STANDARDIZATION AND NEAR INFRARED REFLECTANCE SPECTROSCOPY BASED QUALITY EVALUATION OF THERMALLY PROCESSED TENDER JACKFRUIT (*Artocarpus heterophyllus* L.)

by

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(2017-28-001)

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TAVANUR, MALAPPURAM - 679 573
KERALA, INDIA

2020

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THESIS

Submitted in partial fulfilment of the

requirements for the degree of

DOCTOR OF PHILOSOPHY IN AGRICULTURAL ENGINEERING

Faculty of Agricultural Engineering and Technology

Kerala Agricultural University

DEPARTMENT OF PROCESSING & FOOD ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR, MALAPPURAM - 679 573

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2020

DECLARATION

I hereby declare that this thesis entitled **"Standardization and near infrared reflectance spectroscopy based quality evaluation of thermally processed tender jackfruit (*Artocarpus heterophyllus* L.)"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Tavanur
Date: 05.11.2020

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CERTIFICATE

Certified that this thesis, entitled **"Standardization and near infrared reflectance spectroscopy based quality evaluation of thermally processed tender jackfruit (*Artocarpus heterophyllus* L.)"** is a record of research work done independently by **Ms. Pritty S Babu (2017-28-001)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree fellowship or associateship to her.

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ACKNOWLEDGEMENT

This thesis arouse as a part of my research work in the Department of Processing & Food Engineering (P&FE), Kelappaji College of Agricultural Engineering & Technology (KCAET), Tavanur, since three years. Meanwhile, I have worked with many people who contributed in assorted ways to the research deserves special mention. It is a pleasure to convey my gratitude to all of them in my humble acknowledgement.

At first, I would like to record my profound sense of gratitude to the Chairman of my Advisory Committee, **Dr. Sudheer K.P (**Professor & ICAR National Fellow, Department of Agricultural Engineering, College of Horticulture, Thrissur) for his constant encouragement, scholastic guidance, constructive criticisms and valuable suggestions since the onset of my research. Moreover, I am indebted to him for his timely response in arranging DLP NIRscan Nano spectrophotometer, chemicals, texture analysis and travel facilities without which I could not have completed my work on time.

I express my heartfelt gratefulness to **Dr. Sathian K.K** (The Dean, KCAET, Tavanur) in providing all the necessary facilities to pursue this research. I am thankful to him for his moral support and permitting me to work for an extended duration beyond working hours when needed considering the nature of my analyses.

I am immensely grateful to **Dr. Prince M.V (**Professor and Head, Department of Processing and Food Engineering, KCAET, Tavanur), Member of Advisory Committee for his valuable advice, prompt response and granting me permission to use analytical facilities whenever needed during my research. I express my heartfelt thankfulness to **Dr. Rajesh G.K** (Assistant Professor, Department of Processing and Food Engineering, KCAET, Tavanur), Member of Advisory Committee for his constant motivation, support and providing all the analytical facilities for smooth running of my research. I express my sincere acknowledgement to **Dr. Bindu J** (Principal Scientist, Fish Processing Division, CIFT, Cochin), Member of Advisory Committee for making the canning unit at CIFT operational and facilitating it for my research. I am thankful to her for all the necessary arrangements including accommodation and thereby enabled hassle-free execution of my work at CIFT. I sincerely thank **Dr. Jayan P.R** (Professor

and Head, Department of Farm Machinery and Power Engineering, KCAET, Tavanur) for his suggestions and kind support during the period of my research. I express my heartfelt acknowledgement to **Dr. S. Ganapathy** (Professor, Department of Food Process Engineering, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Coimbatore), Member of Advisory Committee for his guidance and providing spectroradiometer facility during the initial phase of my research. I am thankful to him for arranging the needed accommodation which enable me to complete the intended analyses. I am deeply indebted to **Dr. Santhi Mary Mathew** (Retired Professor and Head, Department of Processing and Food Engineering, KCAET, Tavanur), former Chairman of the Advisory Committee for her valuable advice, moral support and providing necessary facilities to execute work in the initial phase of my research. I take this opportunity to thank the Chairman and all the Advisory Committee members in critically evaluating my thesis.

I am grateful to **Dr. Ravishankar C.N** (Director, CIFT, Cochin) for granting permission and necessary facilities to conduct thermal processing work involved in my research. I would like to express my heartfelt gratitude to **Dr. Girish Gopinath** (Kerala University of Fisheries and Ocean Studies, Cochin) and **Dr. Anand S.S** (Scientist, Space Application Centre, Ahmedabad) for arranging spectroradiometer facility and their technical support. I am extremely thankful to **Dr. Mohan C.O** (Scientist, Fish Processing Division, CIFT, Cochin) for his guidance and necessary support during thermal processing involved in this study. I am grateful to him for demonstrating thermal process calculations for me even in his tight schedule.

I express my gratitude to **Ms. Sreeja R** (Assistant professor, Department of Processing and Food Engineering, KCAET, Tavanur) for providing analytical facilities needed for my research. I am thankful to **Er. Shivaji K.P** (Assistant Professor, Department of Farm Machinery and Power Engineering, KCAET, Tavanur) for permitting vehicle to convey tender jackfruit samples to and from CIFT, Cochin.

I express my wholehearted acknowledgement to **Mr. G. Omanakuttan Nair** (Assistant Chief Technical Officer), **Mr. Suresh** (Senior Technical Assistant) and **Mr. Syam Kumar C** (Young Professional) of CIFT, Cochin for their technical assistance, timely involvement, passionate co-operation throughout the thermal processing and canning

work of this study. I would like to acknowledge **Canning Industries Cochin Limited** (CAICO, Thrissur) for providing purified (reverse osmosis) water for canning involved in my research.

I am obliged to **Dr. Riju M.C (**Assistant Professor, Microbiology, Department of Processing and Food Engineering, KCAET, Tavanur) for providing technical support and facility for microbiological analysis involved in my research. I am thankful to **Dr. K. Surendra Gopal**, (Professor and Head, Department of Microbiology, College of Horticulture, Thrissur) for granting permission to execute microbiological analyses including PCR test of my samples in his laboratory. I acknowledge **Ms. Reshma K.S** (Skilled Assistant, Department of Microbiology, College of Horticulture, Thrissur) for performing the needed microbiological analyses.

I am grateful to both **Dr. Sankalpa (**Research Associate) and **Er. Saranya S** (Senior Research Fellow) of ICAR National Fellow Project, Kerala Agricultural University, Thrissur for their help and co-operation in performing texture analysis of samples involved in my storage study. I am thankful to **Er. Younus Athikkot** (Assistant Professor, Department of Farm Machinery and Power Engineering, KCAET, Tavanur) for arranging transport facility to convey tender jackfruit used for storage evaluation from Wayanad to KCAET Tavanur. I am extremely gratified with the immense services provided by **Mr. Radhakrishnan** (Lab Assistant), **Ms. Geetha** (Lab Assistant), **Ms. Anupama M** (Skilled Assistant), **Ms. Jojitha** (Computer Technician), and **Ms. Praveena N** (Technical Assistant) of Department of Processing and Food Engineering, KCAET, Tavanur.

I would like to express my sincere gratefulness to **Dr. Anu Varughese** (Assistant Professor, Department of Irrigation and Drainage Engineering, KCAET, Tavanur), **Er. Priya G. Nair (**Assistant professor, Department of Land and Water Conservation Engineering, KCAET, Tavanur) and **Dr**. **Najitha Ummer** (Assistant professor, Krishi Vigyan Kendra, Malappuram) for their constant encouragement, moral support and help whenever needed. I am grateful to **Mr. Harris** (Librarian i/c) **and Ms. Pankajam Rajan** (Lab Assistant) for their library services and moral support during the period of my research.

Words do not suffice to express my sincere gratitude to my juniors **Ignatious A Mendez** and **Vishnu K** for their co-operation and immense help during the period of my research in jackfruit collection and sample preparation during thermal processing and reference analyses. Apart from them, I am extremely thankful to my juniors **Anuj Sonal, Harikrishnan M.P, Shyam Kumar, Shibinraj R.P, Rank Prasang Harji, Amal D.J, Sajeer K, Harisankar O.P, Akhil K.G, Nandhulal A.M, Adarsh S.S, Hari Paderi, Athira P, Anjana S.R** and the 2016th batch B.Tech boys of KCAET Tavanur and my cousin sister **Ms. Sneha Bharathan** (Bachelor of Science in Biochemistry**)** for their assistance during reference analyses and spectral measurements involved in my research. I am thankful to my colleagues namely, **Er. Ashitha G.N, Er. Anjali C Sunny and Er. Basavaraj Patil** for their kind help and co-operation during my research.

I wish to acknowledge **Kerala Agricultural University** for awarding me the Senior Fellowship for the research. I am thankful to all levels of administration and services of Kerala Agricultural University and KCAET, Tavanur in particular which enabled the smooth conduct of my research work.

I fail on my part if I do not mention my husband, **Dr. Sarathjith M.C** for his cooperation, help in NIRS data analysis using MATLAB and constant encouragement throughout the study. It is my pleasure and privilege to express my affectionate acknowledgement to my beloved **parents, brother, mother and father in-law** for their prayers and all the support without which I could not have completed this work. Above all, I humbly acknowledge the grace and blessings of the supreme power that capacitates to fulfil this well nurtured dream.

Pritty S Babu

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SYMBOLS AND ABBREVIATIONS

-	:	hyphen
%	:	percentage
&	:	ampersand
χ^2	:	chi square test statistic
ΔE	:	total colour difference
µg	:	microgram
µmol	:	micromol
/	:	per
:	:	colon
;	:	semi colon
<	:	less than
=	:	equal to
>	:	greater than
±	:	plus or minus
×	:	multiplication
≥	:	greater than or equal to
a*	:	redness
A^*	:	absorbance
AA	:	ascorbic acid
AIC	:	Akaike's information criteria
ANOVA	:	analysis of variance
AOAC	:	Association of the Official Agricultural Chemists
b*	:	yellowness
B	:	Ball's process time
C_0	:	cook value
CA	:	citric acid
CC	:	carbohydrate content
CFC	:	crude fibre content

CIE	:	Commission International de l' Eclairage
CIFT	:	Central Institute of Fisheries Technology
cm	:	centimetre
CRD	:	completely randomized design
D	:	decimal reduction time
DF	:	dilution factor
DT	:	de-trend
et al.	:	and others
F	:	thermal death time (pasteurization)
F^*	:	variance statistic
F_0	:	thermal death time (sterilization)
f_c	:	cooling penetration factor or cooling rate index
F_c	:	firmness of core
FD	:	first derivative
f_h	:	heat penetration factor or heat rate index
Fig.	:	figure
F_{ref}	:	reference thermal death time
F_s	:	firmness of skin
F_t	:	firmness of tendril
F_w	:	firmness of whole portion
g	:	gram
g	:	maximum temperature deficit
GAE	:	gallic acid equivalent
h	:	hour(s)
Ha	:	hectare
H_o	:	null hypothesis
Hz	:	Hertz
InGaAs	:	indium gallium arsenide
IS	:	Indian standard

IU	:	International units
j_c	:	lag factor of cooling
j_h	:	lag factor of heating
k	:	rate constant
kg	:	kilogram
kJ	:	kilo joule
kV	:	kilo volt
l	:	come up time
L*	:	lightness
LED		light emitting diode
Ltd.	:	Limited
mg	:	milligram
MHz	:	megahertz
min	:	minute(s)
ml	:	millilitre
mm	:	millimetre
mol/L	:	mol per litre
Mpa	:	mega pascal
ms	:	milliseconds
MSC	:	multiplicative scatter correction
MT	:	metric ton(s)
N	:	newton
N	:	number of viable microorganisms
N.s	:	newton second
N_0	:	initial number of viable microorganisms
NaOH	:	sodium hydroxide
N_{cfu}	:	number of colony forming units
NIR	:	near infrared
NIRS	:	near infrared reflectance spectroscopy

nm	:	nanometre
^{o}	:	degree
^{o}C	:	degree Celsius
^{o}F	:	degree Fahrenheit
P	:	pasteurization
p	:	probability value
PbS	:	lead sulphide
PCR	:	principal component regression
PLSR	:	partial least squares regression
R^{*}	:	reflectance
R^{2}	:	coefficient of determination
RE	:	rutin equivalent
RMSE	:	root mean squared error
RPD	:	residual prediction deviation
rpm	:	revolutions per minute
s	:	second(s)
S	:	sterilization
SD	:	second derivative
SNV	:	standard normal variate
SWIR	:	shortwave infrared
t	:	processing time
T	:	temperature
TA	:	titrable acidity
T_{c}	:	toughness of core
TFC	:	total flavonoid content
TFS	:	tin free steel
T_{ic}	:	initial cooling temperature
T_{ih}	:	initial critical point temperature of the product
T_{p}	:	critical point temperature of the product

TPC	:	total phenol content
T_{pic}	:	pseudo initial cooling temperature
T_{pih}	:	pseudo initial heating temperature
T_r	:	retort temperature
T_{ref}	:	reference temperature
T_s	:	toughness of skin
TSS	:	total soluble solids
T_t	:	toughness of tendril
TV	:	titre value
T_w	:	temperature of water
T_w	:	toughness of whole portion
U	:	thermal process time at retort temperature
VIS	:	visible
W	:	Kendall's coefficient of concordance
wt.	:	weight
z	:	thermal resistance of microorganism
α	:	level of significance

CHAPTER 1
INTRODUCTION

Jackfruit (*Artocarpus heterophyllus* L.) is renowned for its richness in vitamins, minerals, calories, functional, therapeutic, medical and physiological attributes (Baliga *et al.*, 2011; Swami *et al.*, 2016). It is often acknowledged as 'poor man's food' as it is economical and available in plenty during summer season when other food source becomes scarce (Jagtap *et al.*, 2010). Despite the wide range of benefits, jackfruit remained underutilized and is not regarded as a commercial crop in its major growing areas (Reddy *et al.*, 2004; Ranasinghe *et al.*, 2019). However, over the last decade, variety of ready-to-eat and value added food products are being developed from jackfruit seed and mature or ripen fruit (APAARI, 2012; Devi *et al.*, 2014). Most of them are either sugar or oil-based and hence less preferred for daily consumption especially for people who are health conscious or suffering from diabetes and hypertension. The consumption of immature or tender jackfruit (about 60-70 days of maturity) as a vegetable (Rana *et al.*, 2018a) can be recommended as a promising solution to this problem mainly due to its richness in vitamin C and potassium with little sugars (Swami *et al.*, 2016). In addition, the other nutrient components, fibre content and meat like texture together made it popular as a vegetable. These inherent quality attributes of tender jackfruit might have been identified traditionally which implicitly became a reason for its high market value especially in South Asian countries. But, several factors confound its year round availability and thereby affect its market potential adversely. The main factors include its seasonal availability and highly perishable nature. Apart from these factors, practical difficulties in its processing, transportation and storage also limit the year round availability of tender jackfruit in either ready-to-cook or ready-to-eat form. They include the poor infrastructure in the jackfruit growing regions, rapid browning (once cut), tissue softening, phytochemical depletion, among others (Rana *et al.*, 2018b; Ranasinghe *et al.*, 2019). To address the aforementioned challenges, further investigation is warranted for identification of an appropriate preservation technique capable of extending the shelf life of tender jackfruit with due consideration to consumer demand (high quality, natural, fresh/fresh-like, health benefits, devoid of preservatives and additives), acceptance and economic viability.

Several food preservation techniques exists, which can be broadly classified into minimal processing, thermal and non-thermal techniques based on the principle of operations (Prokopov and Tanchev, 2007; Pereira and Vicente, 2010; Jayathunge *et al.*, 2019). Minimal processing of fruits and vegetables involves different steps to obtain a completely edible product with 'fresh-like' attributes, improve their functionality and assure microbiological safety during their conveyance from the production site to the consumer (Ohlsson, 1994; Artés and Allende, 2014; Escobedo-Avellaneda *et al.*, 2018). In thermal processing, the food is subjected to heat treatment from an external source either before (aseptic processing) or after (canning, retort pouch) final packaging (Montanari *et al.*, 2018). On the other hand, non-thermal techniques enable local heating within the food matrix by an even application of either pressure (high-pressure processing), shock wave (ultra sound processing) or pulsed electric field (Prokopov and Tanchev, 2007; Jayathunge *et al.*, 2019). Minimally processed or fresh-cut vegetables remain suitable for consumption (microbiologically safe) for about a week or two only under refrigerated conditions. Although, non-thermal techniques have the advantages of short process time and minimum temperature gradient within the product (Barrett and Lloyd, 2012), they are very expensive and some of their commercial application is still at its infancy. In contrast, thermal processing has been widely used to ensure palatable products with a shelf life of 2 years or more (Barrett and Lloyd, 2012). Moreover, thermally processed products have commercial sterility accomplished by the combined effect of heat treatment and anaerobic condition (prevent the growth of surviving microorganisms) created inside the container as in case of canning (Montanari *et al*., 2018). Hence, thermal processing may be chosen as the most suitable approach among others for year round perseveration of tender jackfruit. Pritty and Sudheer (2012) have demonstrated thermal processing of tender jackfruit in tin cans with preservatives. But, sealed tin-plated cans are generally known to expend tin to strive for available oxygen under anaerobic conditions prevailing within them. Ultimately, it affects the quality of the product especially the phenolic compounds (Rickman *et al.*, 2007); the key antioxidant factor associated with risk reduction to cardiovascular disease (Swami *et al.*, 2012; Ranasinghe *et al.*, 2019). Moreover, dissolution of tin into the product during long term storage may lead to many health issues including diarrhoea, nausea and vomiting (Blunden and Wallace, 2003). Hence, the use of tin-plated cans are generally not recommended for the preservation of fruits and vegetables. An alternative would be the use of tin free steel (TFS) cans. But limited

studies have reported on thermal processing and quality evaluation during storage of tender jackfruit in TFS cans and hence warrant further investigation.

Tender jackfruit with its inherent benefits and popularity qualify as a target commodity for value addition and has drawn remarkable attention among food processing industrialists and business entrepreneurs. For commercial scale processing and value addition of tender jackfruit, it is important to assess the quality of both raw material and final product in a routine manner. In the industry, accurate and timely characterization of raw material/product helps to judge the product compliance with the desired quality standard, enables screening and classification/categorization of products based on their quality. Hence, a rapid and reliable assessment of the quality of tender jackfruit before and after thermal processing is considered to be an essential pre-requisite for quality analysis and quality checking protocols in jackfruit industry. Conventionally, the quality attributes are being assessed using reference analytical methods by experienced personnel. But, the conventional methods are expensive, laborious, time consuming and involve the use of chemicals. Hence, they are not appropriate to serve the aforesaid purpose especially when more number of samples and attributes are to be analysed. The drawbacks associated with the use of conventional methods may be addressed using near infrared reflectance spectroscopy (NIRS) with operational domain in 701-2500 nm wavelength range of the electromagnetic spectrum. Over the last few decades, the approach has been widely recognized as a promising tool for the assessment of the quality of fruits and vegetables (Schulz *et al.*, 1998; Slaughter and Abbott, 2004; Alander *et al.*, 2013; Fu and Ying, 2016). The approach has gained immense popularity due to its ability for a rapid, reliable, non-destructive, non-invasive characterization in a cost-effective manner with little use of chemicals (Bureau *et al.*, 2009; Sanchez *et al.*, 2020). Moreover, NIRS can be used to assess multiple attributes of the target material. In addition, the approach is amenable to both off-line (benchtop, hand-held) and inline/online modes of operation (Huang *et al.*, 2008; Alander *et al.*, 2013). In NIRS, the spectral signature (mainly characterized by the overtones and combinations of fundamental vibrations in mid-infrared frequencies associated with C–H, N–H and O–H functional groups) and quality attribute of target material (determined by reference analytical methods) are linked (Pasquini, 2003; Cen and He, 2007). This linkage (also referred as calibration function) can be later used to estimate attribute

values from spectral signature. To establish a calibration function, the use of several multivariate analytical techniques has been investigated which include principal component regression, partial least squares regression (PLSR), support vector machine and artificial neural networks (Workman *et al.*, 1996; Shao *et al.*, 2011). The PLSR supersedes other techniques with its potential to account for the multicollinearity inherent to spectral variables, computational efficiency and interpretability (De Belie *et al.*, 2003; De Oliveira *et al.*, 2014). Hence, PLSR has become the most prominent, extensive and frequently used algorithm for calibration function development in NIRS studies. Usually, large spectral libraries consisting of diverse spectra-attribute values are used to establish calibration functions. But, no such spectral library exists for either raw or thermal processed tender jackfruit to the best of our knowledge. Moreover, no studies have explored the utility of NIRS to assess the quality attributes of tender jackfruit and hence warrant further investigation.

To accomplish the aforementioned requirements, this study was conducted with prime focus on the standardization and NIRS based quality evaluation of thermally processed tender jackfruit as a vegetable with the following specific objectives.

1) To standardize the thermal processing of tender jack fruit in TFS cans
2) To study the shelf life and quality of canned tender jack fruit
3) To study the utility of NIRS as a novel approach for assessing the quality of tender jackfruit

CHAPTER 2
REVIEW OF LITERATURE

2.1 JACKFRUIT (A*rtocarpus heterophyllus* L.)

2.1.1 Origin and distribution

Jackfruit (*Artocarpus heterophyllus* L.) tree which typically grows in moist and warm regions (Bose, 1985) is considered to have its origin in the rain forests of the Western Ghats in India (Radha and Mathew, 2007; Baliga *et al.*, 2011; Ranasinghe *et al.*, 2019). Over a period of time, they have been introduced to other geographical locations mostly in the tropics. Now, it is an important crop especially in Southeast Asia covering China, India, Indonesia, Malaysia, Myanmar, Philippines, Sri Lanka and Thailand. It is also grown in Brazil, California and Florida of the United States of America, Caribbean islands, northern Australia, Pacific Islands, Puerto Rico and West African forest zones (Bose, 1985; Rahman *et al.*, 1995; Azad *et al.*, 2007; Baliga *et al.*, 2011).

2.1.2 Area, production and value of output of jackfruit in India

In India, jackfruit is mainly grown in the eastern (Bihar, Jharkand, Odisha, West Bengal), north eastern (Arunachal Pradesh, Assam, Manipur. Mizoram, Nagaland, Tripura), central (Uttar Pradesh) and southern (Karnataka, Kerala, Tamil Nadu) regions. The total area and production of jackfruit in the country during last decade are shown in Fig. 2.1 as per the data compiled from the annual 'Horticulture Statistics at a Glance 2015 & 2018' and 'Hand Book on Horticulture Statistics 2014' published by Horticulture Statistics Division, Department of Agriculture, Cooperation & Farmers' Welfare, Ministry of Agriculture & Farmers' Welfare Government of India (available in www.agricoop.nic.in website, accessed on May 20, 2020). In the last decade, both the area and production of jackfruit were noted to have a general increasing pattern with their values varied in the range 36000–187000 Ha and 540000–2088000 MT, respectively. In India, the Kerala state possess major area under jackfruit (Baliga *et al.*, 2011; APAARI, 2012), however, limited reports are available on its state-wise area and production statistics (Rana *et al.*, 2018b). Although, Kerala has a high value of output of jackfruit (based on Horticulture Statistics at a Glance 2018) among other major jackfruit growing states in India (Fig. 2.2), about 75% of the national wastage has been recorded from the state (APAARI, 2012).

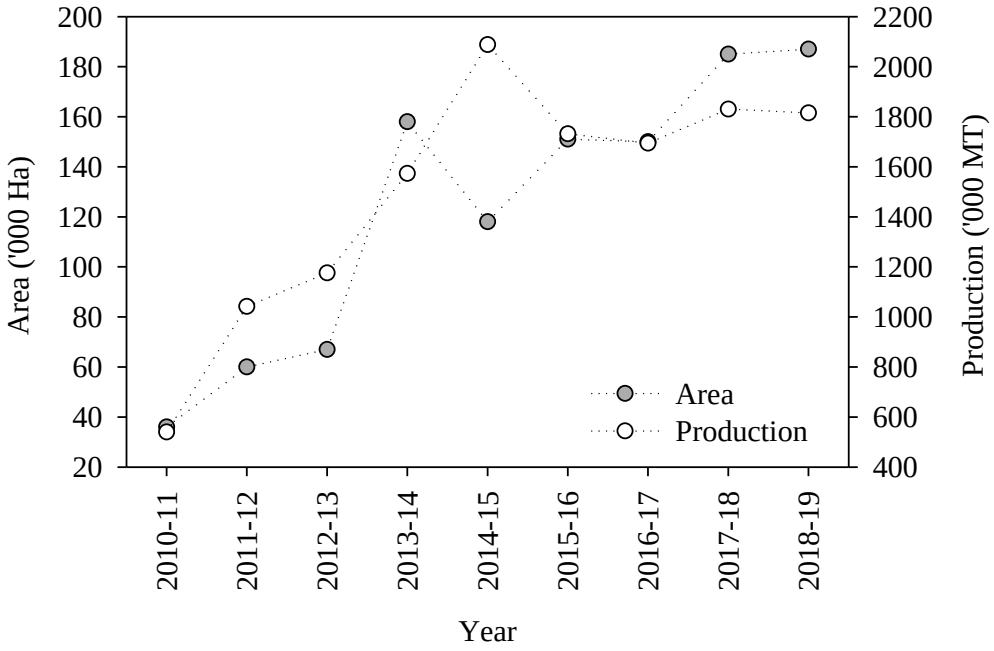

Fig. 2.1 Area and production of jackfruit in India during last decade

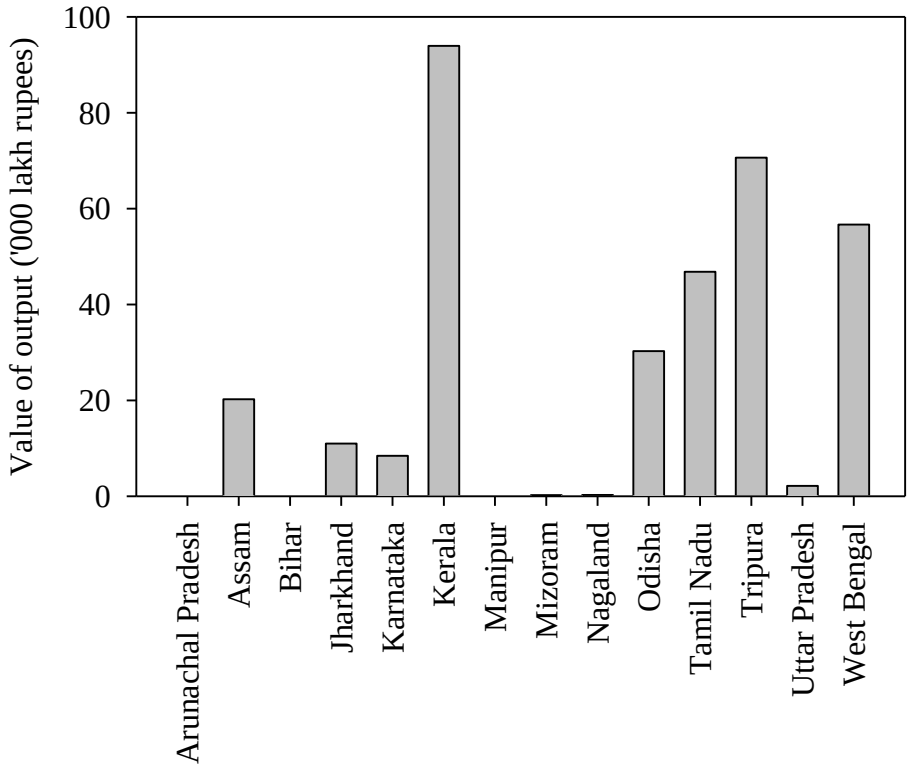

Fig. 2.2 State-wise value of output of jackfruit based on 2015-16 prices

2.1.3 Botanical aspects

Jackfruit tree is monoecious characterized by the presence of both male and female inflorescences (Bose, 1985; Morton, 1987; Baliga *et al.*, 2011). The fruit development generally takes about 3-7 months after successful pollination, despite the time of fruiting varies geographically across different countries (Haq, 2006). The fruit comprises an axis (core), perianth and the true fruit. The axis possess immense latex (secreted by laticiferous cells) by which the fruits are held together. The perianth consists a lower fleshy (edible bulb), middle fused (forms the rind) and upper horny (non-edible spikes) regions. The fruit (arils/flesh) comprise of bulbs and seeds (Prakash *et al.*, 2009).

2.1.4 Varieties of jackfruit

Various types of jackfruit can be seen mainly due to its high cross-pollinated nature and seed based propagation. Indeed, to get true to type plants, vegetative propagation is essential (APAARI, 2012). The jackfruit types vary with regard to both phenotypic (tree size, leaf, form of fruit, fruit bearing age, fruit size, fruit shape, spine density, period of maturity) and organoleptic (fruit pulp quality, colour, texture, odour) traits (Haq, 2006; Baliga *et al.*, 2011). Table 2.1 enlists selected jackfruit varieties grown in different locations of the world. Based on the variety, the colour of jackfruit bulb can be variants of white, yellow and orange colours (Jagadeesh *et al.*, 2007). Jackfruit can be broadly categorized into soft and firm types depending on the consistency of the fruit and its pulp. The former category is characterized by jackfruits with very sweet carpels, soft and spongy flakes while those in the latter bear crisp and crunchy carpels with relatively less sweetness. The soft and firm types are known by the local names Koozha pazham & Varikka chakka (Kerala, India), Tulvo & Barko (Konkani), Kha-nun lamoud & Kha-nun nang (Thailand), Vela & Varaka or Waraka (Srilanka), respectively (Morton, 1987).

2.1.5 Composition and health benefits

Jackfruit contains carbohydrates, proteins, fibre, fat, vitamins (vitamin A, vitamin C, thiamin, riboflavin, niacin), minerals (Ca, K, Fe, Na, Zn), phytochemicals (lignans, isoflavones, saponins) and phenolic compounds including flavonoids, phenolic acids, phenylpropanoids, lignins, melanins and tannins (Baliga *et al.*, 2011; Swami *et al.*, 2012). It has many carotenoids (de Faria *et al.*, 2009) and a low energy content of about

Table 2.1 Jackfruit cultivars in different countries (Morton, 1987; Haq, 2006; Baliga *et al.*, 2011)

Country	Cultivar names
Australia	Black gold, Cheena, Chompa gob, Coching, Fitzroy, Galaxy, Golden nugget, Honey gold, Kapa, Lemon gold, Mutton, Nahen, Varikkha
Bangladesh	Chala, Goal, Hazari, Khaja, Koa, Topa
India	Barica, Bhadaiyan, Bhusila, Champa, Everbearer, Gerissal, Ghila, Gulabi, Handia, Hazari, Jackfruit NJT1, Jackfruit NJT2, Jackfruit NJT3, Jackfruit NJT4, Karcha, Khaja, Kooli, Koozha navarikka, Pazam varikka, Mammoth, Ghula, Rose-scented, Rudrakshi, Safeda, Singapore or the Ceylon Jack, T-Nagar jak, Varikka, Velipala, Khujja or Karcha
Indonesia	Kandel, Mini, Tabouey
Malaysia	J-30, J-31, NS-1, Na2, Na29, Na31
Myanmar	Kala, Talaing
Philippines	J-01, J-02, TVC, Torres
Singapore	Jak/Ceylon jak
Sri Lanka	Kuruwaraka, Peniwaraka, Singapore or the Ceylon Jack, Varaka (Waraka), Vela
Jamaica	Kuruwaraka, Peniwaraka or Honey jack
Thailand	Dang rasimi, Kun Wi Chan, Kha-num nang, Kha-num lamoud
USA	Black gold, Cheena, Dang Rasimi, Delightful, Galaxy, Golden Nugget, Honey Gold, J-30, J-31, Lemon Gold, NS-1, Tabouey

94 calories per 100 g (Mukprasirt and Sajjaanantakul, 2004). The proximate and phytochemical composition of jackfruit varies with the cultivar and growth stages irrespective of its growing region (Baliga *et al.*, 2011). Also the composition vary between jackfruit components (fruit and seed). The proximate composition of fresh jackfruit components (per 100 g) are listed in Table 2.2 as compiled and modified from Arkroyd *et al.* (1966), Azad (2000), Gunasena *et al.* (1996), Haq (2006), Liu *et al.* (2004), Narasimham (1990) and Soepadmo (1992).

