
264	25	2.5	0.1	2	1.9630
265	25	2.5	0.1	1	1.880
266	25	1.5	0.8	5	24.2310
267	25	0.5	0.4	2	4.7230
268	25	2.5	0.2	2	2.1950
269	25	0.5	0.2	5	2.6060
270	25	2.5	0.8	3	23.280
271	25	2.5	0.5	3	5.1740
272	25	2.5	0.4	2	4.5220
273	25	0.5	0.3	2	3.8470
274	25	2.5	0.3	4	3.5690
275	25	1.5	0.3	2	3.7480
276	25	2.5	0.3	5	3.7000
277	25	1.5	0.3	3	3.6130
278	25	0.5	0.3	5	3.8980
279	25	2.5	0.5	4	5.1620
280	25	1.5	0.8	4	23.5400
281	25	0.5	0.5	4	5.6030

282	25	2.5	0.8	1	23.4550
283	25	1.5	0.2	3	2.2960
284	25	0.5	0.5	1	5.6070
285	25	0.5	0.4	1	4.6930
286	25	2.5	0.4	4	4.4960
287	25	0.5	0.8	3	23.9700
288	25	2.5	0.7	4	11.8500
289	25	2.5	0.9	3	46.4000
290	25	2.5	0.8	5	23.7960
291	25	1.5	0.9	4	49.9600
292	25	1.5	0.1	5	1.9720
293	25	0.5	0.4	3	4.7650
294	25	0.5	0.9	1	50.1780
295	25	1.5	0.5	5	5.4110
296	25	0.5	0.4	5	4.7060
297	25	0.5	0.3	1	3.8800
298	25	0.5	0.2	1	2.5410
299	25	0.5	0.4	4	4.6960
300	25	2.5	0.9	4	47.7500
301	25	2.5	0.4	1	4.4600
302	25	0.5	0.1	4	2.0260
303	25	1.5	0.1	4	1.9640
304	25	1.5	0.1	3	1.8750
305	25	0.5	0.7	2	12.1290
306	25	1.5	0.8	2	24.2480
307	25	2.5	0.8	4	23.4800
308	25	1.5	0.2	5	2.5030
309	25	1.5	0.4	5	4.6650
310	25	2.5	0.1	5	1.8700
311	25	1.5	0.1	2	2.0050
312	25	0.5	0.9	2	50.4530
313	25	2.5	0.3	3	3.4500
314	25	1.5	0.7	4	12.1700
315	25	0.5	0.2	4	2.5080
316	25	1.5	0.4	2	4.6640
317	25	0.5	0.1	3	2.0160
318	25	1.5	0.8	3	23.8700
319	25	0.5	0.7	1	12.2860
320	25	1.5	0.4	1	4.6497
321	25	0.5	0.8	1	24.6310
322	25	1.5	0.5	4	5.4820
323	25	1.5	0.9	1	49.1313
324	25	0.5	0.7	5	12.2360
325	25	0.5	0.9	5	51.2550
326	25	1.5	0.5	1	5.4750
327	25	0.5	0.5	3	5.6100
328	25	1.5	0.5	2	5.4010
329	25	0.5	0.2	3	2.5000

330	25	1.5	0.7	2	12.0560
331	25	1.5	0.7	1	12.0954
332	25	2.5	0.5	5	5.1720
333	25	1.5	0.3	4	3.6380
334	25	1.5	0.9	2	49.2570
335	25	1.5	0.7	5	11.9270
336	25	1.5	0.9	3	48.6800
337	25	1.5	0.9	5	49.4050
338	25	1.5	0.3	5	3.8170
339	25	2.5	0.8	2	23.7470
340	25	1.5	0.4	4	4.6140
341	25	2.5	0.2	4	2.2640
342	25	2.5	0.2	3	2.0830
343	25	2.5	0.4	3	4.5660
344	25	2.5	0.9	1	48.2340
345	25	0.5	0.5	5	5.5910
346	25	0.5	0.8	2	25.2390
347	25	2.5	0.7	5	11.0880
348	25	2.5	0.7	2	11.9300
349	25	0.5	0.5	2	5.5220
350	25	1.5	0.2	2	2.3590
351	25	0.5	0.3	4	3.7270
352	25	2.5	0.4	5	4.4230
353	25	1.5	0.1	1	1.9494
354	25	0.5	0.8	5	24.4390
355	25	1.5	0.4	3	4.6490
356	25	0.5	0.3	3	3.8510
357	25	1.5	0.8	1	24.2130
358	25	0.5	0.1	1	2.0670
359	25	2.5	0.9	5	48.5760
360	25	0.5	0.8	4	24.6800