Since ancient times, the use of jackfruit has been highly recognized for its therapeutic and physiological effects (Swami *et al.*, 2012). The nutritional and health benefits of jackfruit have been ascribed to its rich physicochemical compositional attributes as reviewed by Baliga *et al.* (2011), Ranasinghe *et al.* (2019), Swami *et al.* (2012). Jackfruit is a good source of potassium (Table 2.2) which helps to lower blood pressure.

Table 2.2 Proximate composition of fresh jackfruit per 100 g (Swami *et al.*, 2012)

Composition	Young fruit	Ripe fruit	Seed
Water (g)	76.2-85.2	72.0-94.0	51.0-64.5
Protein (g)	2.0-2.6	1.2-1.9	6.6-7.04
Fat (g)	0.1-0.6	0.1-0.4	0.40-0.43
Carbohydrate (g)	9.4-11.5	16.0-25.4	25.8-38.4
Fibre (g)	2.6-3.6	1.0-1.5	1.0-1.5
Total sugars (g)	-	20.6	-
Energy (KJ)	50-210	88-410	133-139
Minerals			
Total minerals (g)	0.9	0.87-0.9	0.9-1.2
Calcium (mg)	30.0-73.2	20.0-37.0	50
Magnesium (mg)	-	27	54
Phosphorus (mg)	20.0-57.2	38.0-41.0	38.0-97.0
Potassium (mg)	287-323	191-407	246
Sodium (mg)	3.0-35.0	2.0-41.0	63.2
Iron (mg)	0.4-1.9	0.5-1.1	1.5
Vitamins			
Vitamin A (IU)	30	175-540	10.0-17.0
Thiamine (mg)	0.05-0.15	0.03-0.09	0.25
Riboflavin (mg)	0.05-0.2	0.05-0.4	0.11-0.3
Vitamin C (mg)	12.0-14.0	7.0-10.0	11.0

It is also rich in vitamin C (ascorbic acid); antioxidant known for its ability to scavenge free radicals, keep the gum healthy and strengthen the immune system (Jagtap *et al.*, 2010). The vitamin C content was reported to be highest in tender jackfruit (young fruit) compared to that of seed, matured or ripen form (Table 2.2). Jackfruit also have vitamin B3 (niacin) of about 4 mg/100 g of pulp (Soobrattee *et al.*, 2005). It plays a significant role in energy metabolism, hormone synthesis and also in nerve functioning. The phytonutrients (lignans, isoflavones, and saponins) present in jackfruit have multiple benefits, a) prevent the growth of cancer cells in the body (anticancer), b) lower blood pressure (antihypertensive), c) combat stomach ulcers (antiulcer) and d) slow down cell degeneration (antiaging). The phenolic compounds present in jackfruit is capable of reducing risk of cardiovascular disease (Swami *et al.*, 2012). More details on the pharmacological uses of jackfruit tree can be seen in the review by Baliga *et al.* (2011).

2.1.6 Reasons for underutilization of jackfruit

Despite nutritional, dietary, pharmacological and functional attributes (Baliga *et al.*, 2011; Swami *et al.*, 2012), the jackfruit remain underutilized and do not qualify as a commercial crop in its major growing areas. Its plantation-scale cultivation on a regular basis is limited mainly due to its short shelf life and insufficient facilities nearby for its processing (Reddy *et al.*, 2004). Some of the reasons for underutilization of jackfruit as compiled and modified from Ranasinghe *et al.* (2019) are listed below.

a) *Perishable nature*: Jackfruit flesh undergoes browning (when cut), tissue softening and loss of flavour (Mondal *et al.*, 2013) after harvest. The tissue softening makes it more vulnerable to bruise and mechanical injury (Ramli, 2009).

b) *Higher inedible proportion*: Inedible parts (outer prickly rind, inner perigones, and central core) of jackfruit accounts for about 60% of the whole fruit (Xu *et al.*, 2018) which result in less cost effectiveness in its processing and marketing.

c) *Wastage*: The edible flesh constitute about 35% of the whole fruit (Narasimham, 1990) while the remaining inedible parts are being wasted in jackfruit processing industries. Although, these wastes are used as animal feed, limited studies have been conducted to develop value added products from them. As immense quantity of waste has been discarded from jackfruit industries (Moorthy *et al.*, 2017), it may cause waste disposal and other environmental issues (Prahas *et al.*, 2008).

d) *Poor postharvest practices*: Lack of proper knowledge on handling, sanitary and storage practices cause rapid deterioration of jackfruit quality after harvesting. Inadequate storage in areas of growing, processing and marketing also result in deterioration of jackfruit (Jagtap *et al.*, 2011; Mondal *et al.*, 2013).

e) *Processing concerns*: Inconsistent size and shape of jackfruit creates complexity in the design of packaging setup. Also, the thick and rough skin together with the latex makes jackfruit preparation and pre-processing very difficult (Ramli, 2009).

f) *Consumer perception*: Jackfruit being a large fruit, its peeling and separation of bulbs from rind are difficult, time consuming and laborious tasks (Jagadeesh *et al.*, 2006; Vargas-Torres *et al.*, 2017) which ultimately makes it less attractive among urban consumers with a busy way of life. Also, the intense flavour of

jackfruit is undesirable to some consumers (Jagadeesh *et al.*, 2006). In addition, there exists a prevalent belief that too much consumption of jackfruit can cause digestive problems (Baliga *et al.*, 2011).

g) *Variation in cultivars and quality attributes*: The vast differences in physical and biochemical compositional attributes of jackfruits across different cultivars limit their use for variety of products (Jagadeesh *et al.*, 2006).

It can be inferred that advanced processing, packaging and storage techniques along with sustainable waste management strategies are inevitable for commercial scale value addition of jackfruit and thereby enhance its utility. Also, the development of value added products from tender jackfruit is a viable approach to reduce wastage and improve its utility. Because, in tender stage, the inedible portion (peel) is relatively less than edible counterpart as compared to that of mature and ripen form.

2.1.7 Post harvest utility

The primary economic product of jackfruit is its fruit and several value added products have been developed from it. The fruit in its tender form (tender jackfruit) is usually consumed as a vegetable (Rana *et al.*, 2018a). It is considered to be a vegetarian substitute for meat (often referred as 'vegetable meat') as it has a remarkable similar texture as that of chicken (APAARI, 2012; Lakshmana *et al.*, 2013). Jackfruit pulp in its mature unripen form is generally used to make chips in rural households. The ripen pulp is sweet and tasty which is usually consumed as such while the seed is either roasted or cooked prior to consumption. Over the years, several value added products are being developed from the fruit and seeds of jackfruit which includes fruit concentrate, jam, jelly, powder, pulp, squash, toffee (Bhatia *et al.*, 1956a; Mondal *et al.*, 2013), dried jack seeds, roasted nut, jack papad (Bhatia *et al.*, 1956b; Lim, 2012), dried green jackfruit, jack pickle (Bhatia *et al.*, 1956c; Lim, 2012), among others. In addition, a variety of other recipes such as bhaji, biryani, chips, curry, cutlet, dumplings, idli, tarte tatin, unni appam, dosa, among others have also been prepared out of raw jackfruit and seed flour (APAARI, 2012; Devi *et al.*, 2014). Although many value added jackfruit products are available in the market, most of them are either oil or sugar based and hence not appropriate for daily consumption especially for people suffering from diabetes and hypertension. In such cases, processing, value addition and storage of tender jackfruit as a vegetable is recognized as a better alternative (Pritty and

Sudheer, 2019). In addition to nutritional and health perspectives, consuming tender jackfruit as a vegetable would help to reduce its overall wastage.

2.2 FOOD PROCESSING TECHNOLOGIES

How to feed a rapidly growing human population (expected to be around 9 billion by 2050) is the major global challenge today (Tavman *et al.*, 2019). It is estimated that a hike in present food production by 70% will be needed to address the challenge. However, agricultural production systems with scarce resources under changing climate may not be adequate to comply with the global food demand. Development and implementation of efficient food wastage reduction strategies has been identified to be a potential global approach for a food secure world. Because, a large share (about 30-50%) of globally produced food is being lost or wasted mostly as spoilage due to shortfalls in production, processing, transportation, market and consumer trends (FAO, 2011; Tavman *et al.*, 2019). The food spoilage has to be minimized effectively to account for the food demand of rapidly growing population. The implementation of efficient food processing/preservation technologies has been identified as a vital step to address the challenge.

Several food processing techniques exists which may be broadly classified as thermal and non-thermal categories (Prokopov and Tanchev, 2007; Jayathunge *et al.*, 2019). Conventional thermal processing involves transfer of heat (by conduction or convection mechanisms) generated from an external source (fuel combustion or electric resistive heating) into the product to destroy microbiological organisms and there by ensure food safety. The technology has a robust scientific basis with well-linked engineering and microbiological fundamentals. Since its introduction (by Nicholas Appert in the early 1800), the technology has advanced with regard to process equipment design, heating media and handling (Tola and Ramaswamy, 2018). In the last few decades, novel thermal technologies capable of volumetric heating within the food have emerged. It includes both ohmic and dielectric heating based techniques. The ohmic heating (also known as Joule/ electrical resistance/ electro-conductive heating) takes place with the heat generated inside the food due to its electrical resistance (De Alwis and Fryer, 1990; Pereira and Vicente, 2010). The dielectric heating based on radiofrequency (1 to 300 MHz) and microwave (300 to 3000 MHz) techniques rely on the heat generated within

the food matrix due to energy dissipation associated with molecular friction (induced by dipole rotation and migration of ions under the oscillating electromagnetic field) (Piyasena *et al.*, 2003). On the other hand, 'non-thermal processing' refers to those techniques which cause microbial inactivation in food at sub-lethal or ambient temperatures. It includes, ultraviolet light, pulsed light, high-intensity ultrasound, oscillating magnetic fields, pulsed electric fields, high hydrostatic pressure (100–800 MPa) based techniques (Butz and Tauscher, 2002; Pereira and Vicente, 2010). The ultraviolet and pulsed light technologies make use of intense and short-duration pulses in the ultraviolet to the near infrared region to induce DNA mutations in microorganisms (Sastry *et al.*, 2000; Elmnasser *et al.*, 2007). The ultrasound disturb cellular structure and functional components (intracellular cavitation) by micro-mechanical shocks generated using sound waves with frequency of 20,000 Hz or more (Vollmer *et al.*, 1998). The oscillating magnetic field (1–100 pulses at 5–500 kHz, 0–50^{o}C, 25–100 ms) technique rely on the deleterious effects of magnetic fields on microbial populations (Barbosa-Canovas *et al.*, 2000). The high voltage pulsed electric fields (20–80 kV/cm for <1 s) inactivate microorganisms by electrical breakdown and electroporation (Grahl and Märkl, 1996). In high hydrostatic pressure (100–800 MPa) technique, microbial inactivation typically occurs due to breakdown of their biological membranes and denaturation of enzymes or proteins (Fabiano, 2012).

Among different food processing technologies discussed above, the emerging thermal and non-thermal technologies are capable of producing safe and quality foods with little interference to the environment (due to better energy efficiency and reduced use of non-renewable resources). But, their high investment cost, process operation difficulties (associated with the full control of variables) and limited regulatory approval confound their commercial scale applications (Pereira and Vicente, 2010). In these contexts, the conventional thermal processing can be regarded as a promising alternative as it is a cost effective approach for improved shelf life of food in the tune of 2 years or more (Barrett and Lloyd, 2012) with relatively less constraints for commercial scale implementation. With its inherent advantages, thermal processing has been the most widely used and effective technique for food preservation (Augusto *et al.*, 2014). As the present study mainly intent to investigate the effect of conventional thermal processing on the quality of tender jackfruit, further discussion is limited to this technology alone.

2.3 FUNDAMENTALS OF THERMAL PROCESSING AND CANNING

Thermal processing is a food preservation technique that intend to destroy/eliminate/inactivate microorganisms and endogenous enzymes by suitable combination of temperature and time. Thermal processing can be carried out as in-container (retort processing) or out-of-container (continuous flow or aseptic processing) process. The in-container process comprise of thermal treatment of the product in hermetically sealed containers for the desired duration and temperature. In contrast, the out-of-container process involves thermal treatment of the product prior to their aseptic filling followed by hermetically sealing in sterile containers (Huang *et al.*, 2016; Perera and Perera, 2019). The process of packaging food in containers (metal cans, bottles, pouches) before (retort processing) or after (aseptic processing) thermal processing is generally referred as canning.

The effectiveness of thermal processing rely on conduction and convection mechanisms of heat transfer from an external source into the product (Pereira and Vicente, 2010). Generally, thermal processing is carried out at a temperature in the range of 50–150^{o}C for a specific duration by which reduction in the desired number of microbes is accomplished (Aamir *et al.*, 2013). Based on the temperature/intensity, thermal processing operations are categorized into blanching, pasteurization (65–100^{o}C), sterilization (110–121^{o}C), and ultrahigh temperature (130–150^{o}C) treatments. Blanching refers to the treatment of food in hot water or steam for a short duration mainly to inactivate oxidative enzymes (such as polyphenol oxidase, catalase, peroxidase and lipoxygenase) and thereby stabilize flavour, texture and nutritional changes caused by them. Further, it helps to clean and destroy microorganisms on the product surface (Ahmed and Shivhare, 2012). Pasteurization refers to mild heat treatment to destroy or deactivate enzymes and vegetative cells of pathogenic microorganisms including vegetative bacteria (Fellows, 2017). Pasteurization of vegetables generally aimed to destroy *Listeria monocytogenes*. However, its heating intensity is not sufficient to destroy *Clostridium botulinum* spores and hence the pasteurized products are to be immediately kept and stored under refrigerated conditions (Aamir *et al.*, 2013). In contrast, sterilized products can be stored in ambient conditions as the thermal process deactivate or destroys all forms of biological agents

and pathogens or microorganisms (including *Clostridium botulinum* spores) and thereby making the product sterile or aseptic. Similarly, ultrahigh temperature treatment results in a commercially sterile product by a very short duration (a few seconds) heat treatment (Swartzel, 1982). As the process requires flow-through equipment, its application generally applies for the processing of low viscous liquid products. However, the selection of an appropriate thermal process operation is governed by the food pH, type and heat resistance of enzyme, spore or target microorganism, storage conditions after thermal processing, preferred shelf life, thermo-physical attributes of the product and the level of food quality degradation acceptable for consumers (Kong *et al.*, 2007; Aamir *et al.*, 2013; Fellows, 2017). Some of these aspects are discussed in the following sections.

2.3.1 pH and thermal process

The pH value of a food represents the presence of free hydrogen ions (specifically, the negative log of the hydrogen ion concentration) and it varies between 0 and 14, numerically. The microbial growth (bacteria, moulds and yeasts) is sensitive to pH value of food. Remarkably, very low and high pH do not favour the growth of microorganisms. But, most foods in their unprocessed state do not have pH close to the extreme values and thus fail to completely inhibit the microbial growth. However, various foods do have low pH values sufficient enough to offer some preservative effect. Based on pH, foods are generally classified into low- ($pH > 4.6$) and high-acid ($pH < 4.6$) categories (Awuah *et al.*, 2007). This classification rely on a pH value of 4.6 that is critical for the survival of dormant form (spore) of *Clostridium botulinum* bacterium that produces neurotoxin causing food-borne illness (botulism). The spores do not survive if food pH is less than 4.6 and hence high acid foods (e.g. most fruits, jams, jellies, pickles, vinegar, and yoghurt) may be given mild heat treatment (pasteurization) for their microbiological safety. In contrast, the spores survive in low acid foods (e.g. most vegetables, milk, meat and poultry) as the pH has little effect on their inhibition. To overcome the heat resistance of spores, the low acid foods shall be subjected to an intense heat treatment (sterilization) for their safety (Patras *et al.*, 2009; Augusto *et al.*, 2014). Thus, pH of food is a key factor, which has a direct influence on microbial growth in addition to its decisive role in thermal process selection for food preservation.

2.3.2 Time–temperature effects on microbial inactivation

The thermal inactivation of microorganisms follows a first-order semi-logarithmic reaction kinetics and hence sterility of the product cannot be assured with certainty even if the processing time is long (Awuah *et al.*, 2007; Toledo-Martín *et al.*, 2018). Although this traditional view is widely recognized, it has been debated (Corradini and Peleg, 2004) against Weibull distribution of microbial heat resistances (Van Boekel, 2002). The first-order reaction kinetics of '*N*' number of viable microorganisms can be denoted by Equation 2.1 with 'k' and 't' as the rate constant and processing time, respectively. It modifies to Equation 2.2 upon integration using $N = N_0$ and t = 0 as the initial condition and expressed in common logarithm.

$$\frac{dN}{dt} = kN \qquad 2.1$$

$$\log\left(\frac{N}{N_0}\right) = -\frac{kt}{2.303} \qquad 2.2$$

Equation 2.2 can be modified in terms of decimal reduction time (D = 2.303/k); the time required for 10 fold reduction of viable microbial population (Equation 2.3). The value of $N < 1$ and $N \geq 1$ in the resultant equation indicates the probability and certainty (100% probability) of spoilage, respectively (Ahmed and Shivhare, 2012; Toledo-Martín *et al.*, 2018). The influence of temperature (temperature sensitivity) on D values is generally expressed in terms of thermal resistance constant (z). The z value corresponds to an increase in temperature needed to reduce D value by 90%. Equation 2.4 denotes the z value corresponding to the D values D1 and D2 at temperatures T1 and T2, respectively. The z value can be used to determine D values at different temperatures (T) from that of a reference temperature with the aid of thermal death time (log D versus T) curve. Usually, a reference temperature of 82.2°C has been chosen to inactivate vegetative cells and low resistant microorganisms (pasteurization) while 121.1°C has been preferred for the inactivation of heat-resistant spores (sterilization).

$$\log\left(\frac{N}{N_0}\right) = -\frac{t}{D} \qquad 2.3$$

$$z = \frac{T_2 - T_1}{\log(D_1) - \log(D_2)} \qquad 2.4$$

Both the D and z values vary with regard to the type of microorganisms. Also, they may have different values for the same microorganisms under different processing

conditions. Due to these reasons, the standardization of time-temperature combination for each product for specific process parameters, formulation, type and size of packaging materials have gained much significance (Ahmed and Shivhare, 2012). The variations in heat resistance of spoilage microorganisms (D and z values) in selected canned vegetables subjected to sterilization are listed in Table 2.3.

Table 2.3 Heat resistance of microorganisms in selected canned vegetables (modified from Toledo *et al.* (2018))

Vegetable	D_0	z	
	(min)	(^oF)	(^oC)
	Clostridium botulinum 213-B		
Green beans	0.22	22	12
Peas	0.22	14	8
	Clostridium botulinum 62A		
Green beans	0.22	20	11
Corn	0.3	18	10
Spinach	0.25	19	11
	Clostridium spp. PA 3679		
Asparagus	1.83	24	13
Green beans	0.7	17	9
Corn	1.2	18	10
Peas	2.55	19	10
Spinach	2.33	23	13
	Bacillus stearothermophilus FS 1518		
Asparagus	4.2	20	11
Green beans	3.96	18	10
Corn	4.32	21	12
Peas	6.16	20	11
Pumpkin	3.5	23	13
Spinach	4.94	21	12

D_0: decimal reduction time at 121.1^{o}C; z: thermal resistance constant

2.4 THERMAL PROCESSING OF VEGETABLES

The type and chemical composition of food are important aspects in choosing an appropriate thermal processing method. Vegetables differ in chemical composition with

that of fruits and many other foods and hence they require different thermal processing conditions. As most vegetables are of low acidic (pH > 4.5) in nature (Table 2.4) with exception to rhubarb (pH = 3.1–3.4), the scope of pasteurization is limited. They generally require severe thermal processing (commercial sterilization) due to their low acidity, probable chance of more heat-resistant soil microbes and to produce better flavour and texture (Ahmed and Shivhare, 2012).

Table 2.4 pH of selected vegetables (Ahmed and Shivhare, 2012)

Vegetable	pH	Vegetable	pH
Asparagus	5.4–5.8	Potato	5.4–5.8
Broccoli	5.2–6.5	Peas	6.0–6.2
Cabbage	5.2–6.3	Spinach	5.2–6.2
Carrots	4.9–5.5	Sweet potato	5.3–5.6
Cauliflower	5.7–6.5	Turnip	5.2–5.6
Celery	5.5–6.0	Corn	6.1–6.3
Coriander leaves	6.0–6.2	Capsicum green	5.1–6.0
Eggplant	5.3–5.8	Jalapeno pepper	6.0–6.6
Lettuce	6.0–6.4	Wax beans	6.0–6.1

2.4.1 Enzymes

Peroxidase is regarded as the most thermally stable enzyme present in vegetables and hence used for indicating the efficiency of blanching. Its inactivation helps to diminish the quality loss of foods during storage (Ahmed and Shivhare, 2012). Several factors influence its thermal inactivation in vegetables including nature, thickness, geometry in addition to processing time and temperature. Hot water blanching at 95 ± 3°C for 1 min was found to reduce peroxidase negligibly in case of amaranth, fenugreek and savoy beet (Negi and Roy, 2000). The same effect was noted when spinach and fenugreek leaves were treated at 85°C for 30 s (Speek *et al.*, 1988) and 95°C for 15 s (Bajaj *et al.*, 1993), respectively. In case of tender jackfruit, no peroxidase activity was detected when blanched in boiling water (100^{o}C) for 1 and 3 min in *varikka* (Pritty and Sudheer, 2012) and *koozha* (Praveena and Sudheer, 2015) varieties, respectively. Although peroxidase inactivation increases with increase in processing temperature, its residual activity was reported in case of carrot pieces after treating at 90°C for 4 min (Lemmens *et al.*, 2009). The study also identified that soaking carrot pieces in Ca^{2+}

solution could reduce the residual activity. However, complete inactivation of peroxidase is not advisable as it leads to the presence of thermally stable isoenzymes in many vegetables and also result in over-blanching (Böttcher, 1975; Ahmed and Shivhare, 2012). This was evident with the superior quality of carrots, green beans and green peas left with some peroxidase activity after blanching (Williams *et al.*, 1986; Güneş and Bayindirli, 1993). In some instances, especially in case of frozen vegetables, the use of peroxidase as blanching indicator was found to be inadequate due to poor correlation among quality and residual peroxidase activity (Williams *et al.*, 1986). Several studies have recommended the use of other enzymes as blanching indicator. For example, Barrett and Theerakulkait (1995) advocated the use of lipoxygenase as blanching indicator based on the result of their study on blanched, frozen, stored vegetables while Severini *et al.* (2003) used polyphenol oxidase in case of potato slices.

2.4.2 Colour

Colour of vegetables plays a decisive role defining their market value and consumer acceptance. Moreover, colour has been used as an indicator of physicochemical changes during processing and storage of vegetables and thus regarded as a vital parameter from their quality assessment perspective. Colour of vegetables come from natural pigments or non-pigment compounds. The natural pigments that impart colour to vegetables includes chlorophyll, carotenoids (β-carotene, lutein, lycopene, and zeaxanthin), anthocyanins (cyanidin, delphinidin, malvidin) and flavonols (querectin, myricetin, kaempferol) while the products of caramelisation or browning reaction mostly constitutes the non-pigment category.

Generally, visual colour (articulated in terms of tri-stimulus values; L*, a*, and b* or their combination) of vegetables degrades depending on time, temperature and medium of blanching. For example, high temperature blanching (80–100°C) resulted in a faster degradation of a* with little effect on L* and b* of soybeans (Song *et al.*, 2003) and jalapeno pepper (Quintero-Ramos *et al.*, 1998) as compared to that at low temperature. With regard to the medium of blanching, Bajaj *et al.* (1993) reported that both boiling water (for 8 min) and microwave blanching (for 2 min) was found to retain maximum L* and a* values of artichoke as that of steam blanching (for 6 min). In the study, hot water medium retained more chlorophyllaceous pigment than microwave blanching. Chlorophyll and chlorophyllides compounds governs the colour formation and

degradation as observed in case of blanched (40–96°C) broccoli and green beans (Tijskens *et al.*, 2001). The colour change of the vegetables from green to yellow noted in their study was due to chlorophyll to pyropheophytin conversion with pheophytin as intermediate. Chlorophyll loss upon blanching have been reported in case of savoy beet (40%), amaranth and fenugreek leaves (10%–15%) (Negi and Roy, 2000), among others.

Many studies have reported the effects of pasteurization and sterilization on the colour values of vegetables which includes spinach (Jung *et al.*, 2013), carrot (Patras *et al.*, 2009; Vervoort *et al.*, 2012; Jung *et al.*, 2013), soybean sprout (Koo *et al.*, 2008), broccoli floret, broccoli stem, sweet potato, red bell pepper (Koskiniemi *et al.*, 2013), pumpkin (Zhou *et al.*, 2014), among others. In these studies, thermal processing has declined the a* value of vegetables with exceptions in case of red bell pepper (0.06% increase), pumpkin (57.41% increase), carrot (1.19% increase) and spinach (39.94% increase) irrespective of the processing conditions. The b* value of thermal processed vegetables superseded their raw form in case of broccoli floret (1.45% increase), red bell pepper (16.55% increase), carrot (10.95% increase), spinach (16.83% increase) and soybean sprout (0.79% increase). Interestingly, in all these studies, the L* value of thermal processed vegetables has a lower value than that of their raw form.

2.4.3 Texture

Food texture refers to “all the rheological and structure (geometrical and surface) attributes of a food product perceptible by means of mechanical, tactile, and where appropriate, visual and auditory receptors” as defined by the International Standards Organization 5492: 2008 (Kadam *et al.*, 2015). It plays a vital role in assessing quality, safety, consumer acceptance and market value (Wilhelm *et al.*, 2004). Texture parameters consist of firmness (hardness), adhesiveness, cohesiveness, gumminess and springiness. Among them, firmness is often used as an indicator of freshness of food in general while others are more relevant in case of meat-based products (Kadam *et al.*, 2015).

In general, thermal processing has a remarkable softening effect on the texture of most of the vegetables as primarily influenced by processing time and temperature. As an example, the combined effect of processing time and temperature on texture

degradation of carrot can be seen in Vervoort *et al.* (2012). The study examined the firmness of carrot processed under three different temperature-time (70, 90, 117^{o}C for 7.5, 19.6 and 23 min, respectively) combinations. The firmness of thermal processed carrots (compared to raw sample) decrease with increase in thermal processing intensity. Leadley *et al.* (2008) reported that the texture (in terms of mean peak force) of green beans decrease with increase in lethality (F_0 = 1, 2 and 3) when sterilized at 117^{o}C temperature. The softening effect of vegetables when subjected to thermal processing can be attributed to biochemical conversions that lead to solubilisation of cell-wall components (mainly pectin), starch gelatinization and degassing of vegetables (Kadam *et al.*, 2015). Pectin solubilisation occur either due to the enzymatic (pectinmethylesterase and polygalacturonase) or non-enzymatic (applied heat) reactions. In the enzymatic solubilisation, pectinmethylesterase cause partial demethylation of pectin with methanol and polygalacturonic acid as the end products. Later, polygalacturonase depolymerize polygalacturonic acid. Non-enzymatic solubilisation involves depolymerisation (β-elimination) and demethoxylation of high methoxylated pectin at elevated temperatures. As a consequence of solubilisation the ability of pectin to adhere cells reduces which eventually result in tissue softening (Sila *et al.*, 2006) as noticed in case of carrot (Vervoort *et al.*, 2012) and beans (Knockaert *et al.*, 2011; Siqueira *et al.*, 2013). Starch gelatinization is an irreversible, endothermic process at which starch granules undergoes considerable swelling due to imbibition of water at processing temperature around 60–80°C. Depending on the starch content of the vegetable, gelatinization cause cell expansion (size and volume), cell-wall distension and cell separation (Kadam *et al.*, 2015) which leads to tissue softening. Rattan and Ramaswamy (2014) attributed starch gelatinization as one of the major causes for soft texture of thermal processed potato. Degassing involves the release of gas enclosed within tissues and intercellular spaces causing rupture of cell structure (Kadam *et al.*, 2015).

Although soft texture as resultant of thermal processing is preferable for some vegetables, it is less desirable for carrot, jalapeno pepper and sweet potato, among others (Ahmed and Shivhare, 2012). In such cases, the texture modification methods including low temperature blanching (<70°C), pH adjustment, infusion of calcium and exogenous pectinmethylesterase may be employed as a precursor to thermal processing (Sila *et al.*, 2008; Kadam *et al.*, 2015). Evidently, low temperature blanching (at 55–

80°C for minutes to hours) retained maximum firmness in case of canned carrot, cauliflower, jalapeno pepper (at 55°C for 60 min), potato, sweet potato (62°C for 90 min) and tomato (Andersson *et al.*, 1994; Stanley *et al.*, 1995; Quintero-Ramos *et al.*, 1998; Truong *et al.*, 1998). On the other hand, high temperature blanching disturb adhesion and integrity of cells and diminish their rigidity. In contrast to these findings, Roy *et al.* (2001) reported that high-temperature-short-time blanching (at 100°C for 0.58 min) yielded firmer texture for carrot than low-temperature-long-time treatment (70°C for 71.10 min). The firmer texture of carrot noted in case of high-temperature-long-time blanching was due to higher concentration of galacturonic acid and sugars in pectin than other blanching conditions. Adams and Robertson (1987) suggested a combination of low- and high-temperature blanching in two stages to retain firmer texture of green beans. During initial low-temperature blanching (at 70°C), partial demethylation of pectin occurs (due to pectinase enzymes) leaving hydroxyl sites available for cross linking (via calcium bridge) with other pectin molecules. The enzymes gets inactivated in the subsequent high-temperature (93^{o}C) treatment stage.