Appendix –B: Experimental conditions and equilibrium moisture content of edible coated solid jaggery cubes

APPENDIX-C

S.No.	Treatments	Moisture content (% db)				
		0 week	1st week	2nd week	3rd week	4th week
1	control	9.62	9.65	9.71	9.81	9.97
2	T_1	9.64	9.68	9.70	9.75	9.82
3	T_2	9.64	9.66	9.69	9.73	9.79
4	T_3	9.64	9.70	9.73	9.77	9.83
5	T_4	9.64	9.68	9.72	9.76	9.80
6	T_5	9.64	9.67	9.69	9.73	9.78
7	T_6	9.64	9.65	9.68	9.72	9.77
8	T_7	9.67	9.70	9.73	9.76	9.81
9	T_8	9.67	9.69	9.72	9.74	9.79
10	T_9	9.67	9.71	9.75	9.78	9.85
11	T_{10}	9.67	9.70	9.74	9.77	9.83
12	T_{11}	9.67	9.69	9.72	9.75	9.82
13	T_{12}	9.67	9.68	9.71	9.74	9.79

Appendix-C1: Changes in moisture content of edible coated jaggery stored in different packaging material at 25^{0}C temperature

S.No.	Treatments	Water activity				
		0 week	1st week	2nd week	3rd week	4th week
1	control	0.373	0.382	0.398	0.408	0.421
2	T_1	0.376	0.379	0.382	0.386	0.391
3	T_2	0.376	0.378	0.381	0.385	0.389
4	T_3	0.376	0.381	0.385	0.388	0.392
5	T_4	0.376	0.380	0.384	0.387	0.391
6	T_5	0.376	0.378	0.380	0.385	0.388
7	T_6	0.376	0.377	0.379	0.384	0.387
8	T_7	0.384	0.387	0.391	0.394	0.397
9	T_8	0.384	0.386	0.390	0.393	0.397
10	T_9	0.384	0.389	0.394	0.397	0.401
11	T_{10}	0.384	0.388	0.392	0.396	0.399
12	T_{11}	0.384	0.386	0.389	0.393	0.397
13	T_{12}	0.384	0.385	0.388	0.393	0.396

Appendix-C2: Changes in water activity of edible coated jaggery stored in different packaging material at 25^{0}C temperature

S.No.	Treatments	Sucrose (% db.)				
		0 week	1st week	2nd week	3rd week	4th week
1	control	82.40	82.39	82.21	82.15	81.97
2	T_1	82.29	82.27	82.18	82.14	82.10
3	T_2	82.29	82.28	82.23	82.19	82.14
4	T_3	82.29	82.26	82.16	82.13	82.06
5	T_4	82.29	82.27	82.17	82.15	82.08
6	T_5	82.29	82.27	82.24	82.20	82.14
7	T_6	82.29	82.28	82.25	82.21	82.16
8	T_7	82.25	82.23	82.19	82.14	82.05
9	T_8	82.25	82.24	82.21	82.16	82.07
10	T_9	82.25	82.22	82.19	82.14	82.03
11	T_{10}	82.25	82.23	82.21	82.16	82.04
12	T_{11}	82.25	82.24	82.22	82.17	82.08
13	T_{12}	82.25	82.25	82.23	82.19	82.09

Appendix-C3: Changes in Sucrose (% db.) of edible coated jaggery stored in different packaging material at 25^{0}C temperature

S.No.	Treatments	Reducing sugar				
		0 week	1st week	2nd week	3rd week	4th week
1	control	6.84	6.85	6.87	6.93	7.11
2	T_1	6.87	6.89	6.98	7.02	7.06
3	T_2	6.87	6.88	6.93	6.97	7.02
4	T_3	6.87	6.91	7.01	7.03	7.10
5	T_4	6.87	6.89	6.99	7.01	7.08
6	T_5	6.87	6.89	6.92	6.96	7.02
7	T_6	6.87	6.88	6.91	6.95	7.00
8	T_7	6.88	6.90	6.94	6.99	7.08
9	T_8	6.88	6.89	6.92	6.97	7.06
10	T_9	6.88	6.91	6.93	6.98	7.08
11	T_{10}	6.88	6.90	6.92	6.97	7.06
12	T_{11}	6.88	6.89	6.91	6.96	7.04
13	T_{12}	6.88	6.88	6.90	6.95	7.03