2.4.4 Vitamins

Vitamins constitute a group of very essential organic compounds for cell metabolism. They are categorized into fat-soluble (vitamin A, D, E, K) and water-soluble (vitamin B complex and vitamin C) vitamins (Lešková *et al.*, 2006). The vitamins B-complex consists of thiamine (vitamin B_1), riboflavin (vitamin B_2), niacin (vitamin B_3), pantothenic acid (vitamin B_5), pyridoxine (vitamin B_6), biotin (vitamin B_7), folic acid (vitamin B_9) and cobalamin (vitamin B_{12}). Hereinafter in this document, vitamin C is synonymously referred as ascorbic acid (AA), its natural form. Generally, vitamins are sensitive to several factors including pH of the medium, heat, light, oxygen or their combinations (Gregory, 1996) and hence prone to be affected by thermal processing. Many studies have evidently shown the degradation of vitamins upon thermal processing of vegetables (Ryley and Kajda, 1994; Lešková *et al.*, 2006). The magnitude of degradation or loss differ with regard to the intensity of heat treatment, type of vitamin and vegetable. As the intensity of heat treatment increases, the vitamin degradation also increases. For example, blanching (mild heat treatment) resulted in loss of thiamine (vitamin B1) by about 4% only while intense heat treatment resulted in its additional 34% loss in case of peas (Lee *et al.*, 1982). The observation remain consistent in case of thiamine degradation of snap beans with loss of 10 and 32% during

blanching and intense heat treatment, respectively (Van Buren *et al.,* 1982). The same study also shown that the percent degradation differ about the type of vitamin; 90% of thiamine was retained against 58% of vitamin B_{12} during blanching. The variation in vitamin contents (vitamin B_1, B_2, B_6 and AA) among different vegetables (asparagus, tomato, mushroom, lentil) after thermal processing was reported by Martín-Belloso and Llanos-Barriobero (2001). In the study, the percent retention after thermal processing was found to be highest in case of vitamin B_2 followed by AA, vitamin B_1 and B_6 irrespective of vegetables.

Among different vitamins, AA has relatively low stability and thus degrades quite easily during thermal processing and storage. Being the less stable vitamin, retention of AA confirms the presence of other nutrients (Bender, 1966; Verma *et al.,* 2017) and hence it is often used to indicate the nutritional quality. Generally, thermal processed vegetables have been testified to have low AA than their fresh form (Rickman *et al.*, 2007). The degradation of AA increase with increase in the intensity (temperature or time) of thermal processing as reported by Arroqui *et al.* (2002), Dewanto *et al.* (2002) and Martín-Belloso and Llanos-Barriobero (2001) among others in case of blanching (potato), pasteurization (tomato) and sterilization (asparagus, tomato, mushroom, lentil), respectively. As reported by Viña *et al.* (2007), the AA did not have significant (p>0.05) difference with that of fresh Brussel sprouts when blanched for 1 and 3 min, however, its value decreased by 24% when blanching time increased to 4 min. The loss of AA during thermal processing could be either due to leaching or degradation or their combination. About 80% of AA of savoy beet was lost due to leaching. Hot water blanching at about 95 ± 3°C for 1 min with potassium metabisulphite was found to be promising in reducing AA leaching (Romero and Barrett, 1997). The AA degradation can be either aerobic or anaerobic (mechanism not fully established) in nature (Wang *et al.,* 2018). The aerobic degradation involves the oxidation of AA to dehydroascorbic acid and water with subsequent hydrolysis and auxiliary oxidation (Gregory, 1996) as catalysed by ascorbic acid oxidase. The other reaction involves the reduction of hydrogen peroxide by AA to form dehydroascorbic acid and water under the influence of peroxidase enzymes (Nishikawa *et al.,* 2003). The enzymatic oxidation accounts for the major loss of AA in broccoli than that due to thermal processing (Yamaguchi *et al.,* 2003; Munyaka, *et al.,* 2010a). In this regard, blanching has been

considered as an essential prerequisite to other thermal processes to reduce AA losses by inactivating ascorbic acid oxidase and peroxidase enzymes (Wang *et al.*, 2018).

2.4.5 Total flavonoid content

Flavonoids constitute a class of secondary plant metabolites (with polyphenolic structure) typically found in fruits and vegetables (Crozier *et al.*, 2006; Kumar and Pandey, 2013). They offer tremendous health benefits and safeguard against several ailments including cardiovascular and chronic health diseases. Moreover, they are capable of preventing cancer, oxidation, inflammation, mutation, osteoporosis, and tumour in addition to the regulation of cellular enzyme function (Nijveldt *et al.*, 2001; Panche *et al.*, 2016). Several flavonoids exists in fruits and vegetables (Ahmed and Eun, 2018) and hence many studies report their composite total flavonoid content (TFC).

Although many studies have reported the detrimental effects of thermal processing on TFC of vegetables, a few research conveyed contrasting results. Thermal processing (irrespective of method and intensity) has resulted in a decline (6.41–93.24%) of TFC value of fresh chaya leaf (John and Opeyemi, 2015), beetroot, cluster beans, drumstick, mushroom, spinach (Rani and Fernando, 2016), brussel sprouts (Olivera *et al.*, 2008), white cauliflower (Ahmed and Ali, 2013), chilli pepper (Shaimaa *et al.*, 2016) and broccoli (Roy *et al.*, 2009) considered together (Table 2.5). The decrease in TFC could be attributed to leaching of flavonoids upon thermal processing (Ahmed and Eun, 2018). Roy *et al.* (2009) observed that the TFC of lipophilic extracts of raw broccoli (TFC = 110.33 µmol QE/100 g) declined by 62.63% when subjected to thermal processing. In contrast, the hydrophilic extracts of thermal processed sample resulted in an increase of TFC value by 295.48% than that of raw broccoli (TFC = 220.33 µmol QE/100 g). Choi *et al.* (2006) also reported an increase in TFC as that of raw Shiitake mushroom when exposed to thermal processing at both 100 and 121^{o}C for 15 and 30 min. However, no significant difference in TFC values were noted among thermal treatments in their study. Dewanto *et al.* (2002) demonstrated the variation in TFC of tomato with respect to the duration (2, 15 and 30 min) of thermal processing at a temperature of 88^{o}C. Thermal processing for 2 min resulted in a slight decrease (by about 0.42%) in TFC of thermal processed samples compared to fresh tomato. In contrary, thermal processing for 15 and 30 min increased TFC by about 1.17 and 9.87%

with respect to that of fresh sample. Increase in TFC when exposed to thermal processing was also reported in case of carrot and spinach parboiled for 7 and 5 min, respectively (Jung *et al.*, 2013).

The thermal processing effects that cause variation in TFC of vegetables may be attributed to one or more of the following as reviewed by Ahmed and Eun (2018): release of bound flavonoids by cell disruption, inactivation of oxidative enzymes (Choi *et al.*, 2006), affect metabolism (Sharma *et al.*, 2015), breakdown of flavonoids, water solubility of flavonoids due to their existence as glycosides, alteration in position and number of hydroxyl groups, influence of enzymes, light and oxygen (Zainol *et al.*, 2009).

2.4.6 Total phenolic content

Phenolic compounds constitute a class of bioactive phytochemicals; non-nutrient plant derived chemicals that are active in biological systems (Huang *et al.*, 2016). Their significance in human nutrition, management of diabetes, preventing or reducing threat of chronic diseases like cancer, cardiovascular diseases has been widely recognized (Kris-Etherton *et al.*, 2002; Lin *et al.*, 2016; Lutz *et al.*, 2019). Phenolic compounds of vegetables depend on several factors including cultivar, maturity and postharvest conditions. In addition, processing and storage conditions (oxygen availability and light exposure) render them vulnerable to chemical degradation. Also, phenolic compounds are lost due to leaching during processing depending on their water solubility (Rickman *et al.*, 2007).

Vegetables contains a variety of phenolic compounds, which often represented collectively as total phenolic content (TPC). Several studies have reported and both the detrimental and beneficial effects of thermal processing on TPC of vegetables (Table 2.6). Thermal processing has resulted in a decrease of TPC of chaya leaf (John and Opeyemi, 2015), drumstick, spinach, cluster beans, beetroot, mushroom (Rani and Fernando, 2016), squash, peas, leek (Turkmen *et al.*, 2005) and pumpkin (Zhou *et al.*, 2014) by about, 7.55–93.21% compared to that of fresh vegetables. The decline in TPC was reported to be mainly influenced by leaching into brine/filling medium than oxidation effects (Rickman *et al.*, 2007). In contrast to the findings of the aforesaid studies, thermal processing has improved the TPC of mushroom (Choi *et al.*, 2006),

Table 2.5 Effect of thermal processing on total flavonoid content of some selected vegetables

Vegetable	Pre-treatment	Method/ Temperature (°C)	Time (min)	Total flavonoid content[§]			Country	Reference[¶]
				Raw	TP	PD		
Tomato		88	2	9.42	9.38	-0.42	USA	[1]
Tomato		88	15	9.42	9.53	1.17	USA	[1]
Tomato		88	30	9.42	10.35	9.87	USA	[1]
Chaya leaf	Boiling water (65°C, 10 min)	100	15	260.00	243.33	-6.41	Nigeria	[2]
Spinach	Boiling	Pressure cooking		324.00	21.89	-93.24	India	[3]
Drumstick	Boiling	Pressure cooking		42.43	8.14	-80.81	India	[3]
Beetroot	Boiling	Pressure cooking		187.5	44.25	-76.40	India	[3]
Mushroom	Boiling	Pressure cooking		83.41	74.87	-10.24	India	[3]
Cluster beans	Boiling	Pressure cooking		50.21	42.14	-16.07	India	[3]
White cauliflower		100	3	267.21	151.17	-43.43	Egypt	[4]
White cauliflower		Steam blanching	3	267.21	236.51	-11.49	Egypt	[4]
White cauliflower		Water boiling	6	267.21	116.52	-56.39	Egypt	[4]
White cauliflower		Steam boiling	6.25	267.21	208.48	-21.98	Egypt	[4]
Chilli pepper		100	15	13.62	14.42	5.87	Egypt	[5]
Broccoli	Steam (10 min)	Pressure cooking		110.33	436.33	295.48	Japan	[6]
Broccoli	Steam (10 min)	Pressure cooking		220.33	82.33	-62.63	Japan	[6]
Mushroom		100	15	0.80	2.40	200.00	South Korea	[7]
Mushroom		100	30	0.80	2.50	212.50	South Korea	[7]
Mushroom		121	15	0.80	2.30	187.50	South Korea	[7]
Mushroom		121	30	0.80	2.10	162.50	South Korea	[7]
Carrot		Parboiling	7	7.96	9.12	14.57	Korea	[8]
Spinach		Parboiling	5	42.35	57.27	35.23	Korea	[8]

[§]Unit differ across studies; TP: total flavonoid content of thermal processed vegetable; PD: computed percent difference in TP after thermal processing

[¶]1: Dewanto *et al.* (2002); 2: John and Opeyemi (2015); 3: Rani and Fernando (2016); 4: Ahmed and Ali (2013); 5: Shaimaa *et al.* (2016); 6: Roy *et al.* (2009); 7: Choi *et al.* (2006); 8: Jung *et al.* (2013)

Table 2.6 Effect of thermal processing on total phenol content of some selected vegetables

Vegetable	Pre-treatment	Method/Temperature (°C)	Time (min)	Total phenol content			Country	Reference[¶]
				Raw	TP	PD		
Beetroot	Boiling	Pressure cooking		196.07	141.60	-27.78	India	[1]
Broccoli	Steam (10 min)	Pressure cooking		135.66	160.34	18.19	Japan	[2]
Broccoli	Steam (10 min)	Pressure cooking		16.73	13.33	-20.32	Japan	[2]
Broccoli		Boiling	5	1204.30	1129.20	-6.23	Turkey	[3]
Broccoli		Steaming	7.5	1204.30	1415.50	17.54	Turkey	[3]
Broccoli		Microwave	1.5	1204.30	1510.40	25.42	Turkey	[3]
Carrot		Parboiling	7	25.17	29.78	18.31	Korea	[4]
Chaya leaf	Boiling water (65°C, 10 min)	100	15	25.50	12.17	-52.27	Nigeria	[5]
Chilli pepper		100	15	19.21	28.68	49.30	Egypt	[6]
Cluster beans	Boiling	Pressure cooking		160.68	80.94	-49.63	India	[1]
Drumstick	Boiling	Pressure cooking		255.80	17.36	-93.21	India	[1]
Green Beans		Boiling	5	355.30	405.20	14.04	Turkey	[3]
Leek		Boiling	5	300.80	193.90	-35.54	Turkey	[3]
Mushroom	Boiling	Pressure cooking		46.70	35.75	-23.45	India	[1]
Mushroom		121	30	29.00	54.60	88.27	South Korea	[7]
Peas		Boiling	5	183.30	139.80	-23.73	Turkey	[3]
Pepper		Boiling	5	1344.80	1538.40	14.40	Turkey	[3]
Pumpkin	Boiling water (90 s)	85	5	464.08	429.02	-7.55	China	[8]
Spinach	Boiling	Pressure cooking		433.00	104.90	-75.77	India	[1]
Spinach		Parboiling	5	86.33	95.31	10.40	Korea	[4]
Spinach		Boiling	5	1274.80	1291.80	1.33	Turkey	[3]
Squash		Boiling	5	833.00	497.30	-40.30	Turkey	[3]
Tomato		88	30	142.40	145.90	2.46	USA	[9]

[§]Unit differ across studies; TP: total phenol content of thermal processed vegetable; PD: computed percent difference in TP after thermal processing

[¶]1: Rani and Fernando (2016); 2: Roy *et al.* (2009); 3: Turkmen *et al.* (2005); 4: Jung *et al.* (2013); 5: John and Opeyemi (2015); 6: Shaimaa *et al.* (2016); 7: Choi *et al.* (2006); 8: Zhou *et al.* (2014); 9: Dewanto *et al.* (2002)

tomato (Dewanto *et al.*, 2002), spinach, carrot (Jung *et al.*, 2013), chilli pepper (Shaimaa *et al.*, 2016) and green beans (Turkmen *et al.*, 2005). Interestingly, both these contradicting results appeared in case of thermal processed broccoli (Turkmen *et al.*, 2005; Roy *et al.*, 2009). As reported by Roy *et al.* (2009), lipophilic extracts of thermal processed broccoli has low TPC as that of raw samples. But, thermal processed samples superseded raw broccoli with regard to TPC of hydrophilic extracts. In Turkmen *et al.* (2005), contrasting TPC values of broccoli occur due to the difference in method of thermal processing; boiling (5 min) yielded low TPC (Table 2.6) while both steaming (7.5 min) and microwave cooking (1.5 min) increased it by 17.54 and 25.42%, respectively than that of raw broccoli (TPC = 1204.3 mg GAE/100 g).

2.4.7 Thermal processing and storage of tender jackfruit

In recent years, thermal processing of tender jackfruit has been identified as a key approach to ensure its year round availability. However, limited attempts have been made in this regard of which some are briefed below.

Lakshmana *et al.* (2013) prepared ready-to-eat tender jackfruit curry in pouches by steam air retort processing (overriding pressure = 15 lbs) for about 45 min (cumulative lethality = 6.0). Retort processing has declined the hardness of tender jackfruit from 39.78 to 0.95 N due to thermal softening. The prepared curry was then stored under ambient temperature (27–30°C) for a period of 12 months. The acceptability and safety of the curry were examined in terms of proximate composition, free fatty acid, peroxide value and microbial quality during the storage period at an interval of 2 months. During the storage period, the curry was found to be microbiologically safe with no remarkable changes in free fatty acids and peroxide value.

Praveena (2015) examined the quality of retort pouch packed tender jackfruit (*koozha* variety) for a period of 90 days. Initially the samples were blanched for about three minutes in hot water with 0.3% citric acid. Then they were subjected to two thermal treatments; sterilization (121°C for 15 min to attain F_0 = 1) and pasteurization (90°C for 24 min to attain F = 10) with prior addition of preservatives namely, 2% brine, 0.3% citric acid, 0.1% potassium metabisulphite and their combinations. It was noted that the samples with citric acid as preservative showed better physicochemical attributes and

acceptability upon sensory evaluation. Moreover, the product was noted to be microbiologically safe during the storage period.

Pritty and Sudheer (2019) have demonstrated thermal processing in conjunction with canning as a promising technique for safe storage (2 months) of ready to cook tender jackfruit (*varikka* variety). The study mainly intended to standardize the time-temperature of thermal processing of tender jackfruit pieces filled in tin containers. Among the thermal treatments with different lethality values, the study advocated pasteurization at 90^{o}C for 19 min or sterilization at 121^{o}C for 38 min for better results in regard to physicochemical quality attributes and microbiological safety.

2.5 FUNDAMENTALS OF NEAR INFRARED REFLECTANCE SPECTROSCOPY

2.5.1 Infrared absorption

Infrared spectroscopy is a technique of measuring, analysing and interpreting the effects of infrared radiation upon incidence on the target of interest. The Herschel's experiment which led to the discovery of infrared radiation of the electromagnetic spectrum formed the basis of infrared reflectance spectroscopy. The experiment revealed that water absorb infrared radiation and strength of absorption depend on wavelength. As infrared radiation interact, internal energy of the target increases (depending on its composition) which eventually result in molecular vibrations (Stuart, 2004). The incident infrared radiation may be absorbed subjected to two criteria; 1) vibrational transitions cause dipole moment change in the molecule and 2) frequency match between the incident radiation and vibrational mode (Johnston and Aochi, 1996; Bokobza, 2002). The dipole moment being the absolute charge difference with distance among atoms in a molecule, its higher value cause stronger absorption and vice versa. It may be noted that homo-nuclear molecules do not pose dipole moment change and hence they bear little role in infrared absorption. The vibrational modes occur due to stretching or bending vibrations. The stretching vibration cause continuous change (symmetric or asymmetric) in interatomic bond length. The symmetric vibrations are weaker than asymmetric counterparts (Stuart, 2004). On the other hand, the bending vibration alter bond angle by rocking, scissoring, twisting and wagging. The stretching vibration supersede bending counterpart with respect to dipole moment change. The vibrations which are capable of inducing dipole moment change in target molecule are referred as

'active vibrations' and the molecules or functional groups causing absorptions are regarded as 'spectrally active' in the infrared wavelength domain. Fundamental absorptions due to spectrally active functional groups namely, O–H, C–H, N–H and S–H predominates in the mid-infrared (3000–4000 nm) region. The overtones and combinations of these fundamental vibrations characterize the absorptions in the NIR domain (Fig. 2.3).

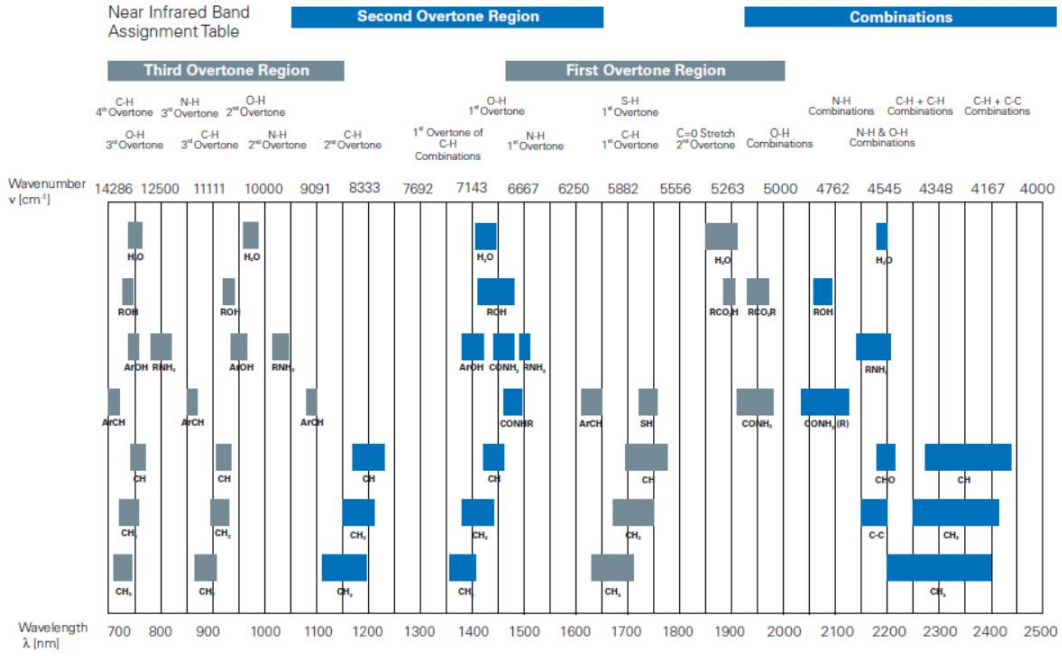

Fig. 2.3 Overtones and combination bands of spectrally active functional groups (Source: Guide for Infrared Spectroscopy, Bruker Optics; www.bruker.com)

2.5.2 Instrumentation

A NIRS instrument typically consists of a light source, detector, wavelength selection component and micro-controller unit to perform necessary signal processing for a desired output spectrum (Fig. 2.4). A tungsten coil or a halogen lamp is the mostly used light source in NIRS instruments. The detectors based on silicon, PbS and InGaAs photoconductive materials which can impart a very high signal-to-noise ratio are commonly used for NIRS measurements. In particular, InGaAs has a very high detection ability and response speed, among others. Based on the technology employed for wavelength selection, NIRS instruments are classified as filter instruments, LED source self-band selection instruments, dispersive grating instruments, and interferometric (Fourier transform) instruments (Pasquini, 2003)

Instrument selection must be guided by end application. Low cost instruments, based on filters and LEDs, suffice for many dedicated laboratory and routine in-field applications. Instruments based on fixed dispersive optics and sensor arrays have proven to be a robust solution when multi-wavelength spectral data for in-field applications are required. Fourier-based instruments must be the choice when research, wide application spectra and calibration transference are of concern as they exhibit the best resolution and signal-to-noise ratios.

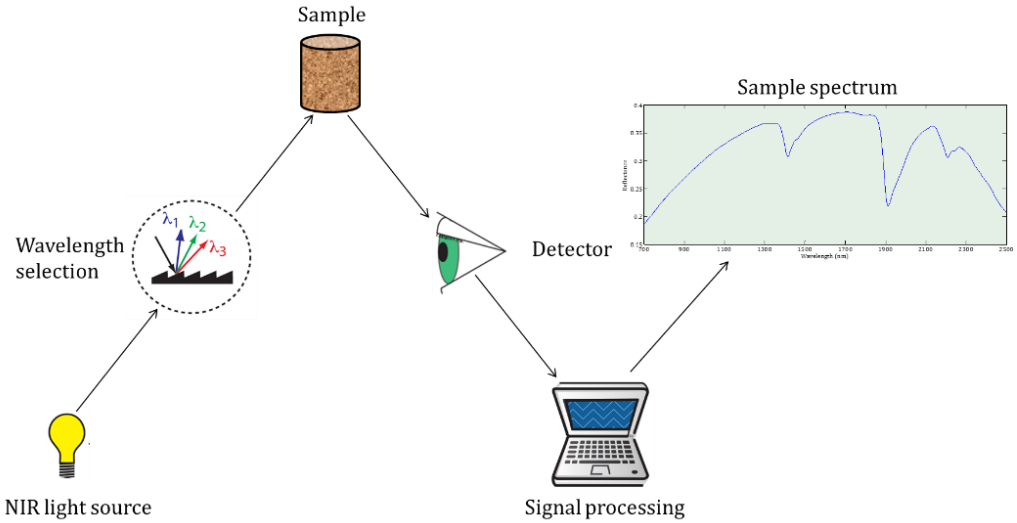

Fig. 2.4 Components of a near infrared reflectance spectroscopic instrument

2.5.3 Measurement mode

Figure 2.5 depicts the most common measurement modes employed in NIRS (Pasquini, 2003). Transmittance (Fig. 2.5a) is obtained for transparent samples (optical path: 1 to 50 mm). The optical path can be doubled by transflectance mode in which the radiation beam travels back and forth through the sample (Fig. 2.5b). Diffuse reflectance mode is usually adapted to measure absorbance and scattering from solid granules (Fig. 2.5c). In the interactance mode (Fig. 2.5d), the radiation beam interact with solid sample but its point of incidence and emergence are different (usually at a distance). Transmittance measurements (Fig. 2.5e) can also be made for solid samples (typically to assess active ingredient of pharmaceutical tablets) which provide signal comprising of internal scattering within sample and thus result in longer optical path length. Both the latter

modes provide spectral information that better describe the average sample content compared to surface dominated diffuse reflectance signature (Pasquini, 2003).

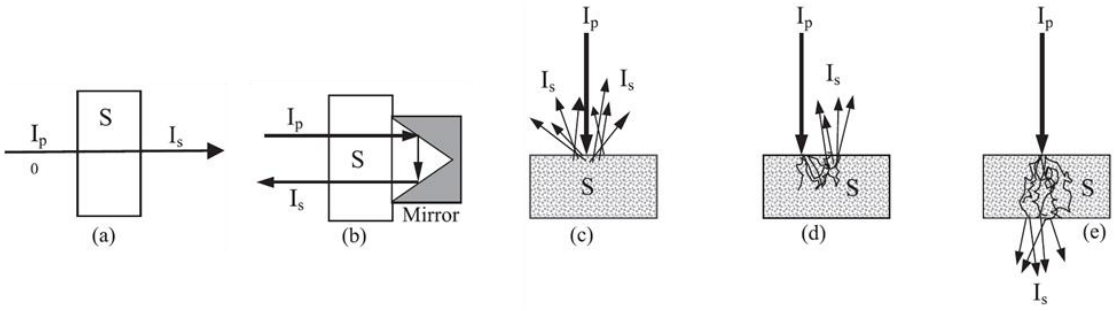

Fig. 2.5 Measurement modes employed in near infrared reflectance spectroscopy; a) transmittance; b) transflectance; c) diffuse reflectance; d) interactance; e) transmittance through scattering medium

2.6 DEVELOPMENT OF NEAR INFRARED REFLECTANCE SPECTROSCOPIC CALIBRATION FUNCTION

The main objective of NIRS data analysis and calibration development is to establish linkage between attribute (determined by reference analysis) and spectral signature of the target material. Such linkage is usually referred as calibration function/model. The NIRS spectra being highly sensitive to sample physical characteristics, redundant and complex (due to highly overlapped and broad peaks), the calibration model development relies on chemometrics (Agelet and Hurburgh, 2010). For more reliable NIRS calibration model, the target attribute should either be of organic nature (direct measurement) or be correlated with sample physical characteristic or another organic compound (indirect measurement). The other relevant aspects in NIRS calibration development are briefly discussed below.

2.6.1 Sample selection

An ideal calibration set of samples should be representative of population to be analysed in terms of chemical, spectral, and physical characteristics (Fearn, 2005). However, no fixed number or rule-of-thumb exists in the determination of optimum number of samples to be included in a calibration. In general, about 20 to 30 samples should be taken for feasibility studies and initial calibrations (Williams, 2001) and one may use few hundred for more robust calibrations. Smaller calibration sets may be used for homogeneous mixtures (e.g. pharmaceutical powders) while agriculture samples (such as whole grains or forages) of high compositional complexity and heterogeneity require

large number of calibration samples. It is always appropriate to ensure uniform distribution of reference values. In contrast, if they are normally distributed (bell shaped distribution), samples with higher or lower reference values may have more relevance in the calibration function, which is not desirable.

2.6.2 Reference method

The accuracy and precision of NIRS calibration functions relies on the attribute values obtained by reference method (Agelet and Hurburgh, 2010). So, the quality of measurement and accuracy of the reference attribute values are important aspects influencing the performance of NIRS calibrations. So, selection of an appropriate reference method is a vital step in the development of a successful NIRS calibration. As NIRS calibration models are based on reference analytical values, NIRS estimates can never be regarded superior as that of reference method.

2.6.3 Spectral pre-processing

Typically, a NIRS spectrum is a collective response of both absorption and scattering of electromagnetic radiation within target material which are usually expressed in terms of reflectance (R^*), absorbance (A^*) or transmittance (T^*) units and they are mutually interconvertible.

$$A^* = ln\left(\frac{1}{R^*}\right) \quad 2.5$$

$$A^* = 2 - ln(T^*) \quad 2.6$$

The absorption characteristics are due to overtones and combinations of fundamental vibrations of spectrally active functional groups present in the material. Hence, the absorption component provide substantial information on material composition. On the other hand, the scattering component have little energy transfer with sample and hence bear little role in compositional analysis. Moreover, scattering effects may result in undesired spectral variations such as non-linearity and baseline shift (Rinnan *et al.*, 2009). This necessitate the removal of scattering effects from spectral signature. Spectral pre-processing mainly intend to remove the physical phenomenon (scattering) from spectra with a view to improve subsequent data analysis, classification, calibration and prediction accuracy (Barnes *et al.,* 1989).

Several spectral pre-processing techniques exist. Rinnan *et al.* (2009) have categorized them under scatter correction methods and spectral derivatives. The multiplicative scatter correction (*MSC*), standard normal variate (*SNV*), normalization and de-trending (*DT*) constitute the scatter correction category. Spectral derivatives class consist of first (*FD*) and second derivatives (*SD*) of the spectral signature. The *MSC* (Martens *et al.*, 1983) is used for baseline correction in spectra. Each spectrum (R^* or its variants) is fitted with a reference spectrum by least square method (Equation 2.7 and 2.8). Generally the average of all the spectra is chosen as the reference spectrum (R_{ref}). This ensures that baseline and amplification effects are at the same average level in every spectrum.

$$R^* = a + bR_{ref} + e \qquad 2.7$$

$$MSC(R^*) = \frac{R^* - a}{b} \qquad 2.8$$

The scattering and offsets are represented by the coefficients '*a*' and '*b*', respectively, while '*e*' represents the sample constituent information.

The *SNV* (Equation 2.9) and *DT* (Barnes *et al.*, 1989) eliminate the multiplicative interferences of scatter and particle size and account for the variation in baseline shift and curvilinearity in diffuse reflectance spectra. The *SNV* performs both the centering and scaling together by subtracting the mean (μ_R) and normalizing with the standard deviation (σ_R) for each reflectance spectrum.

$$SNV(R^*) = \frac{R^* - \mu_R}{\sigma_R} \qquad 2.9$$

DT involves fitting a 2nd order polynomial to the *SNV* transformed spectrum and subtracted from it to correct for wavelength dependent scattering effects.

The spectral derivative techniques namely *FD* (Equation 2.10) and *SD* (Equation 2.11) are used to enhance spectral resolution and to eliminate background effects, respectively. The *FD* removes only the baseline while *SD* removes both baseline and linear trend (Rinnan *et al.*, 2009).

$$FD(R^*) = \frac{R^*_{n+1} - R^*_n}{\lambda_{n+1} - \lambda_n} \qquad 2.10$$

$$SD(R^*) = \frac{FD_{n+1} - FD_n}{0.5(\lambda_{n+2} - \lambda_n)} \qquad 2.11$$

2.6.4 Data modelling

In NIRS approach, compositional attribute and spectral signature of the material are linked. As the spectral signature in the NIRS wavelength domain has complex absorption pattern due to its constituents and structure, the inherent information has to be extracted for linking with the desired attribute. For the purpose, NIRS relies on statistical techniques, data mining algorithms or their combinations to establish attribute-spectra linkage. The early phases of NIRS studies used multiple linear regression (Isaksson *et al.*, 1996) and stepwise multiple linear regression for calibration model development (Norris *et al.*, 1976). The drawback of the multiple linear regression approach is that it cannot account for the multicollinearity associated with the spectral signature. With the ability to resolve the multicollinearity issue and dimension reduction, the principal component regression (PCR) technique gained importance in NIRS studies (Sinnaeve *et al.*, 1997). The PCR involves a mathematical procedure that transforms a number of possibly correlated variables into same number of uncorrelated variables (principal components or scores) by an orthogonal transformation. The orthogonal transformation can be achieved by either Eigen value decomposition of a data covariance matrix or by singular value decomposition of a data matrix. But the transformation consider only the predictor variables (spectra) and do not depend on the response variable (attribute values). In contrast, partial least square regression (PLSR) algorithm (Wold *et al.*, 2001) considers both the predictor and response variables to build scores with the greatest predictive power. The algorithm integrates the compression and regression steps and it selects successive orthogonal factors that maximize the covariance between the predictor and response variables. Majority of the NIRS studies in food analysis employed PLSR for model calibration (De Belie *et al.*, 2003; León *et al.*, 2004; ElMasry *et al.*, 2012; Rébufa *et al.*, 2018). The other linear regression methods used in NIRS studies are multivariate adaptive regression splines, regression tree, and committee trees. The performance of non-linear techniques such as artificial neural networks was also examined. However, PLSR is the most commonly used and widely recognized algorithm for NIRS calibration development due to its inherent peculiarities viz. rapid computation, ability to account for multi-collinearity, statistical efficiency, automatic variable selection, permit both classification and regression (Boulesteix and Strimmer, 2007).

2.6.5 Model evaluation

The performance of NIRS calibration models are generally evaluated by comparing the calibration model predicted values with that of observed ones determined using classical reference method. Usually, a simple linear regression between them is performed and the degree of association can be expressed in terms regression statistics such as coefficient of determination (R^2) (Equation 2.12) and root mean squared error (RMSE) (Equation 2.13). The R^2 indicates the proportion of variance of observed values that can be explained by the values predicted by the calibration model. It is a unit less measure which vary between 0 and 1. As the name implies, RMSE represents the square root of average of squared error (difference between observed and predicted values). It has the same unit as that of the attribute. These two regression statistics are influenced by the range of attribute values (Bellon-Maurel and McBratney, 2011) and hence not appropriate especially when calibration models of different attributes and those of varying range are to be compared.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2}{\sum_{i=1}^{n}(Y_i - \bar{Y})^2} \qquad 2.12$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2} \qquad 2.13$$

In the above equations, Y, $\hat{Y}$, $\bar{Y}$ and n represents observed values, predicted values, mean of observed values and number of samples (observations), respectively.

To account for the aforesaid range dependency concern, a standardized form of RMSE termed as residual prediction deviation (RPD) (Equation 2.14) is being used in spectroscopic studies as proposed by Williams and Sobering (1996). It is computed as the ratio of standard deviation of the observed values to the RMSE. However, its use as a range independent statistic is debatable as the standard deviation differs across diverse population distributions (Fernandez-ahumada *et al.*, 2010).

$$RPD = \left[\frac{\frac{1}{n-1}\sum_{i=1}^{n}(Y_i - \bar{Y})^2}{\frac{1}{n}\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2} \right]^{0.5} \qquad 2.14$$

Majority of the NIRS studies have deployed these three statistics either individually or in combination to judge the performance of calibration model. However, no fixed criterion with statistical basis have been defined for model performance evaluation using these regression statistics. The most popular model accuracy evaluation criteria employed for agricultural products and food analysis are listed in Table 2.7. Although Malley *et al.* (2004) proposed the criteria for soil analysis, it has been recognized in NIRS based assessment of vegetables as well (García-Martínez *et al.*, 2012). Among the different criteria, the one proposed by Williams and Norris (2001) has been widely used in NIRS studies of fruits and vegetables (Yang *et al.*, 2011; Liu *et al.*, 2015; Amodio *et al.*, 2017).

Table 2.7 Criteria for accuracy evaluation of near infrared spectroscopic calibration functions of food materials

Reference	**R^2**	**RPD**	**Performance of calibration function**
Williams and Norris (2001)	-	< 1.50	Poor
	-	1.50 – 2.00	Discrimination
	-	2.00 – 2.50	Coarse quantitative estimation
	-	2.50 – 3.00	Good
	-	> 3.00	Excellent
Malley *et al.* (2004)	0.70 – 0.80	1.75 – 2.25	Moderately useful
	0.80 – 0.90	2.25 – 3.00	Moderately successful
	0.90 – 0.95	3.00 – 4.00	Successful
	> 0.95	> 4.00	Excellent
Conzen (2006)	-	< 2.50	Poor
	-	2.50 – 3.00	Rough screening
	-	> 3.00	Screening
	-	> 5.00	Quality control
	-	> 8.00	Excellent for analytical task

R^2: coefficient of determination; RPD: residual prediction deviation

2.7 NEAR INFRARED REFLECTANCE SPECTROSCOPY FOR QUANTITATIVE ANALYSIS OF VEGETABLES

Since the pioneer studies by Hart *et al.* (1962), Norris *et al.* (1976) and Norris and Hart (1965), NIRS has been recognized as a prominent tool for quantitative assessment of plant and food materials. Over years, the application of NIRS has expanded in food

industry for rapid, cost-effective and reliable assessment of food quality in a non-destructive manner. A wide range of food materials and quality attributes have been estimated via NIRS as reviewed by Cen and He (2007), Huang *et al.* (2008), Nicolaï *et al.* (2007), Osborne (2006), Prieto *et al.* (2017), among others. However, the discussion here is limited to its application in estimating compositional attributes of vegetables. The utility of NIRS approach has been deployed for the estimation of physical, chemical and elemental composition of vegetables (Nicolaï *et al.*, 2007; López *et al.*, 2013; Sanchez *et al.*, 2020). Table 2.8 and 2.9 lists the details of selected recent studies to comprehend NIRS performance in assessing different compositional attributes of vegetables. The NIRS application in recent years cover a wide range of chemical, physical and elemental attributes of vegetables. The sample presentation for NIRS measurement vary across different studies. In case of chemical composition assessment, some studies used pulverized (Sahamishirazi *et al.*, 2017) or grated (Bernhard *et al.*, 2016) samples while others have performed analysis using intact samples. But, only intact and dry powders were used for physical and elemental assessment, respectively. As the studies were performed using different instruments, they differ in terms of instrumental features of wavelength range and sampling interval. However, spectral measurements were made in either A^* or R^* modes. Spectral pre-processing (scatter correction and derivatives) of A^* or R^* appeared to be inherent to data analysis scheme in many studies although some studies were performed without them. Identification of suitable pre-processing technique from these studies is not advisable as they differ with regard to many factors including sample presentation, instrument type (filter, grating and interferometer), wavelength range, sampling interval and measurement conditions.

Interestingly, all the studies presented here and majority of the recent studies have used PLSR or its modified form as the calibration algorithm. The main reason for its use may be associated with its inherent advantages over other algorithms; computational efficiency, capability to address multi-collinearity in the spectra, automatic spectral variable selection, enable classification and regression (Boulesteix and Strimmer, 2007). The PLSR models were found to have moderate to excellent performance (R^2>0.8) in case of reduction potential, total soluble phenolics, soluble solid content, electrical conductivity, dry matter, water activity, protein, moisture content (chemical attributes), average firmness, initial firmness (physical attributes) and all the elemental composition with sulphur as an exception (Table 2.8 and 2.9). But, the accuracy of

Table 2.8 Overview of performance of near infrared reflectance spectroscopy to assess chemical composition of vegetables

Attribute	Vegetable	Spectral range (nm)	Pre-process	Calibration/Cross-validation			Validation				Reference*
				n	R^2	RMSE	*n*	R^2	RMSE	RPD	
Ascorbic acid, mg/100 g	Spinach	1600–2400	A^*+*SD*	91	0.33	51.46	-	-	-	1.21	1
Citric acid, g/kg	Tomato	516–2200	R^*+*SD*	119	0.30	0.96	35	0.31	0.86	1.18	2
Dry matter, %	Potato (G)	968–1530	R^*+*SNV*+*DT*+*FD*	113	0.95	1.14	113	0.93	1.24	3.93	3
Electrical conductivity, mS/cm	Carrot	400–1000	R^*	140	0.88	0.66	-	-	-	-	4
Fructose, g/kg	Tomato	516–2200	R^*+*FD*	113	0.30	3.70	36	0.35	3.80	1.20	2
Glucobrassicin	Broccoli (P)	400–2498	A^*	64	-	0.21	30	0.24	0.33	0.81	5
Glucoiberin	Broccoli (P)	400–2498	A^*	62	-	0.11	30	0.38	0.17	0.67	5
Glucoraphanin	Broccoli (P)	400–2498	A^*	67	-	0.49	30	0.71	0.99	1.63	5
Glucose, g/kg	Tomato	516–2200	R^*+*FD*	113	0.50	4.10	35	0.52	4.40	1.40	2
Lycopene, mg/kg	Tomato	299–1100	A^*	30	0.76	0.82	15	0.73	0.91	-	7
Malic acid, g/kg	Tomato	516–2200	R^*+*SD*	115	0.42	0.24	37	0.27	0.22	1.28	2
Moisture content, %	Moringa (P)	1000–2500	A^*	112	0.97	2.00	53	0.95	1.80	-	8
Nitrate content, mg/kg	Spinach	1600–2400	A^*+*SD*	92	0.41	836.26	-	-	-	1.29	1
pH	Carrot	400–1000	R^*	140	0.68	0.06	-	-	-	-	4
Protein, %	Moringa (P)	1000–2500	A^*	50	0.97	1.36	24	0.92	1.70	-	8
Reducing sugars, %	Potato (L)	1100–2300	R^*+*SNV*+*FD*	90	0.49	0.25	45	0.42	0.24	-	6
Reduction potential, mV	Carrot	400–1000	R^*	140	0.81	23.34	-	-	-	-	4
Soluble solid content, ^{o}Brix	Tomato	299–1100	A^*	30	0.87	0.06	15	0.86	0.07	-	7
Titratable acidity, %	Tomato	516–2200	R^*+*FD*	118	0.70	0.06	37	0.56	0.07	1.83	2
Total glucosinolates	Broccoli (P)	400–2498	A^*	66	-	0.90	30	0.69	1.25	1.36	5
Total soluble phenolics (mg GAE/g)	Potato (L)	1100–2300	R^*+*FD*	152	0.84	1.20	76	0.83	1.41	-	6
Water activity	Moringa (P)	1000–2500	A^*	120	0.95	0.07	60	0.91	0.07	-	8

n: number of samples; R^2: coefficient of determination; RMSE: root mean squared error; RPD: residual prediction deviation; A^*: absorbance; R^*: reflectance; *FD*: first derivative; *SD*: second derivative; *MSC*: multiplicative scatter correction *SNV*: standard normal variate; G: grinded; P: powder; L: lyophilized

*1: Pérez-Marín *et al.* (2019); 2: Torres *et al.* (2015); 3: Bernhard *et al.* (2016); 4: Česonienė *et al.* (2019); 5: Sahamishirazi *et al.* (2017); 6: López-Maestresalas *et al.* (2017); 7: Saad *et al.* (2016); 8: Rébufa *et al.* (2018)

Table 2.9 Overview of performance of near infrared reflectance spectroscopy to assess physical and elemental compositional attributes of vegetables

Attribute	Vegetable	Spectral range (nm)	Pre-process	Calibration/Cross-validation			Validation				Reference*
				n	R^2	RMSE	*n*	R^2	RMSE	RPD	
Colour											
L*	Tomato	516–2200	R^*+*SD*	116	0.48	2.04	36	0.31	2.06	1.37	1
a*	Tomato	516–2200	R^*+*FD*	116	0.47	3.16	37	0.37	4.15	1.36	1
b*	Tomato	516–2200	R^*+*SD*	120	0.34	2.56	37	0.16	2.46	1.21	1
Texture											
Average firmness	Tomato	1100–1800	A^*+*SNV*+*DT*	63	0.96	0.47	33	0.72	1.05	1.82	2
Deformation ratio	Tomato	1100–1800	A^*+*SNV*	63	0.76	0.01	33	0.72	0.01	2.00	2
Degree of elasticity	Tomato	1100–1800	A^*+*MN*	63	0.00	0.04	33	0.04	0.03	1.00	2
Energy absorption	Tomato	1100–1800	A^*+*SNV*	63	0.72	5.50	33	0.72	5.19	1.91	2
Initial firmness	Tomato	1100–1500	A^*+*SNV*	63	0.86	0.80	33	0.72	1.31	1.73	2
Maximum puncture force, N	Spinach	834.00–2502.40	A^*+*FD*	140	0.44	0.44	-	-	-	1.34	3
Modulus of elasticity	Tomato	1100–1800	A^*+*MN*	63	0.71	1.60×10^{-5}	33	0.74	1.43×10^{-5}	1.94	2
Relaxation ratio	Tomato	1100–1800	A^*+*MN*	63	0.49	0.02	33	0.53	0.01	2.00	2
Elements											
Carbon, %	Moringa (P)	1000–2500	A^*	50	0.88	0.65	24	0.83	0.67	-	4
Calcium, g/kg	Tomato (DG)	1332.98–2174.86	A^*	1050	0.96	0.23	1050	0.89	0.36	2.97	5
Copper, mg/kg	Tomato (DG)	1638.81–1731.90	A^*	1050	0.94	0.99	1050	0.87	1.39	2.78	5
Iron, mg/kg	Tomato (DG)	833.61–2174.86	A^*	1050	0.83	7.82	1050	0.41	13.80	1.30	5
Hydrogen, %	Moringa (P)	1000–2500	A^*	50	0.90	0.09	24	0.81	0.10	-	4
Potassium, mg/mg	Moringa (P)	1000–2500	A^*	59	0.80	382	30	0.41	687	-	4
Magnesium, g/kg	Tomato (DG)	1638.81–1836.21	A^*	1050	0.94	0.15	1050	0.84	0.23	2.51	5
Manganese, mg/kg	Tomato (DG)	1638.81–1836.21	A^*	1050	0.97	0.72	1050	0.90	1.29	3.24	5
Nitrogen, %	Potato (L)	1100–2300	R^*+*MSC*+*FD*	90	0.90	0.08	45	0.86	0.10	-	6
Sodium, g/kg	Tomato (DG)	833.61–1836.21	A^*	1050	0.95	0.09	1050	0.77	0.18	2.08	5
Phosphorous, g/kg	Tomato (DG)	1834.86–2174.86	A^*	1050	0.98	0.13	1050	0.84	0.36	2.51	5
Sulphur, %	Moringa (P)	1000–2500	A^*	50	0.73	0.19	24	0.64	0.24	-	4
Zinc, mg/kg	Tomato (DG)	1834.86–2174.86	A^*	1050	0.89	3.61	1050	0.68	5.62	1.77	5

n: number of samples; R^2: coefficient of determination; RMSE: root mean squared error; RPD: residual prediction deviation; *A*: absorbance; *R*: reflectance; *FD*: first derivative; *SD*: second derivative; *DT*: detrend; *SNV*: standard normal variate; *MN*: mean normalization; DG: dry grinded; P: powder

*1: Torres *et al.* (2015); 2: Sirisomboon *et al.* (2012); 3: Entrenas *et al.* (2020); 4: Rébufa *et al.* (2018); 5: García-Martínez *et al.* (2012); 6: López-Maestresalas *et al.* (2017)

NIRS models of chemical composition such as acid-related and glucosinolates reported by Pérez-Marín *et al.* (2019), Sahamishirazi *et al.* (2017) and Torres *et al.* (2015) were mostly found to be suitable only for screening. The low accuracy of quantification noted in their study may be attributed to low range of attribute values in the calibration dataset, time lapse between reference analyses and spectral acquisition. Moreover, those studies performed the analyses using intact samples in which estimation of chemical composition especially acid-related attributes are reported to be difficult (Flores *et al.*, 2009). Both the colour and texture attributes reported by Sirisomboon *et al.* (2012) and Torres *et al.* (2015), respectively did not yield successful results suitable for their quantitative assessment via NIRS. In addition to the general concerns mentioned above, lack of significant association with spectrally active functional groups in the NIRS domain may partly address the low performance noted in their study.

2.7.1 Near infrared reflectance spectroscopy in tender jackfruit analysis

Although, NIRS approach has been widely and frequently tested for quantitative assessment of many vegetables, its application in the quality assessment of tender jackfruit has not been reported in the literature to the best of my knowledge and review.

CHAPTER 3
MATERIALS AND METHODS

This chapter deals with the materials, procedures and equipment used to achieve the desired objectives of the study. It is broadly divided into four sections (Section 3.1–3.4) as given below. The Section 3.1 describes all the reference analyses of quality attributes of tender jackfruit samples performed irrespective of objectives of the study. The details related to the first, second and third objectives of this study are given separately in section 3.2, 3.3 and 3.4, respectively.

3.1 DETERMINATION OF QUALITY ATTRIBUTES OF TENDER JACKFRUIT

A range of quality attributes of tender jackfruit samples were examined to realize the desired objectives of this study. The attributes and their method of determination used in this study are given below.

3.1.1 Colour

The colour of tender jackfruit samples was assessed using a ColorFlex EZ spectrophotometer (Hunter Lab, USA). It express the colour in terms of Commission International de l' Eclairage (CIE) space co-ordinates of L^* (lightness), a^* (redness) and b^* (yellowness) values. The sample was filled with minimum void space as possible in a transparent cup associated with the instrument. The colour measurement was replicated three times for each sample.

The total colour difference (ΔE) value which characterize the colour variation of samples from a reference standard (Gonçalves *et al.*, 2007) was computed for thermal processed samples (Equation 3.1). The L^*, a^*, b^* values of fresh samples were used as the standard and corresponding deviations were noted to be ΔL, Δa and Δb, respectively. The scale proposed by Limbo and Piergiovanni (2006) was used to examine the colour difference between sample and standard as a) no perceptible (ΔE < 0.2), b) very small (0.2 < ΔE < 0.5), c) small (0.5 < ΔE < 2), d) fairly perceptible (2 < ΔE < 3), e) perceptible (3 < ΔE < 6), f) strong (6 < ΔE < 12) and g) different (ΔE > 12).

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \qquad 3.1$$

Other colour indicators namely, whiteness index (Hsu *et al.*, 2003), chroma, browning index and yellowness index (Pathare *et al.*, 2013) were also computed for thermal processed samples as given below.

$$Whiteness\,index = 100 - \sqrt{(100 - L^*)^2 + a^{*2} + b^{*2}} \quad 3.2$$

$$Chroma = \sqrt{a^{*2} + b^{*2}} \quad 3.3$$

$$Browning\,index = \frac{100(x - 0.31)}{0.17} \quad 3.4$$

$$x = \frac{a^* + 1.7L^*}{5.645L^* + a^* - 3.012b^*} \quad 3.5$$

$$Yellowness\,index = \frac{142.86b^*}{L^*} \quad 3.6$$

3.1.2 Texture

In this study, texture analysis of tender jackfruit was performed using two different instruments namely, *TA.HDplus* and *TA.XT2* Texture Analyzer (Stable Micro-System Ltd., UK). The *TA.HDplus* Texture Analyzer equipped with a load cell (50 N) and blade probe was used to measure the firmness and toughness of tender jackfruit samples. Each sample was subjected to a double compression measurement with 0.5 kg trigger force (depth of penetration = 10 mm; velocity = 10 mm s^{-1}) and the force–distance curve was recorded. The firmness and toughness of the sample correspond to the maximum peak force and area under the curve, respectively (Gonçalves *et al.*, 2007). Similarly, the *TA.XT2* Texture Analyzer with a needle probe (distance = 10 mm; load cell = 50 kg; trigger force = 10 g; test speed = 2 mm/s) was used to measure the firmness of skin portion (F_s) of thermal processed samples subjected to storage evaluation and NIRS analyses. Each sample was subjected to three replicated textural measurements.

3.1.3 pH

The pH (logarithm of the reciprocal of hydrogen ion concentration) of tender jackfruit samples (extracted juice) was determined potentiometrically using a digital pH meter (Model: MK VI, Systronics Limited, India). Prior to measurement, the pH meter was standardized using three different buffer solutions with pH of 4.0, 7.0 and 9.2. Each sample was subjected to three replicated measurements and their average value was chosen as the representative pH of the sample.

3.1.4 Total soluble solids

The total soluble solids (TSS) of tender jackfruit was measured using a digital hand-held pocket refractometer (PAL-1, ATAGO, Japan). One or two drops of the juice made out of the crushed sample were placed on the refractometer for TSS measurement in degree Brix units (Ranganna, 1986).

3.1.5 Titrable acidity

Initially, the tender jackfruit slices were crushed in pestle and mortar and mixed thoroughly. A known weight of the pulp and distilled water were taken in a test tube and boiled for 1 h. The evaporation loss was occasionally replaced by adding distilled water. Then, the contents were cooled and made up to 100 ml volume (V) by adding distilled water. About 10 ml of the prepared solution was titrated against 0.1N NaOH after adding 1-2 drops of 1% phenolphthalein solution as indicator. The appearance of a light pink colour defined the end-point that quantified the NaOH required to neutralize the acid present in the sample. Then, the titre value (TV) was noted and the amount of titrable acidity (TA) was calculated (Equation 3.7) in terms of citric acid percentage (Ranganna, 1986).

$$Titrable\,acidity\,(\%) = \frac{Normality\,(NaOH) \times TV \times V \times Equivalent\,weight\,(acid) \times 100}{Volume\,of\ aliquot \times Weight\,of\ sample \times 1000} \qquad 3.7$$

3.1.6 Crude fibre content

Crude fibre content (CFC) comprising of cellulose, hemicellulose, lignin and some minerals of tender jackfruit was estimated using the method proposed by AOAC (1976). About 2 g of the dried ground sample (W) was boiled with 200 ml of 1.25% sulphuric acid and bumping chips for 30 min with occasional stirring. Then, it was filtered through a muslin cloth and washed 2-3 times with hot water ensuring that the washings were not acidic. The residue was then boiled with 200 ml sodium hydroxide (0.313 N) for 30 min. It was filtered through muslin cloth again and washed with boiling 1.25% sulphuric acid (25 ml), hot water (150 ml) and alcohol (25 ml). The residue was transferred to a crucible (W_1) and dried for 2 h at 130 ± 2°C. Weight of the crucible and the residue (W_2) was taken after cooling in a desiccator. Again the crucible was ignited in muffle furnace (600 ± 15°C) for 30 min and weighed after cooling in desiccator (W_3).

$$Crude\,fibre\,content\,(\%) = \frac{(W_2 - W_1) - (W_3 - W_1)}{W} \times 100 \qquad 3.8$$

3.1.7 Carbohydrate content

The carbohydrate content (CC) of tender jackfruit was determined using the anthrone method (Sadasivam and Manickam, 1996). It involves the hydrolysis of carbohydrates present in 100 mg of the sample taken in a boiling tube by addition of diluted hydrochloric acid (2.5 N, 5 ml) and boiling in water bath for 3 h. After cooling the tube to room temperature, the sample was neutralized by adding sodium carbonate (until the effervescence stops). The sample volume was centrifuged (after making up to 100 ml) and 0.5 ml aliquots of the supernatant was taken for analysis.

The stock solution was prepared by dissolving 100 mg of standard glucose (Merck) in 100 ml distilled water of which 10 ml diluted to 100 ml served as the working standard. Then, the standards were set by taking 0, 0.2, 0.4, 0.6, 0.8, and 1 ml of the working standard and making up to 1 ml. The volume of the sample tube was also made up to 1 ml by adding distilled water. Then, 4 ml of anthrone reagent (200 mg anthrone dissolved in ice cold 95% sulphuric acid) was added to all tubes and they were heated in a boiling water bath for about 8 min and rapidly cooled. The CC of the sample was then determined spectrophotometrically. The standard curve describing the linkage between concentration of standard glucose and absorbance at 630 nm (measured using UV-1800 Shimadzu spectrophotometer) used for CC determination is shown in Appendix A.

3.1.8 Ascorbic acid

Ascorbic acid (AA) of tender jackfruit was determined using indophenol dye method (Sadasivam and Manickam, 1996). The reagents necessary for the analysis consisted of oxalic acid (4%), standard ascorbic acid (Sigma Aldrich) and dye solution (42 mg of sodium bicarbonate and 52 mg of 2, 6, dichlorophenolindophenol dye in 200 ml of distilled water). Initially, 100 ml of stock solution was prepared by dissolving 100 mg pure dry crystalline ascorbic acid in oxalic acid. Then, 10 ml of the stock solution was diluted to 100 ml with oxalic acid to form the working standard (100 μg/ml). About 10 ml of the working standard solution was then titrated against the dye solution. The end point of titration was the appearance of pale pink colour which persisted for a few minutes. The amount of dye consumed (V_1) was equivalent to the amount of ascorbic acid in the working standard. Later, a known weight of the sample (W_s) was homogenized, made up

to 100 ml with oxalic acid and centrifuged. Finally, 5 ml of the supernatant together with 10 ml of oxalic acid was titrated against the dye (V_2). The quantity of ascorbic acid (mg) present in 100 g of sample was calculated as follows. The titration was replicated thrice and the concordant value was chosen.

$$Ascorbic\,acid\,(mg/100\,g) = \frac{0.5\,mg}{V_1\,ml} \times \frac{V_2}{5\,ml} \times \frac{100\,ml}{W_s} \times 100 \qquad 3.9$$

3.1.9 Total flavonoid and phenol contents

The total flavonoid (TFC) and phenol (TPC) contents of tender jackfruit samples were estimated using aluminium chloride colorimetric method (Chang *et al.*, 2002; Baba and Malik, 2015) and Folin-Ciocalteu reagent method (Singleton and Rossi, 1965; Jagtap *et al.*, 2010, 2011), respectively. The sample preparation remained the same in both these methods which consisted of 1 g homogenized tender jackfruit sample in 10 ml of ethanol (sample to solvent ratio = 1:10) for 24 h with intermittent shaking at room temperature. Then, the homogenate was centrifuged (at 5000 rpm for 10 min) and the supernatant was stored at −20°C for analysis.

For the estimation of TFC, 0.5 ml of the extract was made up to 5 ml by adding distilled water. Then, 0.3 ml of 5% sodium nitrite was added and incubated for 5 min. To the mixture, 0.3 ml of 10% aluminium chloride solution was added and allowed to stand for 6 min. Then, 2 ml of 1 mol/l sodium hydroxide solution was added and the whole mixture was made up to 10 ml with distilled water. After 15 min, the absorbance of the mixture at 510 nm was measured using a spectrophotometer (UV-1800 Shimadzu, Japan Japan) and standard curve was prepared using rutin (Sigma Aldrich) as the standard (Appendix A). The TFC was calculated from the standard curve in terms of milligram rutin equivalent per gram weight (mg RE/g).

In case of TPC estimation, 0.2 ml of the extract was mixed with 1.8 ml of Folin-Ciocalteu reagent (previously diluted 10-fold with distilled water) and allowed to stand for 5 min. Then, 1.2 ml of 15% sodium carbonate solution was added and absorbance was measured at 765 nm using a spectrophotometer (UV-1800 Shimadzu, Japan). The TPC of the sample was calculated from the standard curve (Appendix A) plotted using Gallic acid (Merck) and expressed as milligrams of gallic acid equivalents per gram weight (mg GAE/g).

3.1.10 Microbiological analysis

Microbiological analysis of tender jackfruit in the study was performed using serial dilution and plate count method (Maturin and Peeler, 1998; Sreenath *et al.*, 2008). Initially, 10 g tender jackfruit sample homogenate (W_s) was prepared aseptically using a sterile pestle and mortar. It was transferred to a sterile conical flask containing 100 ml normal saline and shaken in an orbital shaker for 15 min (10^{-1} dilution). Using a sterile micropipette decimal dilution of 10^{-2} was prepared by transferring 1 ml of 10^{-1} dilution into 9 ml of diluent (normal saline) in a sterile test tube. Both the 10^{-1} and 10^{-2} dilutions were shaken mechanically. Then, 1 ml of each dilution was pipetted into separate sterile petri-dishes in triplicates with suitable labelling. About 20 ml of molten and cooled nutrient medium (45°C) was added for microbial culture. Bacteria were cultured using nutrient agar medium while potato dextrose was used for fungal and yeast culture. Then, the petri-dishes were rotated in both clockwise and anticlockwise direction on a horizontal surface (to ensure proper mixing of nutrient medium and diluents) and allowed to solidify for 30 min. Finally, the petri-dishes were inverted and incubated at 37°C for 24–48 h for microbial growth. After incubation, the number of colony forming units (N_{cfu}) were counted. Then, the number of microbial organisms present in one gram of sample (N_s) for a given dilution factor (DF) was computed as given below.

$$N_s = \frac{N_{cfu} \times DF}{W_s} \qquad 3.10$$

3.1.11 Commercial sterility test

Commercial sterility test (IS:2168, 1971) was performed for thermal processed samples subjected to sterilization treatments. Initially, 3 randomly chosen cans per sterilization treatment were incubated at 37°C for 14 days. After incubation, the cans were opened aseptically and the samples were transferred to sterile thioglycollate broth tubes. Then, sterile liquid paraffin wax was dispensed in each tube to create anaerobic condition. Then, the tubes were incubated at 37°C for a period of 48 h and examined for turbidity development (indicator of microbial survival). Tubes with no turbidity were again incubated under same conditions to ensure their sterility (Sreenath, 2007; Biji *et al.*, 2013).

3.2 STANDARDIZATION OF THERMAL PROCESSING PARAMETERS

It involved the identification of appropriate time-temperature combination for thermal processing of canned tender jackfruit. The flowchart of different steps involved in the standardization procedure is given in Fig. 3.1 and their brief description is given below.

3.2.1 Sample collection

Fresh tender jackfruit (*Artocarpus heterophyllus* L. cv '*Varikka*') samples procured from Fruits Crops Research Station (erstwhile Pineapple Research Centre) of Kerala Agricultural University, Thrissur (Kerala, India) in the month of March, 2019 were used for the study. All the samples were harvested from same jackfruit tree when they were at a maturity of 50-70 days after fruit formation. The collected samples were transferred to Central Institute of Fisheries Technology (CIFT), Cochin (Kerala, India) for subsequent analyses.

3.2.2 Sample preparation

Initially, the samples were washed in tap water to remove the extraneous matter and the prickly non-edible outer skin/rind was removed (peeling). Then, the peeled samples were sliced into circular discs of about 1 cm thickness. Each disc was further cut into eight pieces of almost uniform size. The cut samples were immediately dipped in a solution containing 0.1% potassium metabisulphite (2 litre solution per kg of jackfruit pieces) for 15 min to prevent browning reactions (Walker, 1985; Molla *et al.*, 2008). Later, the samples were transferred into a perforated vessel and subjected to blanching in boiling water (about 100^{o}C) for 1 min (Pritty and Sudheer, 2012). This was done to inactivate naturally occurring enzymes, remove air from the tissue and improve thermal conductivity and packing (Rickman *et al.*, 2007). After blanching, the samples were promptly cooled by water (about 28^{o}C) taken in another vessel. All the utensils and cutting tools used for sample preparation were made of stainless steel.