Appendix-C4: Changes in reducing sugar of edible coated jaggery stored in different packaging material at 25^{0}C temperature

S.No.	Treatments	Hardness (Newton)				
		0 week	1st week	2nd week	3rd week	4th week
1	control	14.627	14.248	13.984	13.512	12.965
2	T_1	17.269	16.920	16.431	15.217	14.875
3	T_2	17.269	17.018	16.954	16.496	16.034
4	T_3	17.269	16.832	16.103	15.208	15.119
5	T_4	17.269	16.953	16.480	15.998	15.547
6	T_5	17.269	16.987	16.394	15.859	15.441
7	T_6	17.269	17.014	16.847	16.521	16.038
8	T_7	16.578	16.321	15.964	15.634	14.951
9	T_8	16.578	16.284	15.999	15.642	15.284
10	T_9	16.578	16.287	15.687	15.264	14.947
11	T_{10}	16.578	16.017	15.645	15.168	14.895
12	T_{11}	16.578	16.136	15.964	15.685	15.289
13	T_{12}	16.578	16.257	15.985	15.732	15.376

Appendix-C5: Changes in Hardness of edible coated jaggery stored in different packaging material at 25^{0}C temperature

S.No.	Treatments	Colour															
		0 week			1st week			2nd week			3rd week			4th week			
		L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	L*	a*	b*	ΔE
1	control	35	14	32	33	16	30	30	18	29	26	19	25	24	20	24	14.866
2	T_1	33	11	21	31	12	23	30	9	24	30	12	26	30	13	29	8.775
3	T_2	33	11	21	33	11	22	31	13	24	30	14	25	29	16	26	8.124
4	T_3	33	11	21	31	13	25	29	14	25	27	16	27	27	16	30	11.916
5	T_4	33	11	21	31	12	24	29	14	25	28	15	26	28	16	27	9.274
6	T_5	33	11	21	31	13	23	30	16	24	28	17	27	27	17	27	10.392
7	T_6	33	11	21	30	12	30	29	14	31	27	14	27	26	15	28	10.677
8	T_7	32	7	29	31	9	31	30	12	32	28	14	32	26	15	33	10.770
9	T_8	32	7	29	30	8	29	28	11	31	26	12	26	25	13	27	9.434
10	T_9	32	7	29	30	10	30	22	9	32	22	10	26	22	12	28	11.225
11	T_{10}	32	7	29	29	9	27	27	9	29	26	11	26	21	12	27	12.247
12	T_{11}	32	7	29	30	10	24	26	10	26	25	13	27	25	14	27	10.100
13	T_{12}	32	7	29	31	9	27	24	10	29	23	12	28	24	13	32	10.440

Appendix-C6: Changes in colour of edible coated jaggery stored in different packaging material at 25^{0}C temperature

APPENDIX-D

SCORE CARD FOR EVALUATION OF EDIBLE COATED SOLID JAGGERY

Product: Made on :

Tested on:

please rate the samples for quality attributes according to the five point scale

Excellent -5; Good -4; Medium -3; Fair -2; Not satisfactory -1

Sensory quality attributes of coated jaggery	Sample description	Sensory scale factors				
		Not satisfactory	Fair	Medium	Good	Excellent
Colour						
	Sample 1					
	Sample 2					
	Sample 3					
	Sample 4					
	Sample 5					
	Sample 6					
	Sample 7					
	Sample 8					
	Sample 9					
	Sample 10					
	Sample 11					
	Sample 12					
Sweetness						
	Sample 1					
	Sample 2					
	Sample 3					
	Sample 4					
	Sample 5					
	Sample 6					
	Sample 7					
	Sample 8					
	Sample 9					
	Sample 10					
	Sample 11					
	Sample 12					
Flavour						
	Sample 1					
	Sample 2					
	Sample 3					
	Sample 4					
	Sample 5					

	Sample 6					
	Sample 7					
	Sample 8					
	Sample 9					
	Sample 10					
	Sample 11					
	Sample 12					
Texture /Appearance						
	Sample 1					
	Sample 2					
	Sample 3					
	Sample 4					
	Sample 5					
	Sample 6					
	Sample 7					
	Sample 8					
	Sample 9					
	Sample 10					
	Sample 11					
	Sample 12					
Sensory scale factors						
Sensory quality attributes of coated jaggery in general		Not at all important	Somewhat important	important	Highly important	Extremely
Colour						
Sweetness						
Flavour						
Texture /Appearance						

RESUME

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Publications : 2

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Signature