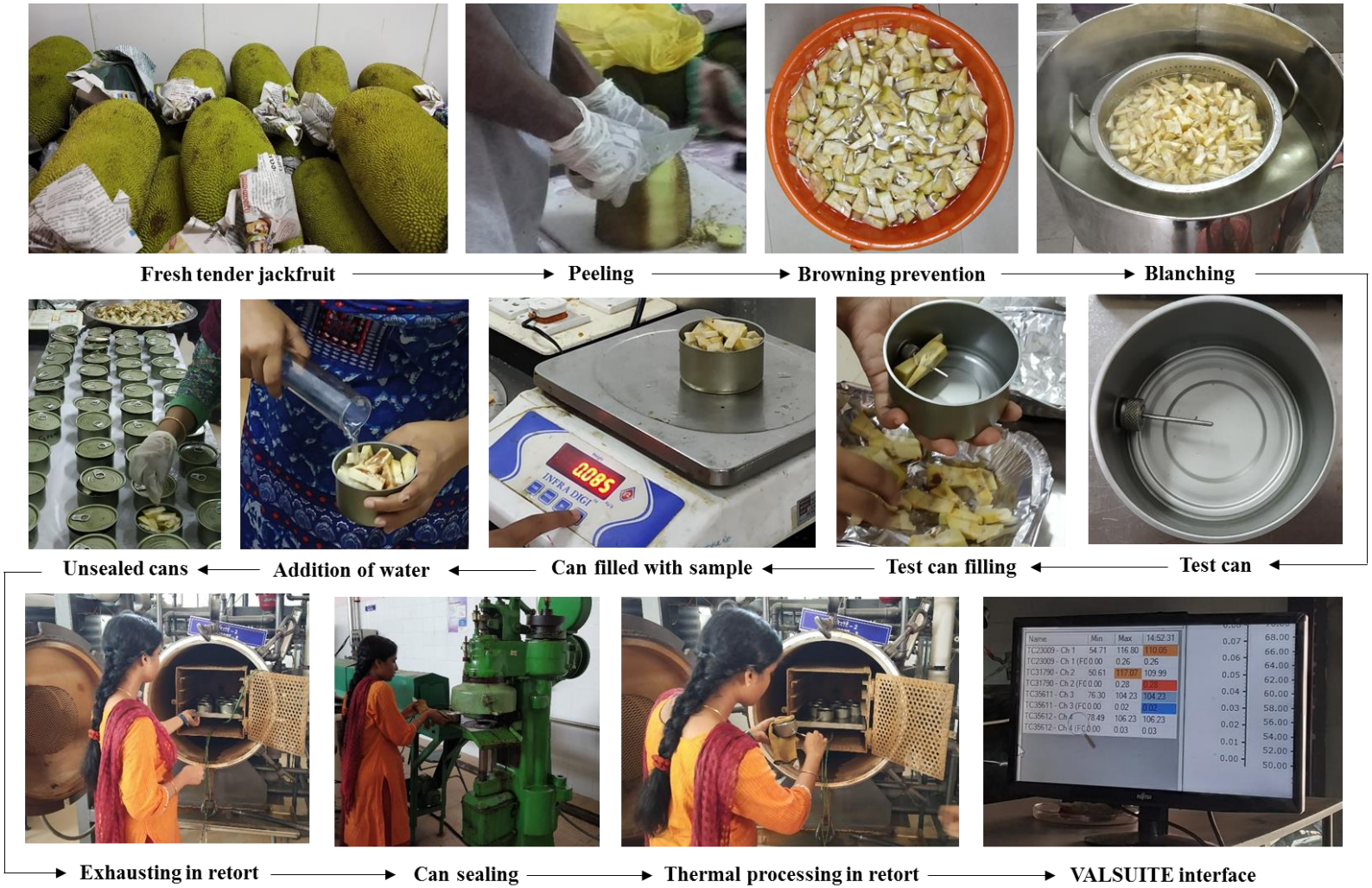

Fig. 3.1 Steps involved in thermal processing and canning of tender jackfruit

3.2.3 Can filling and positioning of thermocouple

The study was conducted using two-piece tin free steel (TFS) cans of imperial size 307 × 113 (corresponds to 84 × 46 mm metric size and 215 ml capacity) manufactured by M/s Metcan Packs Ltd., Mysuru (Karnataka, India). Each can was filled with about 85 g of blanched samples and 140 ml of water with 7 mm headspace. About 12 number of cans were prepared for each treatment. Two cans per treatment (test cans) were used to examine heat penetration characteristics of tender jackfruit. Each test can was initially fitted with a thermocouple gland and a thermocouple probe (length = 40 mm; diameter = 1.2 mm) was inserted through it. The tip of the thermocouple probe was inserted into tender jackfruit pieces (Sreenath *et al.*, 2008). Then, the thermocouple probe was positioned at about one-third of can height along the longitudinal axis passing through the centre of the can base to record the slowest heating point (also referred as coldest core or critical point) temperature (Sreenath, 2007). An Ellab data recorder (model TM 9608) was used to fetch the thermocouple output. After positioning the probe, the remaining portion of the can was filled with tender jackfruit pieces and about 140 ml of water.

3.2.4 Exhausting and can sealing

The cans filled with tender jackfruit pieces were exhausted using steam in retort for about 10 min (Biji *et al.*, 2015) to get rid of residual air and immediately double seamed using a semi-automatic seamer (Super Seam, Chennai, Tamil Nadu, India).

3.2.5 Thermal processing

Thermal processing of canned tender jackfruit was carried out at different time-temperature combinations in a pilot scale retorting system (John Fraser and Sons Ltd., UK). The study examined both pasteurization and sterilization temperatures for thermal processing of canned tender jackfruit. Two different pasteurization (90 and 100^{o}C) and sterilization (110 and 121^{o}C) temperatures were considered. The treatments involved in the analysis consisted of combination of each temperature with time required to attain desired lethality as indicated by F and F_0 values in case of pasteurization and sterilization, respectively. The thermal processing treatments considered in the study for standardization of time-temperature combination are given in Table 3.1. Each treatment was carried out in distinct batches with about 12 number of cans of which

two were used as test cans while the remaining reserved for physicochemical and microbiological analyses. After thermal processing, water (28°C) was pumped into the retort to cool the cans to a temperature of around 40ºC (Biji *et al.*, 2015) and immediately dipped in cold water to prevent overcooking. Both the retort temperature (T_r) and critical point temperature of the product (T_p) during thermal processing were fetched using Ellab recorder with the aid of VALSUITE software together with the corresponding lethality values (in terms of F and F_0 for pasteurization and sterilization, respectively).

Table 3.1 Treatments considered for thermal process standardization

Treatment*	Temperature (ºC)	Lethality¶ (F or F_0 in min)
P1	90	30.00
P2	90	60.00
P3	90	80.00
P4	100	30.00
P5	100	60.00
P6	100	80.00
S1	110	0.25
S2	110	0.50
S3	110	0.75
S4	110	1.00
S5	121	0.25
S6	121	0.50
S7	121	0.75
S8	121	1.00
S9	121	2.00
S10	121	3.00

*Alphabets P and S represents pasteurization and sterilization treatments, respectively

¶ F or F_0 corresponds to lethality of pasteurization and sterilization, respectively

3.2.6 Analysis of heat penetration data

The heat penetration and process parameters were estimated graphically using an inverted semi-logarithmic plot (with 3 log cycles) of T_p versus time (Holdsworth and Simpson, 2016). The graphs corresponding to the heating and cooling phases were

prepared separately. From the heating curve, the heat penetration factor or heat rate index (f_h) described as the time of one log cycle traverse of the straight line segment of the curve was initially determined. It corresponds to the slope of the heat penetration curve. Then, the come-up time (l) (time required to attain the desired temperature inside the retort since the beginning of steam injection into it) and initial critical point temperature of the product (T_{ih}) were noted. Then, the zero corrected time (pseudo initial heating time) was determined considering only 0.4l was at the desired T_r (Stumbo, 1973; Fellows, 2017). The temperature corresponding to the zero corrected time was recorded as the pseudo initial heating temperature (T_{pih}) and the lag factor of heating (j_h) was computed (Equation 3.11). In the same manner, the cooling penetration factor or cooling rate index (f_c) and lag factor of cooling (j_c) (Equation 3.12) were computed after recording the initial cooling temperature (T_{ic}) and pseudo initial cooling temperature (T_{pic}) of product when cooled using water at temperature of 28^0C (T_w).

$$j_h = \frac{T_r - T_{pih}}{T_r - T_{ih}} \qquad 3.11$$

$$j_c = \frac{T_w - T_{pic}}{T_w - T_{ic}} \qquad 3.12$$

Then, thermal process time at T_r (U) equivalent to a reference thermal death time (F_{ref}) was computed (Equation 3.13). The thermal resistance of microorganism (z) was set to 10 and the reference temperature (T_{ref}) for lethality rate computation was 121.1 and 85^{o}C in case of sterilization and pasteurization treatments, respectively. The maximum temperature deficit (g) representing the difference between T_r and the maximum temperature of the product at the critical point was obtained from f_h/U versus j_c table proposed by Stumbo (1973). Using these heat penetration parameters, the Ball's process time (B) was computed (Equation 3.14) which represent the actual time required to attain a desired temperature at a specific location in the container. Finally, the total process time (TPT) and operator's process time (OPT) were computed by adding 0.58l and reducing 0.42l from B, respectively (Stumbo, 1973).

$$U = F_{ref}\, 10^{\frac{T_{ref} - T_r}{z}} \qquad 3.13$$

$$B = f_h \log\left[\frac{j_h (T_r - T_{ih})}{g}\right] \qquad 3.14$$

In addition to the aforesaid heat penetration parameters, the cook value (C_0) was also computed (Equation 3.15). It signifies the equivalent time of cooking or quality loss

caused by desired thermal process of duration *t* at a reference temperature (T_{ref}) of 100°C and *z* value of 33.1°C corresponding to the most heat labile constituents (Rattan and Ramaswamy, 2014; Ling *et al.*, 2015; Holdsworth and Simpson, 2016).

$$C_0 = \int_0^t 10^{\frac{T-T_{ref}}{z}} dt \qquad 3.15$$

3.2.7 Analyses of quality attributes

The standardization of thermal treatments was based on colour, texture, AA, TFC, TPC and microbiological attributes of thermally processed canned tender jackfruit samples. The reference analytical methods used to determine these attributes are described in the Section 3.1. It may be noted that the textural attributes examined were the firmness (F_w) and toughness (T_w) of the whole portion (skin, tendril and core together) of thermal processed canned tender jackfruit samples.

3.2.8 Statistical analysis

Standardization of thermal process parameters involved in this study was based on analysis of variance (ANOVA) at 5% level of significance ($\alpha = 0.05$) under single factor completely randomized design (CRD) framework. The null hypothesis (H_0) was that no significant difference between treatments. Tukey-Kramer test ($\alpha = 0.05$) was performed to compare the mean value of attributes across different treatments. The analysis was performed using MATLAB (version R2017a, Mathworks) software.

3.3 STORAGE EVALUATION OF THERMAL PROCESSED CANNED TENDER JACK FRUIT

3.3.1 Sample collection and preparation

The raw samples required for the storage evaluation of thermal processed canned tender jack fruit were procured from Regional Agricultural Research Station, Ambalavayal, Wayanad (Kerala, India). About 90 kg of raw tender jackfruits (*Varikka* variety) were manually harvested. On the same day, the collected samples were transferred to CIFT, Cochin and kept under room conditions. Next day, they were subjected to canning and thermal processing at standardized time-temperature combinations. The sample preparation for thermal processing remained the same as that performed for the standardization study (Section 3.2.2).

3.3.2 Addition of preservatives and thermal processing

The study evaluated the combined effect of thermal processing (pasteurization and sterilization) and preservative on the quality of canned tender jackfruit during storage. In this, the best pasteurization (P) and sterilization (S) process parameters (temperature, lethality, time) identified as part of the standardization protocol (Section 3.2) were used for thermal processing of samples which later subjected to storage evaluation. The commonly used food preservatives namely brine, potassium metabisulphite (KMS) and citric acid (CA) were used. Forty eight TFS cans with samples were prepared for each thermal process-preservative combination (hereinafter regarded as a treatment for storage evaluation). This many number of cans were needed for monthly analyses of multiple quality attributes and microbiological safety of thermal processed canned tender jackfruit during storage period (7 months) and their sensory evaluation thereafter.

Each can was filled with about 85g of blanched tender jackfruit bits and about 140 ml filling solution with preservatives. Prior to thermal processing (Section 3.2.5), the cans were exhausted and double seamed (Section 3.2.4). In addition, same number of cans with no preservatives (NP) were included for thermal processing at standardized conditions. This resulted in 4 different treatments (3 preservatives + 1 non-preservative) for storage evaluation for each thermal process. Apart from them, an additional set comprised of 6 treatments (with and without preservatives) based on blanching (Pritty, 2012; Pritty and Sudheer, 2012) and exhausting together as a mild treatment (M) were also subjected to storage evaluation. Thus, a total of 14 treatments were examined as part of the storage study. The details of storage treatments along with the concentration of preservatives used (Singh *et al.*, 1996; Thakur, 2018) are given in Table 3.2.

3.3.3 Analyses of quality attributes

The quality evaluation of thermal processed canned tender jackfruit samples were made on monthly basis for a period of 7 months. The attributes examined included L*, a*, b*, ΔE, F_s, pH, TSS, TA, CFC, CC, AA, TFC and TPC. They were determined using respective standard methods as described in Section 3.1.

Table 3.2 Treatments considered for storage evaluation of thermal processed canned tender jackfruit

Treatment	Description
	Mild treatments (blanching + exhausting)
M-NP	Mild treatment of canned tender jackfruit with no preservative
M-B	Mild treatment of canned tender jackfruit with 2% brine
M-KMS	Mild treatment of canned tender jackfruit with 0.1% KMS
M-CA	Mild treatment of canned tender jackfruit with 0.3% CA
M-B+KMS	Mild treatment of canned tender jackfruit with 2% brine & 0.1% KMS
M-KMS+CA	Mild treatment of canned tender jackfruit with 0.1% KMS & 0.3% CA
	Pasteurization treatments
P-NP	Pasteurization of canned tender jackfruit with no preservative
P-B	Pasteurization of canned tender jackfruit with 2% brine
P-KMS	Pasteurization of canned tender jackfruit with 0.1% KMS
P-CA	Pasteurization of canned tender jackfruit with 0.3% CA
	Sterilization treatments
S-NP	Sterilization of canned tender jackfruit with no preservative
S-B	Sterilization of canned tender jackfruit with 2% brine
S-KMS	Sterilization of canned tender jackfruit with 0.1% KMS
S-CA	Sterilization of canned tender jackfruit with 0.3% CA

KMS: potassium metabisulphite; CA: citric acid

3.3.4 Microbiological analysis

Microbiological analysis of thermal processed canned tender jackfruit samples was performed during storage period (7 months) using serial dilution and plating method as described in Section 3.1.10. An additional analysis was performed to ascertain microbiological safety prior to sensory evaluation.

3.3.5 Sensory evaluation

Sensory evaluation of thermal processed canned tender jackfruit samples and curry made out of them were conducted separately after 8 months of storage. The details of samples including preservative type, processing and storage conditions were kept anonymous during sensory analysis. Organoleptic attributes namely, appearance, colour, flavour, odour, taste, texture and overall acceptability of canned tender jackfruit and curry were adjudged based on a 9 point hedonic scale by a panel consisted of 39

and 40 untrained judges, respectively. The 9 point hedonic scale (Ranganna, 1986) used for sensory evaluation in this study is as the following, 9: like extremely; 8: like very much; 7: like moderately; 6: like slightly; 5: neither like nor dislike; 4: dislike slightly; 3: dislike moderately; 2: dislike very much; 1: dislike extremely. For each treatment, the mean of scores given by all the panellists were computed. Then, a non-parametric Kendall's concordance test was performed using IBM SPSS Statistics software (International Business Machines Corporation, New York) to assess significance of agreement among the judges. The H_0 was that no agreement among the judges at 5% level of significance ($\alpha = 0.05$). The software accounted for any ties in scores given to different treatments as noted in several judgements in this study. The test results consisting of the mean of tie corrected scores (hereinafter referred as mean rank) of different treatments, degree of freedom (*df*), chi-square test statistic (χ^2), Kendall's coefficient of concordance (*W*) and probability (*p*) values were recorded.

3.3.6 Statistical analysis

Storage evaluation of the quality of thermal processed canned tender jackfruit samples with preservatives was based on ANOVA ($\alpha = 0.05$) under two factor CRD framework. The H_0 was that no difference in the quality attribute values during storage (first factor) and across treatments (second factor). The Tukey-Kramer test ($\alpha = 0.05$) was performed to compare the mean value of attributes across different treatments. The statistical analysis was performed using MATLAB software (version R2017a, Mathworks).

3.3.7 Cost estimation

The total cost involved in the production of thermal processed canned tender jackfruit was estimated using standard procedure with suitable assumptions (Appendix G).

3.4 QUALITY ASSESSMENT OF TENDER JACKFRUIT USING NIRS

In this study, the utility of NIRS was examined to assess the quality attributes of both fresh and thermal processed tender jackfruit samples. In addition, its ability to characterize intra sample or inter component (skin, tendril and core) variability (with regard to TFC and TPC) of fresh tender jackfruit was also investigated. These objectives were realized using three different sets of samples hereinafter referred as Set-1 (fresh whole), Set-2 (thermal processed) and Set-3 (component wise), respectively. More details of the samples and analyses performed using them are described below.

Sample collection details of fresh tender jackfruit used in NIRS analyses (Set-1 and Set-3) including variety, geographical coordinates, location, and physical dimensions (length, diameter, arithmetic mean diameter, geometric mean diameter, sphericity and aspect ratio) were also recorded with a view to keep comprehensive information of the samples in the spectral library (Table B1 and B2 of Appendix B).

3.4.1 Sample collection, preparation and reference analyses

The Set-1 comprised of 58 fresh tender jackfruit samples (50-70 days maturity) collected from four districts of Kerala (India) namely, Alappuzha, Kollam, Malappuram and Pathanamthitta. Manually harvested samples were transferred to the laboratory and stored in room condition for subsequent analyses the very next day. Each sample was cut into two similar parts about the midpoint of the longitudinal axis; one portion was used for reference analyses while the second reserved for spectral measurements (described in Section 3.4.2). The part kept for reference analyses of quality attributes was initially peeled and sliced. Then, they were subjected to colour measurements (Section 3.1.1). The samples were crushed and the extracted juice was subjected to both pH (Section 3.1.3) and TSS (Section 3.1.4) measurements. A few slices were crushed into homogenized pulp for the determination of TA by titrimetric analysis (Section 3.1.5). In addition, the firmness and toughness measurements of skin (F_s and T_s), tendril (F_t and T_t) and core (F_c and T_c) components were made separately using *TA.HDplus* Texture Analyser (Section 3.1.2).

The canned tender jackfruit samples (n = 48) subjected to pasteurization (treatment P2) and sterilization (treatment S10) with different preservatives (as mentioned in section 3.3.2) and stored for six months constituted the Set-2. Both the spectra measurements and reference analyses were performed once a month for a period of six months. Initially, tender jackfruit bits taken outside from TFS can were spread over a tissue paper to remove the filling solution adsorbed to their surface. Then, they were subjected to colour (described in Section 3.1.1), F_s (described in Section 3.1.2) and spectral measurements (described in Section 3.4.2). Later, the samples were crushed manually using a pestle and mortar and made into a pulp for other reference analyses and spectral measurements. The other portion of sample was then oven dried, mechanically grinded and stored in airtight containers. The quality attributes examined included L*, a*, b*, F_s, TA, AA, CC, CFC, TFC and TPC.

The Set-3 consisted of 57 fresh tender jackfruit samples manually picked from different locations of Malappuram, Palakkad and Thrissur districts of Kerala (India). The samples collected were stored in room condition and subjected to analyses the very next day. Each sample was cut into two halves about the midpoint of the longitudinal axis. One portion was used for spectra acquisition of intact skin, tendril and core components, separately (described in Section 3.4.2). After spectra acquisition, both the portions were peeled, the components (skin, tendril and core) were separated and oven dried (65^{o}C) for 24 hours. The dried samples were mechanically grinded and the powder was stored in air tight containers for subsequent reference analyses (TFC and TPC) and spectral measurements.

3.4.2 Spectra acquisition

The spectral measurements in this study were made using two instruments namely, Fieldspec 4 (Analytical System Devices, USA) and DLP NIRscan Nano (Texas Instruments, USA), respectively. The former instrument was used for spectra acquisition of Set-1 samples in both grated and intact form. The latter instrument was used to scan both Set-2 and Set-3 samples. In case of Set-2 samples, spectra of both the pulp and dry powder were acquired. Spectra of both intact and dried powder of tender jackfruit components were taken in case of Set-3 samples. More details of spectral measurements using these instruments are given below. It may be noted that the spectra acquisition of all tender jackfruit sample types (except dry powder) were performed simultaneously in parallel to sample preparation for their reference analyses.

In case of Set-1 spectral measurement, the reserved portion of each fresh sample was initially peeled, grated and filled in a circular container of 10 cm diameter and 2 cm thickness. The grated sample surface was then levelled using a glass petri dish and ensured no light penetration through the sample. Then, the prepared sample was subjected to bi-directional spectral measurements (Plate C1 of Appendix C) using the portable Fieldspec 4 spectroradiometer (Analytical System Devices, USA). The instrument operates in 350-2500 nm wavelength range at 1 nm sampling interval. The bare fibre optic cable sensor (25^{o} conical angle) was fixed at about 11 cm vertically above the centre of sample container to have circular field of view of about 5 cm diameter on the sample surface. A 200 W quartz-halogen lamp (45^{o} illumination angle)

was used as the illumination source. A white reference spectrum was acquired using a 5”×5” size Spectralon panel (Labsphere, USA) before each sample measurement. Four R^* spectra were collected from each grated sample by rotating the container at 90^o after each measurement. Using the same experimental setup, replicated R^* of intact circular disc (thickness of about 1 cm) of peeled samples (n = 36) were also derived. Due to the low-signal-to-noise, the spectral values in the wavelength ranges 350–400 and 2451–2500 nm were not considered in this study.

Spectral measurements (900–1700 nm) using DLP NIRscan Nano (Plate C2 of Appendix C) were performed with the aid of an associated graphical user interface (DLP NIRscan Nano GUI v2.1.0, Texas Instruments). The digital resolution of the device was 228 and 6 number of repeated scans were chosen for internal spectral average. The measurement include the placement of sample window of the device in perfect contact with the sample without any space in between. The sample window was covered using a layer of transparent polythene material for spectral measurements of tender jackfruit pulp (in case of thermal processed samples) and intact components of fresh samples. This was done to protect the sensor from moisture and gum present in the sample. In case of fresh intact measurement, the gum present in the sample was wiped using a tissue paper prior to every spectrum measurement. In case of spectra acquisition of powder of oven dried tender jackfruit components, samples were taken in small transparent polythene pouches and they were directly exposed to the sample window. Four replicated spectra per sample were acquired for fresh and thermally processed samples while three spectral replications were made for oven dried samples.

3.4.3 Spectral data analysis

The MATLAB software (R2017a, Mathworks) was used to perform necessary data analyses involved in this study. Prior to data modelling, the replicated spectra of samples were subjected to third-order Savitsky–Golay smoothing of span 9 nm (Sahadevan *et al.*, 2013) and averaged to make their representative spectrum. The basic idea behind the implemented NIRS approach was to establish linkage (calibration function or model) between spectra (acquired using NIRS instrument) and quality attribute (determined by classical reference method). The general scheme implemented in the study to develop spectra-attribute linkage of fresh and thermal processed tender

jackfruit samples is depicted in Fig. 3.2. Typically, spectra in the NIRS domain provide composite information related to both absorption and scattering components of the electromagnetic radiation upon interaction with the target material. The scattering component provide little information on composition as it do not partake in energy interaction with the material. But, it form the major source for undesired variations (non-linearity and baseline shift) in the acquired spectra. The pre-processing steps mainly intend to remove such effects from the spectra (Rinnan *et al.*, 2009). The pre-processing techniques implemented in the study consists of both scatter correction methods (*MSC, DT* and *SNV*), spectral derivatives (*FD* and *SD*) and their pairwise combinations (except *DT*+*SD* as it yielded same value as that of *SD*). In addition, the R^* with no pre-processing (*Raw*) was also incorporated in the analysis. Hence, a total of 11 pre-processing techniques (6 individual + 5 combinations) were examined in all the three sample sets of this study. In case of fresh sample analysis (Set-1), an additional set of pre-processing based on A^* (derived from R^* as $A^* = \ln(1/R^*)$) was also included.

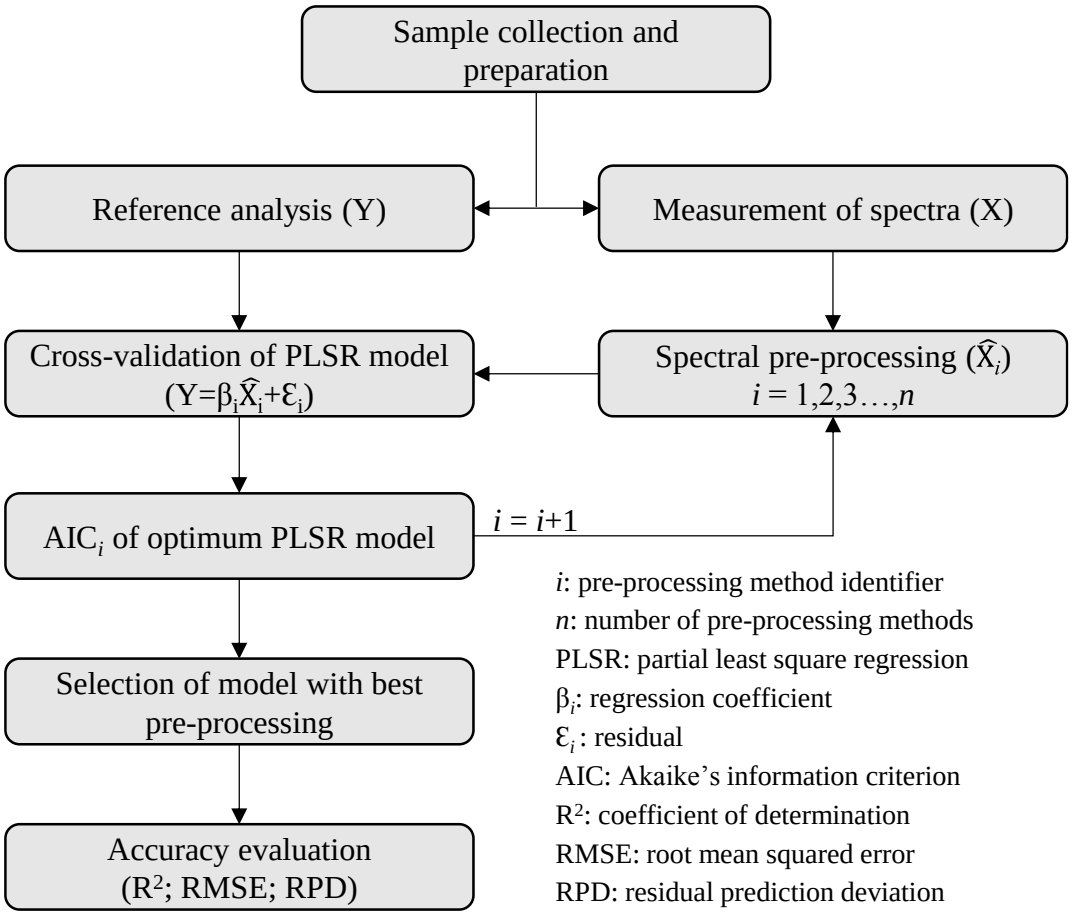

Fig. 3.2 Partial least square regression modelling scheme

The NIRS approach implemented in this study used PLSR algorithm (Wold *et al.*, 2001) to develop pre-processed spectra-attribute linkage. Leave-one-out cross-validation (Viscarra Rossel, 2007) was adopted to select optimum number of latent variables (*LV*) to avoid over- or under-fitting behaviour of PLSR model. In this approach, the dataset (consisting of *n* number of samples) was divided into calibration and validation subsets. The validation subset comprised of one sample of the dataset while all the remaining samples ($n - 1$) constitute the calibration subset. Then, a PLSR model was trained and tested using calibration and validation subsets, respectively with one *LV*. The step was iterated until all the samples became a validation sample exactly once and the corresponding mean squared error (MSE) was recorded. This procedure was repeated for a predefined number of *LV* (chosen as 5 in this study). Then, the number of *LV* corresponding to the minimum MSE was chosen as the optimum. The calibration function developed using optimum number of *LV* was regarded as optimum PLSR model.

The cross validation performance of optimum PLSR models were evaluated in terms of R^2 (Equation 2.12), RMSE (Equation 2.13) and RPD (Equation 2.14). The RPD criteria suggested by Williams and Norris (2001) was used to adjudge model performance. Accordingly, models were treated as excellent (RPD > 3.0), good (2.5 < RPD < 3.0), suitable for coarse quantitative estimation (2.0 < RPD < 2.5), capable of discriminating their low and high values (1.5 < RPD < 2.0) and poor (RPD < 1.5). Apart from the aforesaid regression statistics, Akaike's information criterion (AIC) was also computed to account for both model accuracy (in terms of RMSE) and complexity (in terms of *LV*) together (Equation 3.16). Minimum AIC criteria (Akaike, 1973) was adopted to identify the best among PLSR models generated using different pre-processing techniques. All the aforesaid steps remain common across different NIRS analyses (sample sets) involved in this study.

$$\mathrm{AIC} = n \times \ln(\mathrm{RMSE}) + 2 \times LV \qquad 3.16$$

CHAPTER 4
RESULTS AND DISCUSSION

4.1 STANDARDIZATION OF THERMAL PROCESSING PARAMETERS

4.1.1 Thermal process characteristics of canned tender jackfruit

The heating and cooling behaviour of canned tender jackfruit over time (at 1 min interval) at critical point (T_p profile) when subjected to different pasteurization and sterilization treatments inside a still retort are shown in Fig. 4.1 and 4.2, respectively. In addition, the T_r profile and lethality values attained during thermal processing are also depicted in these figures. Both the T_r and T_p profile of tender jackfruit samples in TFS cans exhibited similar pattern during thermal processing (irrespective of treatments) with heating, hold on and cooling stages. The steam injection (since zero time) has resulted in an increase in temperature values in the initial phase of thermal processing (heating stage) up to the desired T_r. The horizontal portion of the temperature profiles corresponds to the hold on period during which the T_r was regulated to be constant. Once the desired lethality was achieved, cooling water was injected into the retort which resulted in a decrease of both T_r and T_p values (cooling stage). The corresponding thermal processing characteristics of the samples are listed in Table 4.1. The *l* value needed to attain the desired thermal processing temperature inside retort varied within 2–4 min across different treatments (Singh *et al.*, 2015). The f_h varied in the range of 2.95–4.40 and 3.20–8.60 in case of pasteurization and sterilization treatments, respectively. All the sterilization treatments at 110°C and others namely P3, S6 and S10 exhibited very little lag in heating ($j_h < 1$) while contrasting values ($j_h \geq 1$) were noted for the remaining treatments. The pasteurization treatments (j_c = 1.05–1.44) appeared to have low range of j_c values as that of sterilization counterparts (j_c = 1.01–1.71). The *g* value decreased with increase in lethality of thermal processing at a particular temperature (Sreenath *et al.*, 2008) as noted in case of P1–P3 (at 90°C), P4–P6 (at 100°C), S1–S4 (at 110°C) and S5–S10 (at 121°C) treatments. In contrast, *B*, TPT and OPT values increased with increase in lethality values. On the other hand, low *B*, TPT and OPT values were noted for treatments at higher temperature and of same lethality. This remained consistent across both pasteurization and sterilization treatments. The C_0 value was also found to be influenced by the desired lethality of the thermal process at a particular temperature (Sreenath *et al.*, 2008); it

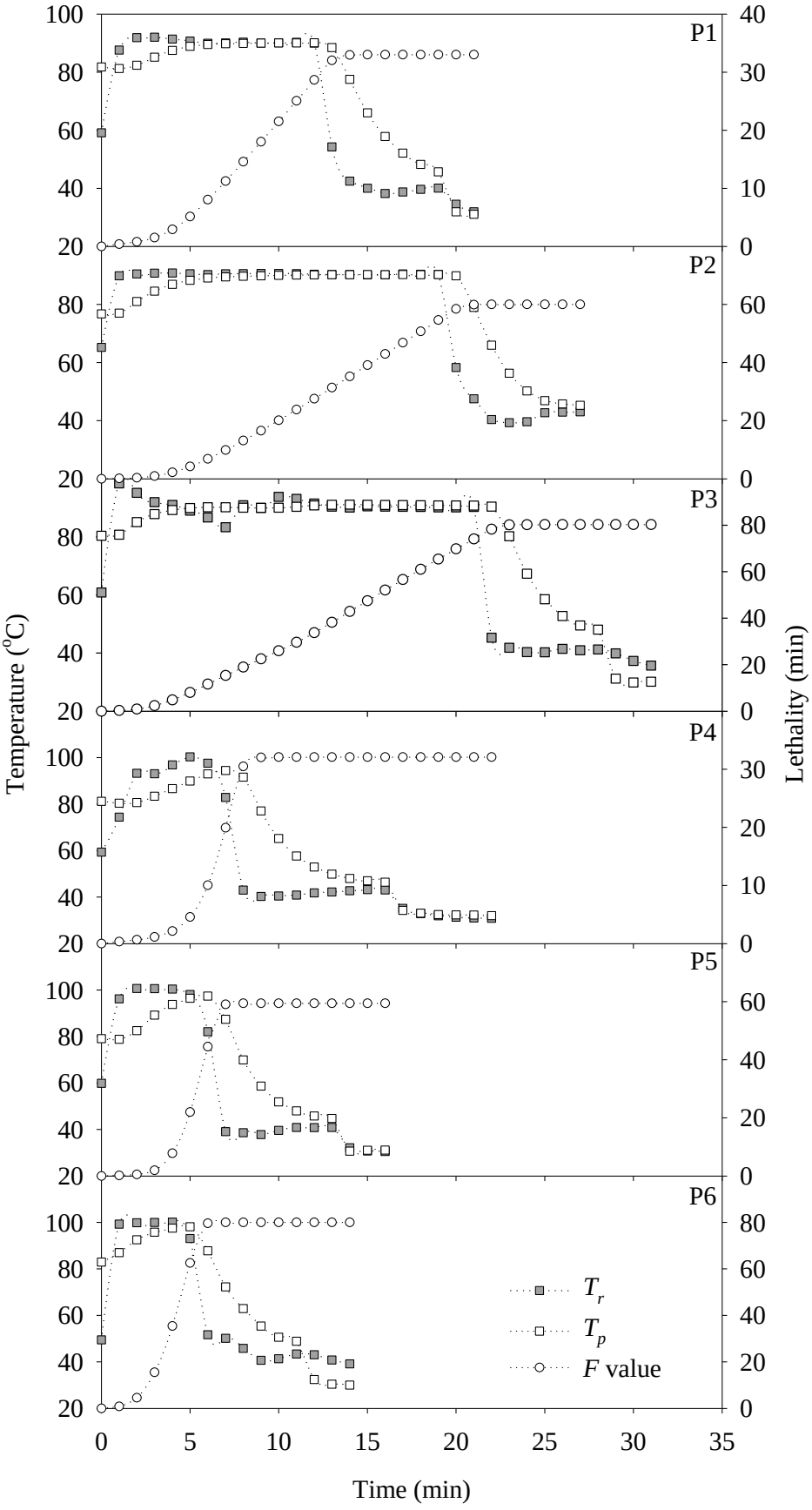

Fig. 4.1 Heat penetration characteristics of tender jackfruit samples in TFS cans subjected to different pasteurization treatments

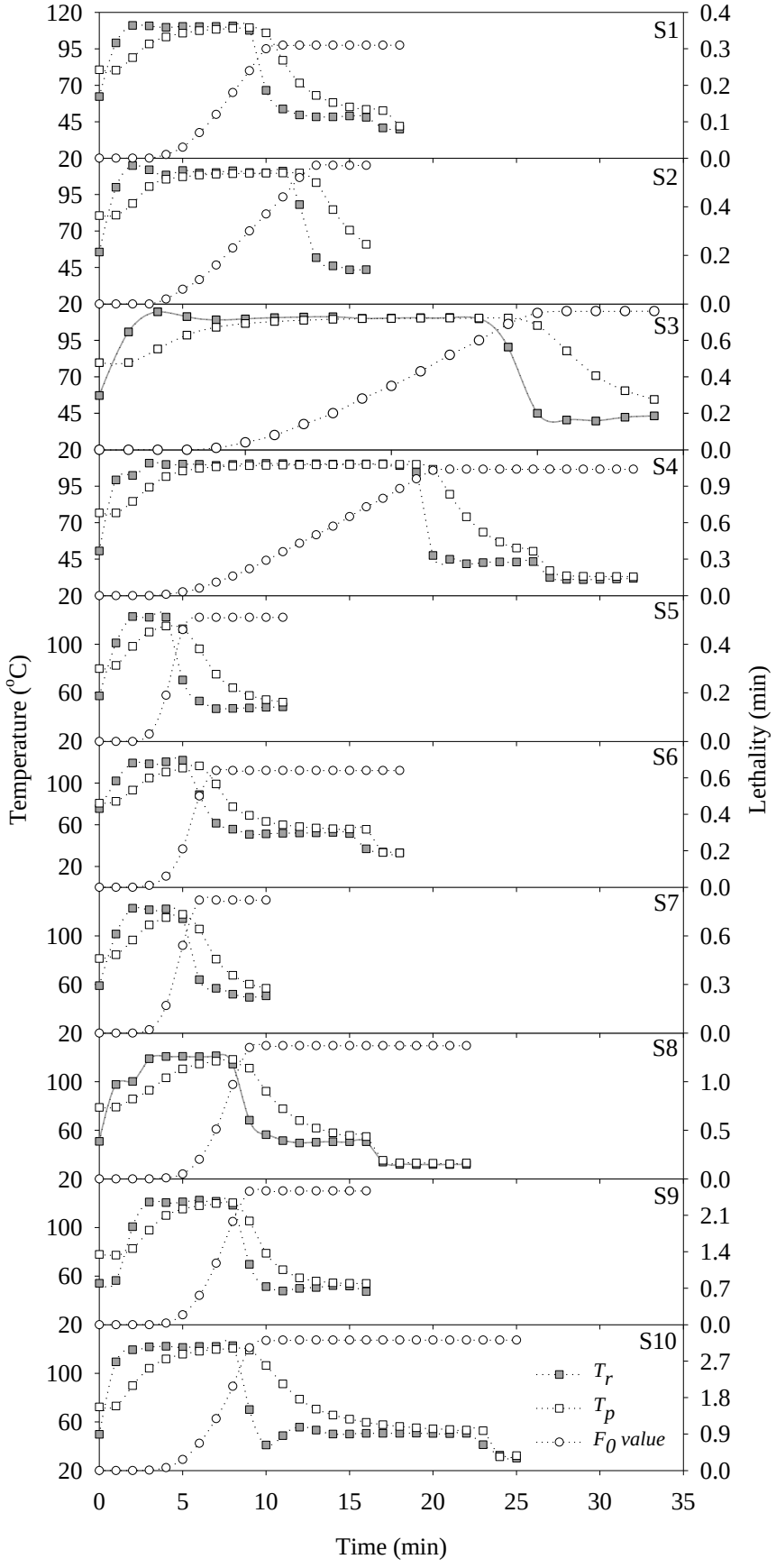

Fig. 4.2 Heat penetration characteristics of tender jackfruit samples in TFS cans subjected to different sterilization treatments

Table 4.1 Thermal process parameters of canned tender jackfruit

Treatment	l (min)	f_h (min)	j_h	f_c (min)	j_c	g (°C)	B (min)	TPT (min)	OPT (min)
P1	2	2.95	2.80	8.65	1.08	8.33×10^{-03}	10.15	11.31	9.31
P2	2	4.10	1.36	8.65	1.05	1.09×10^{-03}	17.29	18.45	16.45
P3	2	3.65	0.94	8.70	1.09	7.22×10^{-05}	18.60	19.76	17.76
P4	4	3.40	1.02	10.60	1.29	6.05	2.59	4.91	0.91
P5	2	4.40	1.34	6.80	1.24	3.52	3.96	5.12	3.12
P6	2	4.00	1.14	7.15	1.44	2.39	4.00	5.16	3.16
S1	2	7.10	0.95	8.30	1.23	2.37	7.61	8.77	6.77
S2	2	7.20	0.95	8.30	1.22	0.75	11.33	12.49	10.49
S3	2	6.10	0.96	9.00	1.70	0.16	13.71	14.87	12.87
S4	3	8.60	0.81	9.00	1.71	0.21	18.23	19.97	16.97
S5	2	3.23	1.02	6.25	1.18	10.29	1.97	3.13	1.13
S6	4	4.85	0.55	6.45	1.13	8.76	1.94	4.26	0.26
S7	2	3.20	1.24	6.00	1.36	5.07	3.15	4.31	2.31
S8	4	4.60	1.00	9.10	1.22	5.22	4.16	6.48	2.48
S9	3	3.40	1.21	6.00	1.30	1.61	5.13	6.87	3.87
S10	3	3.85	0.70	11.60	1.01	0.88	6.11	7.85	4.85

l: come-up time; f_h: heat rate index; j_h: heat lag factor; f_c: cooling rate index; j_c: cooling lag factor; g: final temperature deficit; B: Ball's process time; TPT: total process time; OPT: operator's process time

increased with an increase in F (pasteurization) or F_0 (sterilization) value. The C_0 value of pasteurization and sterilization treatments of same temperature ranged within 6.46–11.67 (P1–P3), 2.78–4.56 (P4–P6), 14.22–33.46 (S1–S4) and 9.88–25.89 min (S5–S10). The variation in C_0 value of treatments during thermal processing at a particular temperature with different lethality values are shown in Fig. 4.3.

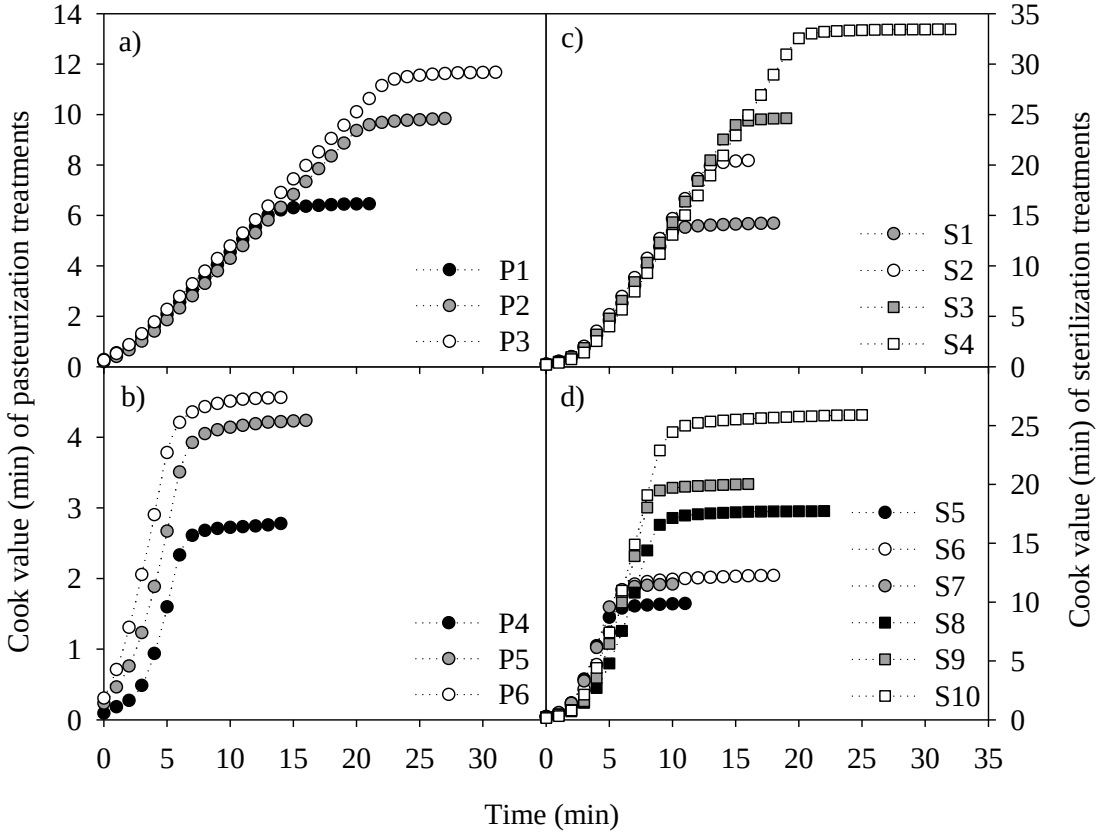

Fig. 4.3 Cook value of thermal process treatments; a) pasteurization at 90°C, b) pasteurization at 100°C, c) sterilization at 110°C, d) sterilization at 121°C

4.1.2 Colour

The CIE colour space coordinates (L*, a* and b*) of thermal processed samples were found to have statistically significant difference ($p < \alpha$) between treatments based on the result of single factor ANOVA (Table 4.2). Also, the colour values of thermal processed samples (Table 4.3) were found to be remarkably different with those of fresh sample (L* = 78.32; a* = 0.31; b* = 17.96). The main reason for the variation may be attributed to thermal degradation of pigments mainly chlorophyll (conversion to pheophytin), xanthophyll (carotenoids), lycopene (Tijskens *et al.*, 2001; Medeni, 2006; Paciulli *et al.*, 2018). The thermal degradation resulted in reduction of L* and increase of a* and b* values of thermal processed samples compared to that of fresh counterpart. The variation in colour values of thermal processed samples was found to be related with TPT and temperature of treatments. In case of treatments at a given temperature, the variation increased with increase in TPT. For example, in case of pasteurization treatments at 90°C (P1 to P3), L* value decreased from 68.00 to 65.05, a* increased from 1.81 to 2.38 and b* value increased from 11.70 to 12.23 as the TPT varied from 11.31–19.76 min. Also, colour values have significant variation across treatments at

different temperatures, however the variation was statistically insignificant ($p > \alpha$) in some cases (Table 4.3).

The variation in colour indices across different treatments was also examined (Table 4.3) as descriptive of synergistic effect of L*, a* and b* values. The value of ΔE across pasteurization treatments vary in the range 12.15–18.01 while that of sterilization was noted to be 19.89–28.25. The range noted in this study value is comparable with that obtained for Pritty and Sudheer (2019) in their analysis related to thermal processing of tender jackfruit in tin cans. Based on the criterion proposed by Limbo and Piergiovanni (2006), samples of all the thermal processed treatments were found to have different colour (ΔE > 12) compared to that of fresh sample. In case of pasteurization, the low and high ΔE values were noted for P1 and P6, respectively with gradual increase in regard to temperature and lethality. On the contrary, two sterilization treatments at 110^{o}C namely, S3 (ΔE = 25.00) and S4 (ΔE = 28.25) appeared to have high ΔE values compared to its counterpart treatments S7 (ΔE = 22.05) and S8 (ΔE = 22.55) at 121^{o}C of same lethality. The main reason for this could be associated with the effect of relatively long TPT of S3 (TPT = 14.87 min) and S4 (TPT = 19.97 min) with that of S7 (TPT = 4.31 min) and S8 (TPT = 6.48 min) treatments, respectively. With the desire to have resemblance between thermal processed and fresh sample, a treatment with low ΔE value was chosen as the best. Accordingly, P1 and S1 was found to be the best among the pasteurization and sterilization treatments, respectively. The result remained consistent in case of chroma, browning, whiteness, and yellowness indices as well (Table 4.3).

4.1.3 Texture

The textural attributes of fresh tender jackfruit in terms of F_w and T_w were found to be 85.67 N and 182.62 N.s, respectively. A considerable decrease in F_w in the tune of 8.54–50.22% (in case of pasteurization) and 58.60– 80.78% (in case of sterilization) was noted when subjected to thermal processing (Table 4.4). The percent decrease in T_w was noted to be in the range 28.66–53.05 and 59.66–78.50% in case of pasteurization and sterilization treatments, respectively. More resemblance of thermal processed samples with that of fresh sample (low percent decrease) with regard to both F_w and T_w was noted for P1 and S1 among pasteurization and sterilization treatments,

Table 4.2 Results of single factor analysis of variance of quality attributes of thermal processed canned tender jackfruit

Attribute	Source of variation	*SS*	*df*	*MSS*	F^*	*p*
L*	Between groups	774.00	15	51.60	121.58	7.53×10^{-24}
	Within groups	13.58	32	0.42		
	Total	787.59	47			
a*	Between groups	41.64	15	2.78	69.67	4.20×10^{-20}
	Within groups	1.28	32	0.04		
	Total	42.92	47			
b*	Between groups	27.13	15	1.81	80.09	4.92×10^{-21}
	Within groups	0.72	32	0.02		
	Total	27.85	47			
ΔE	Between groups	675.81	15	45.05	114.68	1.87×10^{-23}
	Within groups	12.57	32	0.39		
	Total	688.38	47			
Chroma	Between groups	40.61	15	2.71	76.25	1.05×10^{-20}
	Within groups	1.14	32	0.04		
	Total	41.74	47			
WI	Between groups	791.22	15	52.75	160.43	9.78×10^{-26}
	Within groups	10.52	32	0.33		
	Total	801.75	47			
BI	Between groups	1005.03	15	67.00	506.25	1.23×10^{-33}
	Within groups	4.24	32	0.13		
	Total	1009.27	47			
YI	Between groups	642.25	15	42.82	695.73	7.82×10^{-36}
	Within groups	1.97	32	0.06		
	Total	644.22	47			
Firmness	Between groups	12491.28	15	832.75	451.98	7.49×10^{-33}
	Within groups	58.96	32	1.84		
	Total	12550.24	47			
Toughness	Between groups	18930.05	15	1262.00	215.12	9.64×10^{-28}
	Within groups	187.73	32	5.87		
	Total	19117.78	47			
AA	Between groups	34.38	15	2.29	106.50	5.93×10^{-23}
	Within groups	0.69	32	0.02		
	Total	35.07	47			
TFC	Between groups	32.61	15	2.17	36.90	6.16×10^{-16}
	Within groups	1.89	32	0.06		
	Total	34.49	47			
TPC	Between groups	0.24	15	0.02	20.82	2.34×10^{-12}
	Within groups	0.02	32	0.00		
	Total	0.26	47			

SS: sum of squares; *MSS*: mean sum of squares; *df*: degrees of freedom; F^*: ratio of the mean squares (*F*-statistic); *p*: probability that *F*-statistic greater than test statistic

Table 4.3 Colour attributes of canned tender jackfruit samples subjected to different thermal treatments

Treatment	L*	a*	b*	ΔE	Chroma	WI	BI	YI
P1	68.00±0.36^{a}	1.81±0.11^{d}	11.70±0.07^{f}	12.16±0.32^{f}	11.84±0.08^{e}	65.88±0.31^{a}	20.44±0.12^{h}	24.59±0.01^{i}
P2	65.05±0.02^{b}	1.85±0.09^{d}	11.71±0.05^{f}	14.75±0.03^{e}	11.85±0.06^{e}	63.09±0.01^{b}	21.53±0.19^{h}	25.72±0.11^{h}
P3	63.23±1.14^{b}	2.38±0.20^{cd}	12.23±0.08^{e}	16.28±1.06^{de}	12.46±0.11^{d}	61.17±1.04^{c}	23.83±0.09^{g}	27.64±0.33^{g}
P4	64.27±0.11^{b}	2.22±0.03^{cd}	13.31±0.03^{c}	14.92±0.11^{e}	13.49±0.03^{c}	61.81±0.09^{b}c	25.26±0.03^{f}	29.57±0.01^{f}
P5	61.12±0.78^{c}	2.64±0.25^{c}	13.5±0.11^{bc}	17.93±0.75^{d}	13.75±0.16^{bc}	58.76±0.68^{d}	27.64±0.14^{e}	31.55±0.14^{e}
P6	61.02±0.10^{c}	3.13±0.07^{bc}	13.81±0.25^{ab}	18.01±0.15^{d}	14.16±0.26^{b}	58.52±0.01^{de}	28.95±0.54^{d}	32.34±0.52^{d}
S1	59.36±0.24^{cd}	4.18±0.05^{a}	13.36±0.07^{bc}	19.89±0.23^{cd}	13.99±0.08^{bc}	57.02±0.20^{e}	30.21±0.06^{c}	32.14±0.03^{de}
S2	57.99±1.52^{de}	4.51±0.25^{a}	13.78±0.26^{b}	21.18±1.46^{bc}	14.50±0.32^{ab}	55.55±1.33^{ef}	32.37±0.05^{b}	33.94±0.25^{c}
S3	54.00±0.31^{f}	4.52±0.21^{a}	14.02±0.00^{ab}	25.00±0.27^{a}	14.73±0.07^{ab}	51.70±0.28^{g}	35.69±0.07^{a}	37.08±0.20^{a}
S4	54.01±0.52^{f}	4.57±0.21^{a}	14.27±0.06^{a}	24.95±0.47^{a}	14.98±0.12^{a}	51.63±0.45^{g}	36.37±0.03^{a}	37.73±0.21^{a}
S5	58.44±0.96^{d}	3.21±0.08^{bc}	12.84±0.21^{d}	20.73±0.96^{c}	13.23±0.22^{c}	56.38±0.85^{ef}	28.38±0.04^{de}	31.39±0.00^{e}
S6	57.34±0.55^{de}	3.49±0.19^{b}	13.41±0.10^{bc}	21.70±0.53^{bc}	13.86±0.15^{bc}	55.15±0.48^{f}	30.64±0.14^{c}	33.42±0.07^{c}
S7	57.01±0.10^{de}	3.50±0.25^{b}	13.30±0.09^{cd}	22.05±0.08^{bc}	13.75±0.15^{bc}	54.86±0.05^{f}	30.58±0.47^{c}	33.32±0.16^{c}
S8	56.48±0.71^{de}	4.02±0.01^{ab}	13.74±0.17^{bc}	22.55±0.72^{bc}	14.31±0.17^{b}	54.18±0.63^{fg}	32.61±0.06^{b}	34.75±0.01^{b}
S9	56.15±0.19^{e}	4.10±0.50^{a}	13.92±0.29^{ab}	22.86±0.15^{b}	14.51±0.42^{ab}	53.81±0.04^{fg}	33.35±1.22^{b}	35.40±0.62^{b}
S10	55.14±0.48^{ef}	4.09±0.04^{ab}	13.54±0.16^{bc}	23.90±0.49^{ab}	14.15±0.16^{b}	52.96±0.41^{g}	33.14±0.10^{b}	35.08±0.10^{b}

Attribute values are mean ± standard deviation of triplicates. Superscripts within each column represents significant difference ($p < 0.05$) between treatments based on single factor Analysis of Variance and Tukey-Kramer test. L*, a*, b* represents CIE colour space coordinates; ΔE, WI, BI and YI denotes total colour difference, whiteness, browning and yellowness indices.

Table 4.4 Quality attributes of canned tender jackfruit samples subjected to different thermal treatments

Treatment	F_w (N)	T_w (N.s)	pH	AA (mg/100 g)	TFC (mg RE/g)	TPC (mg GAE/g)
P1	78.35±0.75^{a}	130.28±1.59^{a}	5.50±0.03^{ab}	7.66±0.06^{a}	5.42±0.07^{e}	0.51±0.01^{c}
P2	59.48±0.25^{b}	100.57±0.40^{b}	5.50±0.02^{ab}	7.70±0.05^{a}	7.05±0.15^{cd}	0.62±0.01^{ab}
P3	42.65±2.22^{c}	85.76±0.83^{c}	5.51±0.08^{ab}	7.50±0.17^{ab}	7.07±0.05^{cd}	0.62±0.04^{ab}
P4	58.30±0.22^{b}	91.49±0.51^{c}	5.58±0.03^{a}	7.12±0.01^{b}	6.49±0.08^{d}	0.52±0.01^{bc}
P5	55.93±0.18^{b}	86.76±0.41^{c}	5.49±0.05^{ab}	6.80±0.18^{b}	6.53±0.31^{d}	0.50±0.02^{c}
P6	56.70±1.46^{b}	85.73±3.59^{c}	5.45±0.06^{ab}	7.03±0.01^{b}	7.21±0.15^{cd}	0.53±0.03^{bc}
S1	35.47±1.42^{d}	73.67±3.13^{d}	5.59±0.06^{a}	5.76±0.14^{cd}	5.85±0.29^{de}	0.52±0.02^{bc}
S2	26.94±2.64^{e}	67.33±5.36^{de}	5.43±0.08^{b}	5.79±0.26^{c}	6.75±0.49^{cd}	0.64±0.04^{ab}
S3	18.27±1.35^{f}	54.43±2.14^{f}	5.37±0.04^{bc}	5.57±0.13^{cd}	6.58±0.37^{d}	0.67±0.03^{ab}
S4	16.47±0.94^{f}	39.26±2.21^{g}	5.26±0.02^{c}	5.56±0.12^{cd}	7.56±0.31^{bc}	0.60±0.02^{b}
S5	35.02±0.91^{d}	72.76±1.64^{d}	5.47±0.06^{ab}	5.74±0.18^{cd}	6.65±0.36^{cd}	0.49±0.02^{c}
S6	34.22±1.20^{d}	72.01±0.30^{de}	5.36±0.05^{bc}	5.63±0.15^{cd}	7.19±0.10^{cd}	0.51±0.02^{c}
S7	33.82±0.55^{d}	69.33±3.45^{de}	5.37±0.05^{bc}	5.54±0.16^{cd}	7.32±0.25^{c}	0.51±0.03^{c}
S8	33.35±1.62^{d}	68.05±1.25^{de}	5.25±0.03^{c}	5.73±0.17^{cd}	7.27±0.13^{cd}	0.65±0.03^{ab}
S9	33.78±1.50^{d}	67.18±0.43^{de}	5.21±0.03^{c}	5.59±0.19^{cd}	8.19±0.11^{b}	0.69±0.05^{a}
S10	32.83±1.62^{d}	65.10±3.58^{e}	5.20±0.02^{c}	5.31±0.09^{d}	9.05±0.04^{a}	0.68±0.04^{a}

Attribute values are mean ± standard deviation of triplicates. Superscripts within each column represents significant difference ($p < 0.05$) between treatments based on single factor Analysis of Variance and Tukey-Kramer test. AA: ascorbic acid; TFC: total flavonoid content; TPC: total phenol content; F_w: firmness; T_w: toughness

respectively. The decrease in textural attribute values upon thermal processing noted in this study is in agreement to those obtained for thermal processed tender jackfruit in tin cans as reported by Pritty and Sudheer (2019). The decrease in textural attributes upon thermal processing can be related with tissue softening, degradation of pectin and starch gelatinization (Rao and Lund, 1986; Alvarez *et al.*, 2001; Peng *et al.*, 2017).

It was noted that a statistically significant difference exists between the treatments which led to the rejection of H_0 of single factor ANOVA at 5% level of significance for both F_w ($p = 7.49\times10^{-33}$) and T_w ($p = 9.64\times10^{-28}$) values (Table 4.2). Moreover, both the textural attributes differ significantly between pasteurization and sterilization treatments and also within each treatment group (Table 4.4). The textural degradation noted in this study was found to be related with the thermal process severity (Rattan and Ramaswamy, 2014) which in turn depended on temperature and TPT. In this regard, a few observations may be made from textural attribute values given in Table 4.4, a) for all treatments at a given temperature, the textural attributes was found to have higher values for treatments with low TPT, b) treatments with similar TPT in each pasteurization and sterilization category appeared to have no statistical significant difference in both the textural attributes, c) high temperature-short time treatments (121^{o}C for 4.26–6.48 min) namely S6–S8 resulted in lesser degradation of texture compared to relatively low temperature-long-time treatments S2–S4 (110^{o}C for 12.49–19.97 min) while attaining same lethality.

4.1.4 Ascorbic acid

The thermal processing treatments appeared to be significantly different with respect to AA as manifested by the rejection of H_0 ($p = 5.93\times10^{-23}$) of single factor ANOVA at 5% level of significance (Table 4.2). It was noted that a remarkable difference existed between pasteurization and sterilization treatments; the former being superior to the latter. This difference could be associated with the heat sensitivity and thermal degradation of AA (Garrote *et al.*, 2009; Munyaka, *et al.*, 2010b; Wang *et al.*, 2018). The mean AA of pasteurization treatments vary in the range 6.80–7.70 mg/100 g with minimum and maximum values noted for P5 and P2, respectively (Table 4.4). In case of sterilization, the lower and upper extremes of mean AA were noted for S10 (5.31 mg/100 g) and S2 (5.79 mg/100 g), respectively. The result of post hoc analysis

(Tukey–Kramer test) implied that a significant difference existed within pasteurization and sterilization treatments. For example, the AA of P1 and P2 were significantly higher than other pasteurization treatments. Similarly, S2 and S10 have significantly different AA values while they appeared to be on par with other sterilization treatments.

The AA of thermally processed samples appeared to be lower than that of fresh sample (9.82 mg/100 g). This may be due to thermal degradation, water solubility and leaching of AA upon thermal processing (Wang *et al.*, 2018). Also, thermal processing accelerates the chemical degradation; oxidation of AA to dehydroascorbic acid which result in inactive products after subsequent hydrolysis and polymerization (Dewanto *et al.*, 2002). The percent loss of AA varied between 27.53 and 84.93% across all the thermal processing treatments examined in this study. The AA losses noted in this study are comparable to that observed for broccoli (84%) (Murcia *et al.*, 2000), canned green beans (63%) (Jiratanan and Liut, 2004) and white cauliflower (11.49–56.39%) (Ahmed and Ali, 2013), among others.

4.1.5 Total flavonoid and phenol contents

The TFC of fresh tender jackfruit sample was found to be 5.21 mg RE/g. An increase in TFC (with respect to fresh sample) was noted for thermal processed canned tender jackfruit samples as apparent with their higher mean values in the range 5.42–9.05 mg RE/g across different treatments (Table 4.4). It may be noted that significant difference ($p < \alpha$) exist between the treatments considered in the study with regard to TFC as revealed by the single factor ANOVA (Table 4.2). The percentage increase was found to be lowest and highest in case of P1 (4.03%) & P6 (38.39%) and S1 (12.28%) & S10 (73.70%) among pasteurization and sterilization treatments, respectively. The increase in TFC may be attributed to combined effects of degradation of oxidative enzymes while blanching and release of bound TFC due to cell rupture caused by thermal treatment (Ahmed and Eun, 2018). Evidently, the effect of blanching on TFC was prominent in the study reported by Salau *et al.* (2015) on leafy vegetables including *Amaranthus spp.*, *Crassocephalum ruben*, *Amaranthus viridis* and *Manihot esculenta* for which the percent increase in TFC can be computed as 227.09, 823.29, 1085.46, and 337.14%, respectively. Also, as reported by Roy *et al.* (2009), steam blanching of broccoli (*Brassica oleracea*) using a home cooker for 5 and 10 min resulted in 225.99

and 295.48% increase in TFC, respectively. The increase in free TFC due to release of bound counterpart can be seen in studies related to Shiitake mushroom (*Lentinus edodes*) and onion as reported by Choi *et al.* (2006) and Sharma *et al.* (2015), respectively. In the former study, the increase in TFC of samples was found to be highest when heat treated at 100°C (212.50%) than at 121°C (162.50%) for 30 min. On the contrary, in the latter study for the case of Colossal variety, better TFC was observed by thermal treatment for 30 min at 120°C (3.81%) compared to others at 80°C (0.96%) and 100°C (-4.41%) The result remained consistent for other varieties considered in their study. Similarly, in our study the highest TFC was noted for sterilization treatment at 121°C (S10) with significant difference to all other treatments at low temperature and lethality values (Table 4.4).

As similar to TFC, the TPC also increased by thermal processing with respect to fresh sample (TPC = 0.50 mg GAE/g) as noted for majority of the treatments considered in this study (Table 4.4). The mean TPC of thermal processed samples varied in the 0.50–0.70 mg/g range with low and high values noted for P5 (no increase) and S9 (40% increase) treatments, respectively. Among the pasteurization treatments, the higher TPC was noted in case of P2 and P3 while S9 and S10 yielded higher values in case of different sterilization treatments. These treatments appeared to be statistically similar with regard to TPC values as revealed with the results of Tukey-Kramer test. The increase in TPC with thermal processing was also observed for the case of canned tomato puree (Singh *et al.*, 2017), Shiitake mushroom (Choi *et al.*, 2006), onion (Sharma *et al.*, 2015), among others. Singh *et al.* (2017) observed about 5% increase in TPC of canned tomato puree with reciprocating agitation thermal processing. As reported by Choi *et al.* (2006), the TPC of raw sample (29.0 mg/100 g) increased to 36.1 and 37.5 mg/100 g by thermal treatment at 100°C for 15 and 30 min, respectively. Further increase in TPC was noted when the samples were treated for 15 (38.3 mg/100 g) and 30 min (54.6 mg/100 g) at 121°C. Sharma *et al.* (2015) also observed high TPC value for treatment at 120°C which resulted in 106.79–179.18% increase in TPC value (compared to raw sample at ambient temperature) for different varieties on onion considered in their study.

As detailed above, thermal processing have resulted in a significant increase in both TFC and TPC of canned tender jackfruit. The reason for their apparent increase may be associated with the formation of non-enzymatic browning (Maillard reaction) products or release of bound phenolic compounds (by breaking the esterified and glycosylated bond) upon thermal treatment (Patras *et al.*, 2009; Sharma *et al.*, 2015). Also, thermal processing might have deactivated hydrolytic and oxidative enzymes which degrade phytonutrients (Chism and Haard, 1996; Dewanto *et al.*, 2002; Adkison *et al.*, 2018).

4.1.6 Microbiological analysis and commercial sterility test

The results of microbiological analyses of canned tender jackfruit samples which were subjected to different thermal treatments are shown in Table 4.5.

Table 4.5 Results of microbiological analyses of canned tender jackfruit subjected to different thermal treatments

Treatment	Microbial load[#]		Sterility test
	10^{-1} dilution (cfu/g)	10^{-2} dilution (cfu/g)	
P1	5	1	-
P2	< 1	< 1	-
P3	< 1	< 1	-
P4	2	< 1	-
P5	< 1	< 1	-
P6	< 1	< 1	-
S1	3	< 1	Turbid
S2	1	< 1	Turbid
S3	< 1	< 1	Turbid
S4	< 1	< 1	Sterile
S5	1	< 1	Turbid
S6	1	< 1	Turbid
S7	< 1	< 1	Turbid
S8	< 1	< 1	Sterile
S9	< 1	< 1	Sterile
S10	< 1	< 1	Sterile

[#] Conventionally, microbial load of < 1 corresponds to zero plate count

All the pasteurization treatments except P1 and P4 were observed to be microbiologically safe (microbial load < 1×10^1 cfu/g). In case of samples subjected to sterilization treatments namely, S1, S2, S5 and S6 were found to have microbial load. However, the microbial count found in all these treatments (Appendix D) were within the permissible limit of 50/ml based on the Prevention of Food Adulteration Act, 1954 and Rules, 1955 (PFA, 2002). Further, polymerase chain reaction test was performed to detect the microorganism responsible for the contamination. The result of the test ascertained the presence of *Exiguobacterium alkaliphilum, Staphylococcus epidermidis* and *Alcanivorax xenomutans* in these samples.

The samples subjected to sterilization treatments namely, S1, S2, S3, S5, S6 and S7 appeared to have developed turbidity in the commercial sterility test. This represented the survival of microorganisms in those samples/treatments. In contrary, the other sterilization treatments (S4, S8, S9 and S10) were found to be commercially sterile. Among the commercially sterile treatments, lowest lethality was observed for both S4 and S8 (F_0 = 1). Hence, this lethality value may be recommended to bring about commercial sterility of canned tender jackfruit samples.

4.1.7 Selection of best thermal processing treatment

The fundamental objective of thermal processing is the destruction of microorganisms and endogenous enzymes of food (Aamir *et al.*, 2013) to enhance its safety and shelf life. The desired lethality can be accomplished by a variety of time-temperature combinations of the thermal process. However, the intensity/severity (time-temperature effects) of thermal process is decisive of changes in the food quality (physical, chemical, organoleptic) attributes (Rattan and Ramaswamy, 2014). Generally, for low acid food (pH > 4.6), sterilization (high temperature) treatments are recommended to destroy spores of *Clostridium botulinum*, if present (William, 2003). However, due to low temperature in pasteurization treatments, food quality retention is higher compared to sterilization treatments as noted for the case of vitamin C (Wang *et al.*, 2018), colour and texture (Rattan and Ramaswamy, 2014), among others. With inherent merits associated with both sterilization and pasteurization, this study intended to standardize the best treatment in each category separately. The criteria to adjudge the best treatment in each category relied primarily on microbiological safety (Table 4.5) followed by physicochemical quality (Table 4.3 and 4.4) aspects of the thermal processed samples.

Based on the microbiological analyses, the samples subjected to P1, P4, S1, S2, S5 and S6 treatments were noticed to have survival of microorganism after thermal processing. Although, the microbial load found in them was within permissible limit, they were not considered in further investigation for a standardized treatment as they fail to ensure microbiological safety. The treatments S3 and S7 appeared to have no microbial load but not found to be commercially sterile. So these two treatments were also excluded from the investigation. All the remaining treatments namely P2, P3, P5, P6, S4, S8, S9 and S10 qualified the microbiological safety criterion implemented in this study. Among the microbiologically safe pasteurization treatments (P2, P3, P5, P6), P2 appeared to be significantly superior compared to others in terms of all colour attributes (except L*) as given in Table 4.3, F_w, T_w and AA (Table 4.4). The mean value of TFC and TPC was found to be higher in case of P6 and P3, respectively. However, the respective values of P2 were on par with them. Hence, P2 was chosen as the best among the pasteurization treatments considered in the study. In case of commercially sterile treatments (S4, S8, S9, S10), S4 being a low-temperature (110^{o}C) and long-time treatment (TPT = 19.97 min) resulted in more degradation of colour and texture attributes when compared to other treatments (temperature = 121^{o}C; TPT = 6.48–7.85 min). Also, S4 yielded low TFC and TPC values. All these treatments were found to have comparable values with regard to AA. The treatment S10 yielded statistically significant higher value of TFC than all other treatments. The mean value of TPC was also found to be higher in case of S10 and both S8 and S9 were on par with it. Apart from superior antioxidant values, S10 has the highest target lethality which was achieved without much difference in TPT as compared to that of other commercially sterile treatments. More importantly, the lethality of S10 correspond to the recommended value (F_0 = 2.52, rounded to 3.00) for 12D reduction of *Clostridium botulinum* spores by thermal processing (Chen and Rosenthal, 2009; Lemmens *et al.*, 2013). Hence, the aforesaid collective observations endorsed S10 as the best sterilization treatment in this study.

4.2 EVALUATION OF QUALITY OF THERMAL PROCESSED CANNED TENDER JACKFRUIT DURING STORAGE

The microbiological analyses performed during the initial stage of storage has detected the growth of microorganisms in all the mild treatments (M-NP, M-B, M-KMS, M-CA, M-B+KMS and M-KMS+CA) considered in this study (Plate E1 of Appendix E). Even though, the bacterial count in these treatments were within the permissible limit of 50/ml (PFA, 2002), they were regarded unsafe considering the possibility of further bacterial proliferation. Hence, all these mild treatments were excluded from all the further analyses in this study. Thus, the discussion below is limited to the storage evaluation of quality attributes of canned tender jackfruit subjected to pasteurization and sterilization treatments only.

4.2.1 Colour

The CIE colour space coordinates of thermal processed canned tender jackfruit samples were remarkably different to that of fresh sample (L* = 75.78; a* = 0.36; b* = 14.26) which may be due to thermal degradation of pigments (Tijskens *et al.*, 2001; Medeni, 2006; Paciulli *et al.*, 2018). The L* value decreased while both a* and b* (except in case of P-B) increased upon thermal processing as consistent with the observation made during standardization study (Section 4.1.2). The L*, a* and b* values after thermal processing (Month 0) varied in the range 53.27–72.73, 1.29–8.97 and 14.61–20.76 respectively, across different treatments. The corresponding ΔE value (indicating the total colour difference from fresh sample due to thermal processing) was computed to be 21.79 (S-NP), 24.09 (S-B), 11.49 (S-KMS), 19.65 (S-CA), 9.44 (P-NP), 13.52 (P-B), 4.10 (P-KMS) and 7.41 (P-CA). Based on the ΔE scale suggested by Limbo and Piergiovanni (2006), the colour of thermal processed samples were found to have perceptible (P-KMS), strong (S-KMS, P-NP, P-CA) and different (S-NP, S-B, S-CA, P-B) colour as that of fresh sample.

During storage, the CIE colour space coordinates varied significantly as revealed by the results of two factor ANOVA (Table 4.6); the L* value decreased ($p = 4.48\times10^{-92}$) while a* ($p = 4.90\times10^{-36}$) and b* ($p = 1.04\times10^{-49}$) increased irrespective of different treatments considered in the study (Fig. 4.4 and Table 4.7). The variation in colour of thermal processed vegetables during storage has been already reported in the literature

(Montanari *et al.*, 2018). The variation in colour values noted in this study is similar to that of retort pouched tender jackfruit stored for 3 months (Praveena, 2015). Among different treatments based on sterilization and pasteurization, those with KMS as preservative were found to have more resemblance to fresh sample during storage while considering L*, a* and b* values together (Table 4.8). This may be associated with the effect of KMS causing reduction of o-quinones to diphenol or their conversion to other colourless compounds (Marshall *et al.*, 2000; Arora *et al.*, 2018). Remarkably, the CA

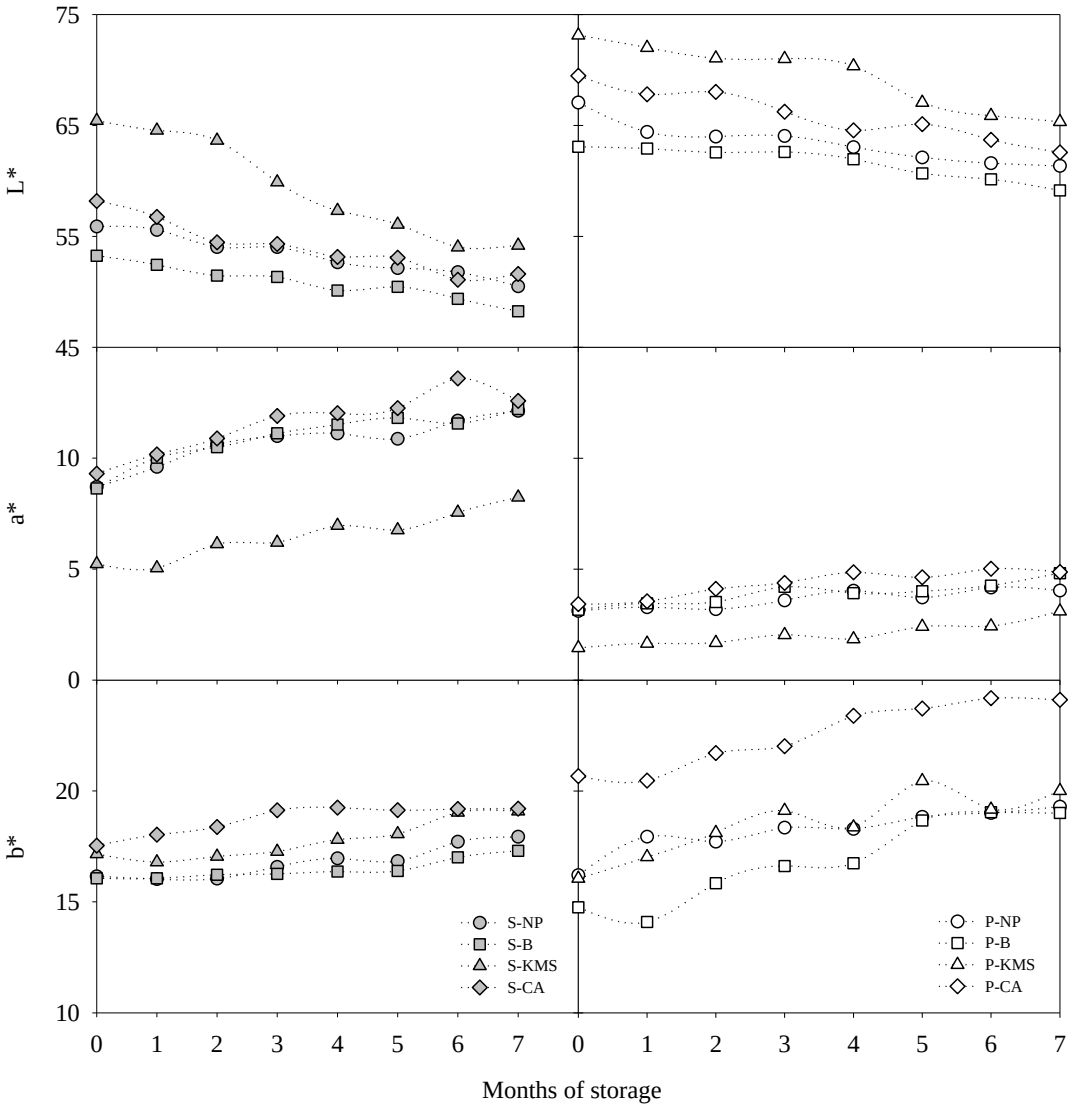

Fig. 4.4 Effect of treatments on colour of canned tender jackfruit during storage

treatments appeared to have higher b* values (yellowness) among other treatments during storage which may be due to the combined effects of acidification and thermal processing similar to that reported by Zareifard *et al.* (2015) in case of green beans. The variation in L* ($p = 9.17\times10^{-149}$), a* ($p = 4.01\times10^{-114}$) and b* ($p = 9.78\times10^{-83}$) values

was found to be significant based on the ANOVA results. The treatment-storage interaction was also found to have significant effect on L* ($p = 1.43\times10^{-38}$), a* ($p = 1.55\times10^{-5}$) and b* ($p = 6.42\times10^{-15}$) values (Table 4.6).

4.2.2 Firmness

Thermal processing brought about a decrease in F_s of canned tender jackfruit (irrespective of treatments) compared to that of fresh sample (F_s = 21.00 N). This can be attributed to tissue softening, degradation of pectin and starch gelatinization upon thermal processing (Rao and Lund, 1986; Alvarez *et al.*, 2001; Peng *et al.*, 2017). The mean F_s (across replicates) varied in the range 2.09–4.08 N and 5.46–11.55 N in case of sterilization and pasteurization treatments, respectively. The percent decrease (with respect to the fresh sample) was found to be the least in case of S-CA (80.59%) and P-CA (44.98%) while it was highest for S-B (90.06%) and P-B (73.99%) among sterilization and pasteurization treatments, respectively. The high F_s values noted in case of CA treatments compared to that of other preservatives may be linked to the effect of acidification (lower pH) on texture of vegetables (Andrés-Bello *et al.*, 2013; Zareifard *et al.*, 2015; Peng *et al.*, 2017). The pH of S-CA and P-CA treatments were 4.16 and 4.31, respectively and the firmness of plant tissues was reported to be maximum in the pH range of 4–4.5 with lower values outside this range (Doesburg, 1961). It was further endorsed by the findings of Ben-Shalom *et al.* (1992) (carrot) and Brandt *et al.* (1984) (beans, cauliflower, corn, peas and potatoes) in which the firmness of vegetables exhibited maximum values at pH of 4.4 and 4.0, respectively. All the other preservative treatments have pH above 4.5 (greater than the upper limit of the said range) which might have caused β-elimination reaction of pectin (base catalysed de-polymerization) resulting in low firmness values upon thermal processing (Andrés-Bello *et al.*, 2013). The ANOVA revealed a statistically significant ($p = 4.31\times10^{-93}$) difference in F_s among different treatments (Table 4.6). The result of Tukey Kramer test implied that the mean F_s of treatments vary significantly among one another except S-NP and S-KMS (Table 4.8).

During storage, F_s of thermal processed canned tender jackfruit exhibited a declining trend and the variation was found to be statistically significant ($p = 6.98\times10^{-9}$) based on the result of two factor ANOVA (Table 4.6 and Fig 4.5). The post hoc test revealed that there existed no significant difference in F_s value up to three months of storage while it

varied significantly thereafter with respect to that after thermal processing (Table 4.7). The percent decrease of F_s at the end of storage period (compared to that after thermal processing) was noted to be 17.84%. Similar finding was also reported in case of retort pouch processed ready to cook tender jackfruit (Praveena and Sudheer, 2015) and ready to eat tender jackfruit curry (Lakshmana *et al.*, 2013) stored for 3 and 12 months, respectively. The treatment-storage interaction was found to have no significant (p = 0.51) effect on F_s of thermal processed canned tender jackfruit (Table 4.6).

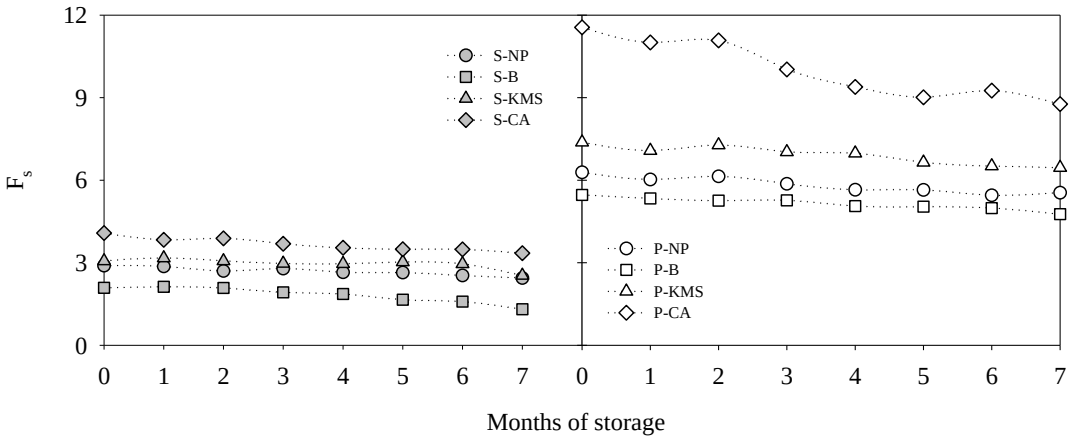

Fig. 4.5 Effect of treatments on skin firmness of canned tender jackfruit during storage

4.2.3 pH

The pH of canned tender jackfruit exhibited a decreasing pattern during the storage period irrespective of sterilization and pasteurization treatments (Fig. 4.6). The two factor ANOVA revealed that this variation in pH was found to be significantly different ($p = 9.01\times10^{-107}$) during storage (Table 4.6) as underlined with the results of Tukey-Kramer post hoc test (Table 4.7). Across different treatments, the pH decreased from 4.81 to 4.35 (S-NP), 4.64 to 4.21 (S-B), 4.72 to 4.31 (S-KMS), 4.16 to 3.56 (S-CA), 5.25 to 4.85 (P-NP), 5.01 to 4.73 (P-B), 5.21 to 4.83 (P-KMS), 4.31 to 3.68 (P-CA) over the storage period (Fig. 4.6). It may be noted that at some points during storage, the sterilization treatments accomplished a pH value less than the critical limit of 4.6 below which *Clostridium botulinum* do not survive, if present. Specifically, the pH of S-NP, S-B and S-KMS was found to be less than the limit after 5, 4 and 2 months of storage, respectively. In contrast, the pasteurization treatments (except P-CA) did not have low values than the limit during storage. The CA treatments namely S-CA and P-CA have pH less than the limit throughout the storage period. Among all the

sterilization and pasteurization treatments, the percent decrease in pH during storage was found to be the highest and lowest in case of P-CA (9.62%) and P-B (5.59%), respectively.

The pH was found to have a statistically significant difference ($p = 1.49\times10^{-162}$) across treatments (Table 4.6 and 4.8). In general, the pH of pasteurization treatments appeared to have higher values compared to the respective sterilization counterparts (Fig. 4.6 and Table 4.8). Among all the sterilization and pasteurization treatments, those with preservatives appeared to have low pH compared to those with no preservatives. This can be related to the increased activity coefficient of H^+ ions (Puolanne *et al.*, 2001; Sani *et al.*, 2019) and formation of sulphurous acid (Garcia-Fuentes *et al.*, 2015; Yousaf *et al.*, 2016) in case of brine (S-B and P-B) and KMS (S-KMS and P-KMS) treatments, respectively. The effect was prominent in case of CA treatments which have low pH values in the tune of 13.51 (sterilization) and 17.90% (pasteurization) as compared to that of no preservative counterparts at the beginning (Month 0) of the storage period. The corresponding percent decrease at the end of storage period was noted to be 18.16 and 24.12% in case of sterilization and pasteurization treatments, respectively. The two factor ANOVA also revealed that the interaction between treatments and storage period have significant ($p = 5.17\times10^{-44}$) effect on pH of canned tender jackfruit (Table 4.6).

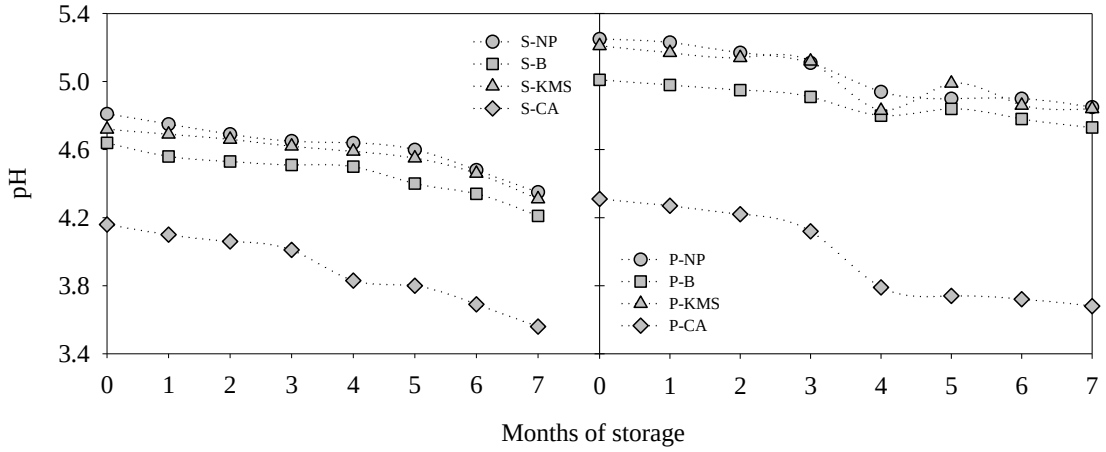

Fig. 4.6 Effect of treatments on pH of canned tender jackfruit during storage

4.2.4 Titrable acidity

The two factor ANOVA revealed that the TA of thermal processed canned tender jackfruit do not have significant variation ($p = 0.02$) during storage (Table 4.6). Similar

finding was reported in case of storage evaluation of onion paste for a period of 71 days (Ahmed and Shivhare, 2001). However, TA varied significantly across different treatments ($p = 1.48\times10^{-118}$). Also, the treatment-storage interaction was found to have significant ($p = 6.29\times10^{-09}$) effect on the TA values (Table 4.6).

As expected, those treatments with CA as preservative (S-CA and P-CA) were noted to have high values of TA compared to others (Fig. 4.7 and Table 4.6). The percent increase in the mean value of TA (across storage period) was computed to be 81.31 and 94.50% for S-CA and P-CA, respectively as compared to their non-preservative counterparts. This could be due to the presence of additional hydrogen ions contributed by CA. In contrast, the other preservative treatments namely, S-B, S-KMS (in case of sterilization) and P-B, P-KMS (in case of pasteurization) were found to be on par with that of non-preservative counterparts (Table 4.8). Also, as evident in Fig. 4.7 and Table 4.8 that the sterilization treatments have high mean values of TA as compared to that of pasteurization with same preservatives. This may be due to the utilization of citric acid during hydrolysis of polysaccharides and non-reducing sugars to hexose sugars upon the intensity of heat treatment (Dev *et al.*, 2006).

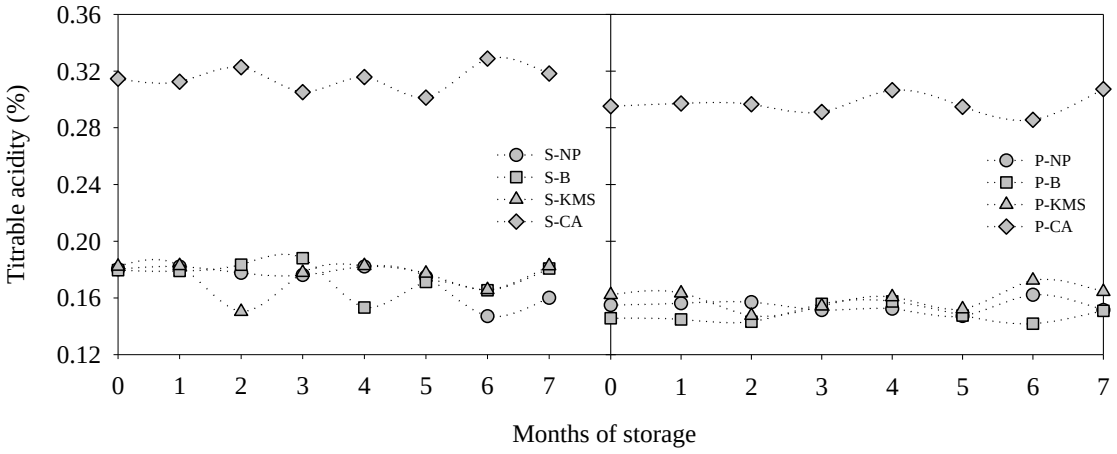

Fig. 4.7 Effect of treatments on titrable acidity of canned tender jackfruit during storage

4.2.5 Total soluble solids

Thermal processing has remarkably decreased the TSS of fresh tender jackfruit by about 20.4–49.0% (sterilization) and 26.5–53.1% (pasteurization). The mean TSS of triplicates of canned tender jackfruit subjected to different treatments were noted to be 2.6 (S-NP), 3.8 (S-B), 2.9 (S-KMS), 2.6 (S-CA), 2.4 (P-NP), 3.5 (P-B), 2.4 (P-KMS) and 2.6°Brix (P-CA) after canning (prior to storage). During storage, no significant

change (p = 0.08) in TSS values was noted as indicated by the result of two factor ANOVA (Table 4.6 and 4.7). These observations were similar to the findings of Adkison *et al.* (2018) in which they investigated the effect of thermal processing (93 to 96°C for 8 to 12 min) and storage evaluation (3 months) of commercially canned fresh apricots. Kaur and Aggarwal (2015) found no significant variation in TSS during 6 months storage of pasteurized (100°C for 20 min) tomato juice.

The TSS appeared to vary significantly ($p = 5.39\times10^{-78}$) across different treatments considered in this study (Table 4.6 and 4.8). The variation in TSS subjected to different treatments over the storage period is illustrated in Fig. 4.8. Among the sterilization and pasteurization treatments, those using brine as the canning medium, namely S-B (3.77°Brix) and P-B (3.62°Brix) appeared to have higher mean TSS value (across storage period) than others, respectively (Table 4.8). All the remaining sterilization treatments appeared to be on par while the pasteurization counterparts differ significantly with regard to TSS. It was noted that the interaction between treatment and storage period has no significant (p = 0.40) effect on TSS of canned tender jackfruit.

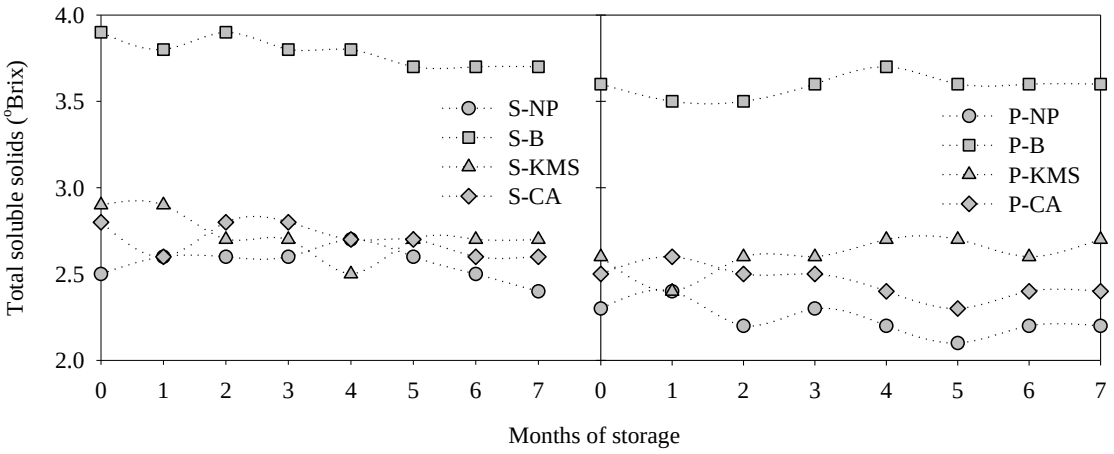

Fig. 4.8 Effect of treatments on total soluble solids of canned tender jackfruit during storage

4.2.6 Carbohydrate content

The CC of fresh tender jackfruit was estimated to be 22.26 mg/100 g (dry wt.). Thermal processing has resulted in its percent decrease (with respect to fresh sample) by about 6.89 (S-NP), 21.85 (S-B), 12.36 (S-KMS), 14.10 (S-CA), 9.23 (P-NP), 22.00 (P-B), 9.98 (P-KMS) and 14.62% (P-CA) in different treatments considered in this study. The decrease in CC upon thermal processing (blanching at 98°C for 2 min; sterilization at

116ºC for 25 min) was also reported by Martín-Belloso and Llanos-Barriobero, (2001). In their study on canned vegetables, white asparagus, mushroom and lentils in water solution retained CC in the tune of 79, 65 and 85%, respectively. The percent loss of CC obtained in our study (6.89–22%) was noted to be less compared to their study (15–35%). The decrease in CC may be associated with the effects of high temperature processing causing caramelization of sugars and Maillard reactions in addition to the possibility of its dissolution in water during washing and blanching (Martín-Belloso and Llanos-Barriobero, 2001; Belitz *et al.*, 2009).

During storage, no significant (p = 0.55) changes in CC were noted as evident with the result of two factor ANOVA (Table 4.6 and 4.7). Similar finding was also reported by Lakshmana *et al.* (2013) based on their 12 months of storage evaluation of tender jackfruit curry processed in retort pouches. A significant difference in CC existed among the treatments considered in this study (Table 4.6 and 4.8). The mean CC of brine treatments namely S-B and P-B were found to have low values among sterilization and pasteurization treatments, respectively (Table 4.8) throughout the storage period (Fig. 4.9). The mean CC of brine treatments (across storage) has 11.66% (S-B) and 10.21% (P-B) low values than those with no preservatives. The treatments with no preservatives and KMS appeared to have similar values while considering sterilization (S-NP and S-KMS) and pasteurization (P-NP and P-KMS) treatments separately (Table 4.8). The treatment-storage interaction was found to have no significant (p = 0.16) effect on CC of canned tender jackfruit (Table 4.6).

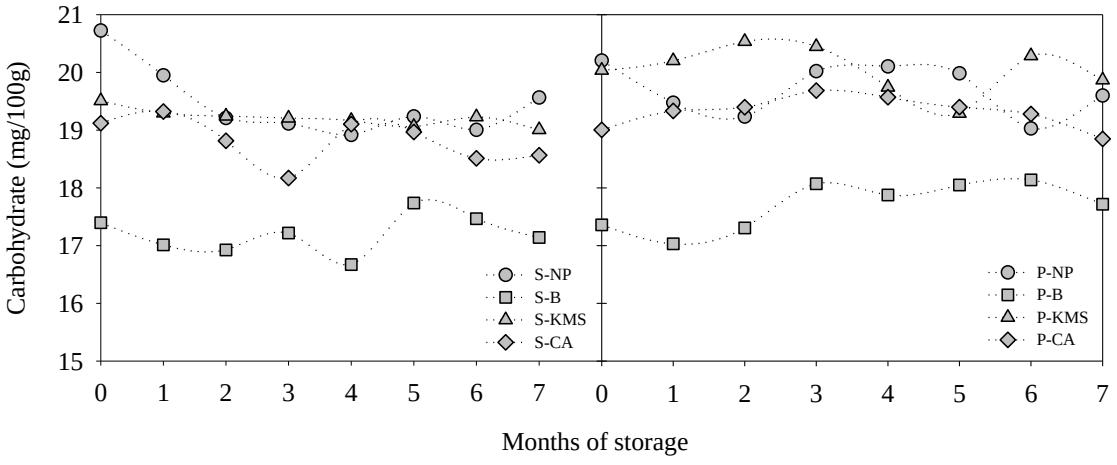

Fig. 4.9 Effect of treatments on carbohydrate content of canned tender jackfruit during storage

4.2.7 Crude fibre content

Thermal processing has resulted in an increase in CFC of canned tender jackfruit as compared to that of the fresh sample. The CFC of fresh sample was estimated to be 2.26% while that of samples subjected to sterilization and pasteurization treatments varied in the range 2.42–2.51 and 2.44–2.47%, respectively. The increase in CFC of canned tender jack fruit samples might be due to the effect of thermal processing (including blanching) on the release of cell-wall components. The bivalent ions may bound with pectins and remain indigested by the alkali treatment of the FDA method of CFC determination. A similar observation was also made by Sistrunk *et al.* (1958) in their study on canned beans stored at different temperatures.

The result of two factor AVONA revealed that CFC of canned tender jackfruit have no significant variation (p = 0.99) during storage (Table 4.6 and 4.7). Similar finding was also reported in case of retort pouch processed (temperature = 121^{o}C; F_0 = 6.0) tender jackfruit curry stored for 12 months (Lakshmana *et al.*, 2013). Saldana *et al.* (1979) also reported an insignificant variation in CFC during annual storage of canned beets and tomatoes. The statistical analysis also showed that the treatments (p = 0.06) and their interaction with storage period (p = 1.00) have no significant effect on CFC of canned tender jackfruit (Table 4.6 and 4.8).

4.2.8 Ascorbic acid

The mean value of AA appeared to have a slight decrease (across treatments) over the storage period (Fig. 4.10). The variation in AA can be considered significant over the storage period (p = 0.01) based on the result of two factor ANOVA (Table 4.6). However, the result of post hoc test revealed that the mean AA values were on par up to 6 months of storage after canning (Table 4.7). Thereafter, in the seventh month, the mean AA value declined by about 2.14% as compared to that of the initial month of storage. This indicate the strong AA retention behaviour (> 85%) of canned products (Kramer, 1982; Rickman *et al.*, 2007) as evident with the findings of some classical studies. For example, Marchesini *et al.* (1975) and Abou-Fadel and Miller (1983) observed no significant variation (p > 0.05) in AA values of canned green beans during ambient storage of 6 and 4 months, respectively. Similar result was also observed in a recent study which investigated the thermal processing effects on AA during three

months storage of fresh apricots (Adkison *et al.*, 2018). Also, Moschette *et al.* (1947) observed high retention of AA in canned orange juice (73–97%) and tomatoes (82–106%) during 12 months of storage under constant temperature and warehouse conditions. Elkins (1979) reported only 6% reduction in AA of canned beans only after 18 months of storage. The results of storage evaluation of AA obtained in this study are comparable with findings of the aforesaid investigations.

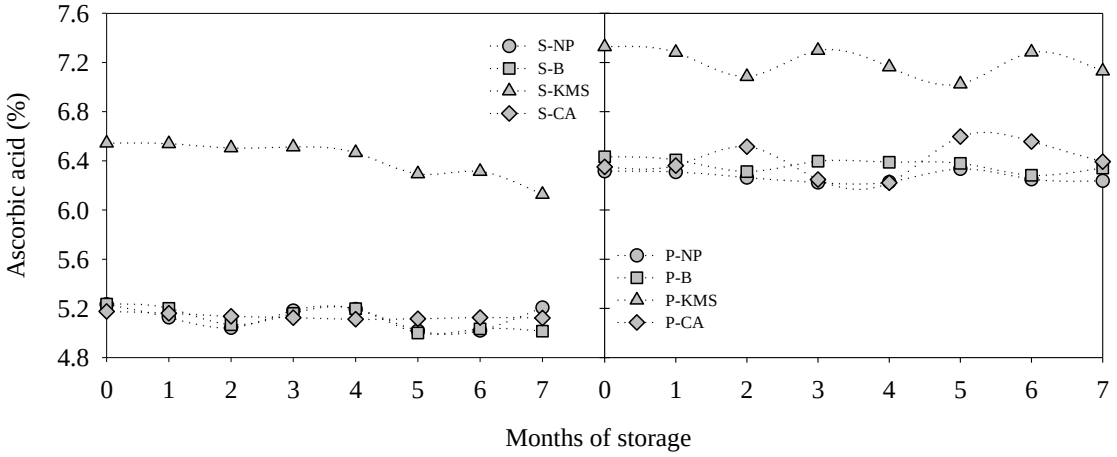

Fig. 4.10 Effect of treatments on ascorbic acid content of canned tender jackfruit during storage

The mean value of AA of thermal processed canned tender jackfruit after canning (prior to storage) was found to be lower than fresh sample (AA = 8.96 mg/100 g). In case of sterilization treatments, the percent decrease was noted to be 41.60 (S-NP), 41.57 (S-B), 26.97 (S-KMS) and 42.24 (S-CA). As expected, the pasteurization treatments were found to have better AA values than sterilization counterparts (Fig. 4.10) due to relatively mild thermal effects on AA degradation caused by the former category (Munyaka, *et al.*, 2010b; Wang *et al.*, 2018). The percent difference between the mean AA of pasteurization treatments and fresh sample were computed to be 29.52, 28.21, 18.22 and 29.13 in case of P-NP, P-B, P-KMS and P-CA, respectively. Among different preservative treatments, S-KMS and P-KMS have high AA content than others among sterilization and pasteurization categories, respectively. The high AA values in case of KMS based treatments may be related to its anti-oxidant effect causing more AA retention in the product (Dev *et al.*, 2006; Kaur and Aggarwal, 2015). The variation in AA values of treatments was found to be statistically significant (Table 4.6 and 4.8). Among all the treatments, the mean AA (across storage period) was found to be the statistically higher in case of P-KMS followed by P-CA and S-KMS while the lowest

was noted for S-B, although S-NP and S-CA were on par with it. The ANOVA also revealed the significant (p = 0.01) effect of treatment-storage interaction on AA values of canned tender jackfruit samples.

4.2.9 Total flavonoid and phenol contents

Thermal processing has resulted in an apparent increase in both TFC and TPC of canned tender jackfruit (irrespective of treatments) compared to that of fresh sample (TFC = 5.62 mg RE/g; TPC = 0.13 mg GAE/g). In case of TFC, the percent increment after canning (corresponding to Month 0 of storage) varied from 59.62 (S-CA) to 90.94% (S-KMS) and 46.49 (P-CA) to 74.91% (P-KMS) in case of sterilization and pasteurization treatments, respectively. In case of TPC, the lower and higher percent difference were noted for S-B & S-KMS and P-CA & P-KMS among sterilization and pasteurization treatments, respectively. The hike in TFC and TPC upon thermal processing could be related to several reasons; degradation of oxidative enzymes, release of bound constituents due to cell rupture, water solubility of phytonutrients upon thermal processing, formation of non-enzymatic browning products, among others (Dewanto *et al.*, 2002; Choi *et al.*, 2006; Adkison *et al.*, 2018; Ahmed and Eun, 2018).

During storage, a declining trend in the mean of both TFC and TPC values (across treatments) were noted as confirmed to be statistically significant (Table 4.6 and 4.7). The trend was also evident in case of individual treatments during storage as illustrated in Fig. 4.11. The percent decrease in TFC values of different treatments at the end of storage period with regard to that after canning (Month 0) was noted to be 28.40 (S-NP), 30.78 (S-B), 7.76 (S-KMS), 29.85 (S-CA), 20.48 (P-NP), 27.61 (P-B), 19.42 (P-KMS) and 28.87% (P-CA). Similarly, in case of TPC, the percent decrease noted in each treatment at the end of storage period was about 32.63 (S-NP), 30.77 (S-B), 90.71 (S-KMS), 31.69 (S-CA), 27.23 (P-NP), 30.53 (P-B), 76.64 (P-KMS) and 26.31% (P-CA). However, it may be noted that the level of both TFC and TPC at the end of storage period were noted to be still higher than that of fresh tender jackfruit (irrespective of treatments), owing to their increment during thermal processing. Similar observation was reported in case of canned peaches (Asami *et al.*, 2002) and cherries (Chaovanalikit and Wrolstad, 2004) stored for 3 and 5 months, respectively. The probable reason for the decline of TFC and TPC during storage could be the migration (leaching) of polyphenols from tender jackfruit into the canning medium (Huang *et al.*, 2016) as

endorsed by the findings of Chaovanalikit and Wrolstad (2004) and Hong *et al.* (2004). Although the canning medium of all the samples throughout the storage period was not assayed, the leaching of phytochemicals was verified by performing reference analyses for TFC and TPC of the canning medium of a limited number of randomly chosen containers at last two months of storage. The result of the analyses confirmed the presence of TFC and TPC in the canning medium and hence verified the hypothesis.

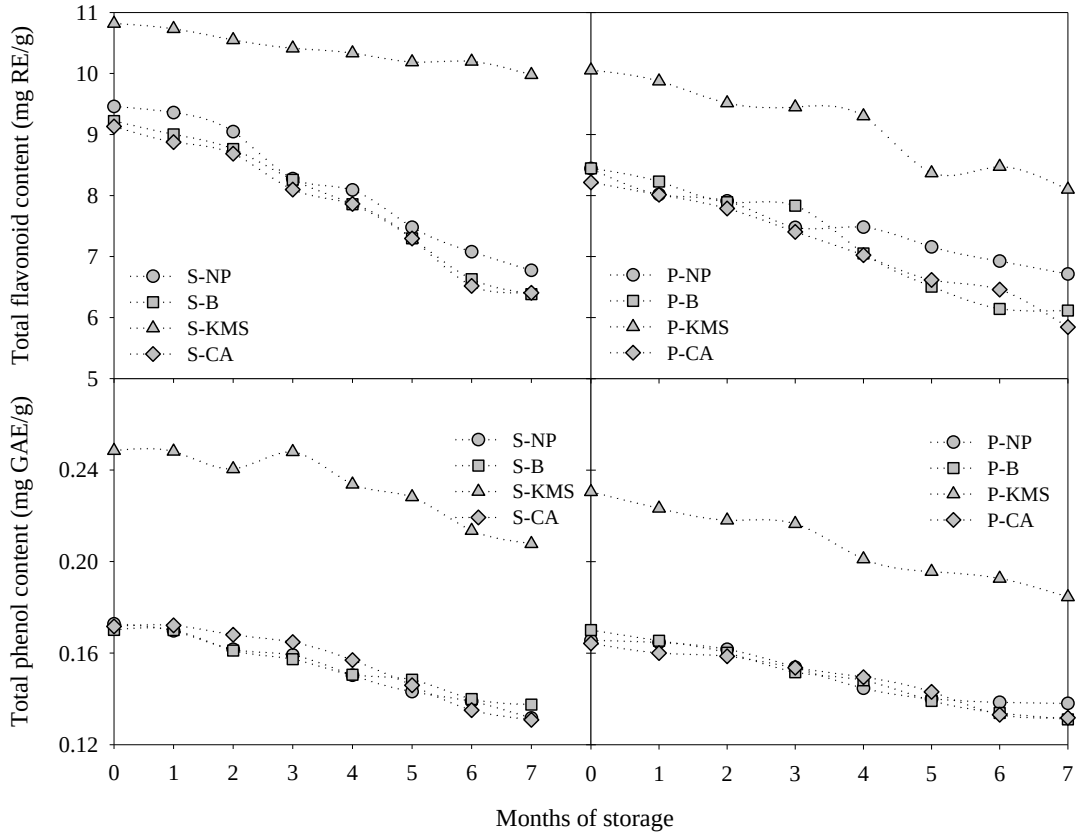

Fig. 4.11 Effect of treatments on total flavonoid and phenol contents of canned tender jackfruit during storage

The mean values of TFC ($p = 5.36\times10^{-86}$) and TPC ($p = 2.81\times10^{-207}$) replicates were found to be statistically significant at 5% significance level across the treatments considered in this study (Table 4.6 and 4.8). It was noted that the treatments namely S-KMS and P-KMS yielded high TFC and TPC values among others of sterilization and pasteurization categories which may be related to the antioxidant property of KMS. Among sterilization and pasteurization treatments, the mean TFC was found to be the lowest in case of S-CA and P-CA while it was noted for S-B and P-CA in case of TPC, respectively. The treatment-storage period interaction was found to have significant effect on both TFC ($p = 6.37\times10^{-11}$) and TPC ($p = 4.38\times10^{-62}$) values of thermal processed canned tender jackfruit (Table 4.6).

Table 4.6 Results of two factor analysis of variance of quality attributes of thermal processed canned tender jackfruit during storage

Attribute	Source	*SS*	*df*	*MS*	F^*	*p*
L*	Columns	918.97	7	131.28	546.33	4.48×10^{-92}
	Rows	7277.90	7	1039.70	4326.72	9.17×10^{-149}
	Interaction	213.45	49	4.36	18.13	1.43×10^{-38}
	Error	30.76	128	0.24	-	-
	Total	8441.07	191	-	-	-
a*	Columns	111.58	7	15.94	56.19	4.90×10^{-36}
	Rows	2444.12	7	349.16	1230.69	4.01×10^{-114}
	Interaction	31.25	49	0.64	2.25	1.55×10^{-5}
	Error	36.31	128	0.28	-	-
	Total	2623.26	191	-	-	-
b*	Columns	169.97	7	24.28	104.08	1.04×10^{-49}
	Rows	628.74	7	89.82	384.99	9.78×10^{-83}
	Interaction	62.48	49	1.28	5.47	6.42×10^{-15}
	Error	29.86	128	0.23	-	-
	Total	891.06	191	-	-	-
Firmness	Columns	19.02	7	2.72	8.88	6.98×10^{-09}
	Rows	1215.93	7	173.70	567.39	4.31×10^{-93}
	Interaction	14.77	49	0.30	0.98	0.51
	Error	39.19	128	0.31	-	-
	Total	1288.91	191	-	-	-
pH	Columns	4.26	7	0.61	940.25	9.01×10^{-107}
	Rows	32.28	7	4.61	7117.91	1.49×10^{-162}
	Interaction	0.73	49	0.01	22.85	5.17×10^{-44}
	Error	0.08	128	0.00	-	-
	Total	37.36	191	-	-	-
Titrable acidity	Columns	0.00	7	0.00	2.44	0.02
	Rows	0.74	7	0.11	1446.81	1.48×10^{-118}
	Interaction	0.01	49	0.00	3.53	6.29×10^{-09}
	Error	0.01	128	0.00	-	-
	Total	0.77	191	-	-	-
Total soluble solids	Columns	0.31	7	0.04	1.88	0.08
	Rows	52.30	7	7.47	321.63	5.39×10^{-78}
	Interaction	1.20	49	0.02	1.05	0.40
	Error	2.97	128	0.02	-	-
	Total	56.77	191	-	-	-

Table 4.6 continued

Attribute	Source	*SS*	*df*	*MS*	F^*	*p*
Carbohydrate content	Columns	2.40	7	0.34	0.71	0.67
	Rows	348.94	7	49.85	103.04	1.78×10^{-49}
	Interaction	24.46	49	0.50	1.03	0.43
	Error	61.92	128	0.48	-	-
	Total	437.71	191	-	-	-
Crude fibre content	Columns	0.01	7	0.00	0.19	0.99
	Rows	0.09	7	0.01	1.97	0.06
	Interaction	0.15	49	0.00	0.45	1.00
	Error	0.88	128	0.01	-	-
	Total	1.14	191	-	-	-
Ascorbic acid	Columns	0.30	7	0.04	2.70	0.01
	Rows	102.70	7	14.67	923.30	2.82×10^{-106}
	Interaction	1.32	49	0.03	1.69	0.01
	Error	2.03	128	0.02	-	-
	Total	106.36	191	-	-	-
Total flavonoid content	Columns	109.72	7	15.67	239.50	2.50×10^{-70}
	Rows	199.41	7	28.49	435.28	5.36×10^{-86}
	Interaction	13.29	49	0.27	4.14	6.37×10^{-11}
	Error	8.38	128	0.07	-	-
	Total	330.80	191	-	-	-
Total phenol content	Columns	0.03	7	0.00	6770.89	3.62×10^{-161}
	Rows	0.18	7	0.03	35653.91	2.81×10^{-207}
	Interaction	0.00	49	0.00	47.14	4.38×10^{-62}
	Error	0.00	128	0.00	-	-
	Total	0.21	191	-	-	-

SS: sum of squares; *df*: degree of freedom; *MS*: mean squares; F^*:*F*-statistic; *p*: probability

Table 4.7 Mean value of quality attributes of canned tender jackfruit samples across different preservative treatments during storage

Storage (month)	L*	a*	b*	Firmness (N)	pH	Titrable acidity (%)
0	63.19 ± 6.63^{a}	5.38 ± 2.99^{e}	16.83 ± 1.77^{e}	5.35 ± 2.97^{a}	4.77 ± 0.38^{a}	0.20 ± 0.06
1	62.06 ± 6.34^{b}	5.85 ± 3.36^{d}	17.06 ± 1.81^{e}	5.18 ± 2.81^{ab}	4.72 ± 0.39^{b}	0.20 ± 0.06
2	61.15 ± 6.78^{c}	6.33 ± 3.66^{c}	17.64 ± 1.87^{d}	5.19 ± 2.87^{ab}	4.68 ± 0.39^{c}	0.20 ± 0.07
3	60.43 ± 6.52^{d}	6.80 ± 3.77^{b}	18.17 ± 1.86^{c}	4.95 ± 2.63^{ab}	4.63 ± 0.4^{d}	0.20 ± 0.06
4	59.14 ± 6.68^{e}	7.03 ± 3.86^{b}	18.40 ± 2.19^{c}	4.76 ± 2.48^{b}	4.50 ± 0.43^{e}	0.20 ± 0.07
5	58.34 ± 6.00^{f}	7.06 ± 3.87^{b}	19.01 ± 2.23^{b}	4.64 ± 2.37^{b}	4.49 ± 0.46^{f}	0.20 ± 0.06
6	57.19 ± 6.10^{g}	7.54 ± 4.05^{a}	19.29 ± 2.08^{ab}	4.60 ± 2.42^{b}	4.41 ± 0.46^{g}	0.20 ± 0.07
7	56.62 ± 6.04^{h}	7.75 ± 3.89^{a}	19.49 ± 1.98^{a}	4.40 ± 2.39^{b}	4.32 ± 0.48^{h}	0.20 ± 0.07
Storage (month)	Total soluble solids (^{o}Brix)	Carbohydrate content (mg/100g)	Crude fibre content (%)	Ascorbic acid (mg/100g)	Total flavonoid content (mg RE/g)	Total phenol content (mg GAE/g)
0	2.88 ± 0.57	19.93 ± 1.66	2.47 ± 0.08	6.08 ± 0.76^{a}	9.22 ± 0.87	0.19 ± 0.03
1	2.85 ± 0.52	19.72 ± 1.68	2.47 ± 0.08	6.05 ± 0.77^{ab}	9.01 ± 0.93	0.18 ± 0.03
2	2.85 ± 0.56	19.59 ± 1.67	2.47 ± 0.08	5.99 ± 0.77^{ab}	8.77 ± 0.95	0.18 ± 0.03
3	2.86 ± 0.54	19.76 ± 1.59	2.48 ± 0.08	6.02 ± 0.76^{ab}	8.40 ± 0.99	0.18 ± 0.03
4	2.84 ± 0.58	19.66 ± 1.64	2.48 ± 0.08	6.00 ± 0.72^{ab}	8.12 ± 1.12	0.17 ± 0.03
5	2.78 ± 0.57	19.73 ± 1.29	2.47 ± 0.08	5.97 ± 0.77^{ab}	7.61 ± 1.14	0.16 ± 0.03
6	2.78 ± 0.54	19.63 ± 1.34	2.48 ± 0.08	5.98 ± 0.80^{ab}	7.30 ± 1.33	0.15 ± 0.03
7	2.78 ± 0.55	19.55 ± 1.38	2.46 ± 0.07	5.95 ± 0.72^{b}	7.04 ± 1.33	0.15 ± 0.03

Attribute values are mean ± standard deviation across preservative treatments. Superscripts under each attribute represents their significant difference ($p < 0.05$) during storage based on two factor Analysis of Variance and Tukey-Kramer test. No superscripts are provided if the mean attribute value do not statistically change with storage.

Table 4.8 Mean value of quality attributes of canned tender jackfruit samples during storage across different preservative treatments

Treatment	L*	a*	b*	Firmness (N)	pH	Titrable acidity (%)
S-NP	53.32 ± 1.89^{g}	10.72 ± 1.1^{b}	16.78 ± 0.73^{d}	2.69 ± 0.16^{f}	4.63 ± 0.15^{c}	0.17 ± 0.01^{c}
S-B	50.83 ± 1.63^{h}	10.92 ± 1.16^{b}	16.46 ± 0.45^{d}	1.83 ± 0.29^{g}	4.46 ± 0.14^{e}	0.18 ± 0.01^{c}
S-KMS	59.39 ± 4.67^{e}	6.52 ± 1.09^{c}	17.78 ± 0.89^{c}	2.97 ± 0.19^{f}	4.58 ± 0.14^{d}	0.18 ± 0.01^{c}
S-CA	54.08 ± 2.42^{f}	11.59 ± 1.39^{a}	18.73 ± 0.66^{b}	3.67 ± 0.25^{e}	3.91 ± 0.21^{g}	0.31 ± 0.01^{a}
P-NP	63.45 ± 1.87^{c}	3.64 ± 0.41^{e}	18.21 ± 0.97^{c}	5.83 ± 0.3^{c}	5.05 ± 0.16^{a}	0.15 ± 0.00^{de}
P-NB	61.63 ± 1.46^{d}	$3.92 \pm 0.53d^{e}$	16.85 ± 1.92^{d}	5.15 ± 0.22^{d}	4.89 ± 0.10^{b}	0.15 ± 0.01^{e}
P-KMS	69.48 ± 2.96^{a}	2.08 ± 0.54^{f}	18.54 ± 1.48^{bc}	6.92 ± 0.34^{b}	5.03 ± 0.15^{a}	0.16 ± 0.01^{d}
P-CA	65.93 ± 2.37^{b}	4.35 ± 0.61^{d}	22.53 ± 1.51^{a}	10.01 ± 1.07^{a}	3.98 ± 0.27^{f}	0.30 ± 0.01^{b}
Treatment	Total soluble solids (^{o}Brix)	Carbohydrate content (mg/100g)	Crude fibre content (%)	Ascorbic acid (mg/100g)	Total flavonoid content (mg RE/g)	Total phenol content (mg GAE/g)
S-NP	2.59 ± 0.10^{c}	19.46 ± 0.61^{b}	2.47 ± 0.02^{ab}	5.13 ± 0.09^{d}	8.19 ± 1.03^{c}	0.15 ± 0.01^{e}
S-B	3.78 ± 0.10^{a}	17.2 ± 0.34^{d}	2.44 ± 0.04^{b}	5.11 ± 0.09^{d}	7.93 ± 1.08^{d}	0.15 ± 0.01^{d}
S-KMS	2.71 ± 0.11^{c}	19.21 ± 0.15^{bc}	2.49 ± 0.04^{ab}	6.41 ± 0.15^{b}	10.40 ± 0.29^{a}	0.23 ± 0.02^{a}
S-CA	2.67 ± 0.09^{c}	18.82 ± 0.38^{c}	2.47 ± 0.03^{ab}	5.13 ± 0.02^{d}	7.86 ± 1.04^{d}	0.16 ± 0.02^{c}
P-NP	2.23 ± 0.10^{e}	19.71 ± 0.44^{ab}	2.48 ± 0.03^{ab}	6.27 ± 0.04^{c}	7.51 ± 0.58^{e}	0.15 ± 0.01^{f}
P-NB	3.62 ± 0.06^{b}	17.69 ± 0.41^{d}	2.48 ± 0.03^{ab}	6.37 ± 0.05^{bc}	7.28 ± 0.94^{f}	0.15 ± 0.01^{g}
P-KMS	2.59 ± 0.08^{c}	20.05 ± 0.41^{a}	2.52 ± 0.02^{a}	7.20 ± 0.11^{a}	9.14 ± 0.73^{b}	0.21 ± 0.02^{b}
P-CA	2.45 ± 0.10^{d}	19.31 ± 0.28^{bc}	2.46 ± 0.03^{ab}	6.41 ± 0.14^{b}	7.17 ± 0.83^{f}	0.15 ± 0.01^{g}

Attribute values are mean ± standard deviation across preservative treatments. Superscripts under each attribute represents their significant difference ($p < 0.05$) during storage based on two factor Analysis of Variance and Tukey-Kramer test. No superscripts are provided if the mean attribute value do not statistically change with storage.

4.2.10 Microbiological analysis

The results of microbiological analyses of thermal processed canned tender jackfruit samples during 8 months storage revealed no microbial growth in any of the treatments considered in this study. Hence, all the thermal processing treatments (irrespective of sterilization, pasteurization and preservatives) can be regarded as microbiologically safe. Evidently, the petri plates with culture medium (10^{-1} dilution) used for plate count after 8 months of storage showed zero microbial load (bacteria, fungus and yeast) as can be seen in Plate E2 and E3 of Appendix E. Although the analysis was triplicated in both 10^{-1} and 10^{-2} dilutions, the petri plates of only one replication of the former dilution are shown as the result remained invariable in others. There exist no ambiguity in the result of this study as thermal processed canned vegetables and curry are generally known to be microbiologically safe for about 1-2 years (Elkins, 1979; Saldana *et al.*, 1979; Barrett and Lloyd, 2012; Lakshmana *et al.*, 2013; Pritty and Sudheer, 2020).

4.2.11 Sensory evaluation

Figure 4.12 illustrates the mean score (white bars) and rank corrected for ties (grey bars) of organoleptic traits of canned tender jackfruit subjected to different storage treatments (Plate F1 of Appendix F). Results of statistical analysis of sensory scores are also included in the figure. Both the mean score and rank values were found to have similar pattern, although the latter were of lower magnitude due to tie correction. The $p < \alpha$ noted in case of all the organoleptic traits allowed us to reject the H_0 despite low W values. In other words, there existed some level of agreement between the judges. With regard to appearance of canned tender jackfruit, S-CA and P-KMS have gained better scores/rank among other sterilization and pasteurization treatments, respectively. The CA treatments namely, S-CA and P-CA yielded high mean rank values with respect to the colour of samples. However, the brine treatments S-B and P-B outperformed others with respect to all the other organoleptic traits in both sterilization and pasteurization cases, respectively. The best (which obtained high mean rank) sterilization treatments were found to be inferior to that of pasteurization. The percent difference in mean rank values between best sterilization and pasteurization treatments across organoleptic traits were noted to be 18.54 (appearance), 7.91 (colour), 1.09 (flavour), 2.23 (odour), 4.10 (taste), 11.72 (texture) and 3.84% (overall acceptability).

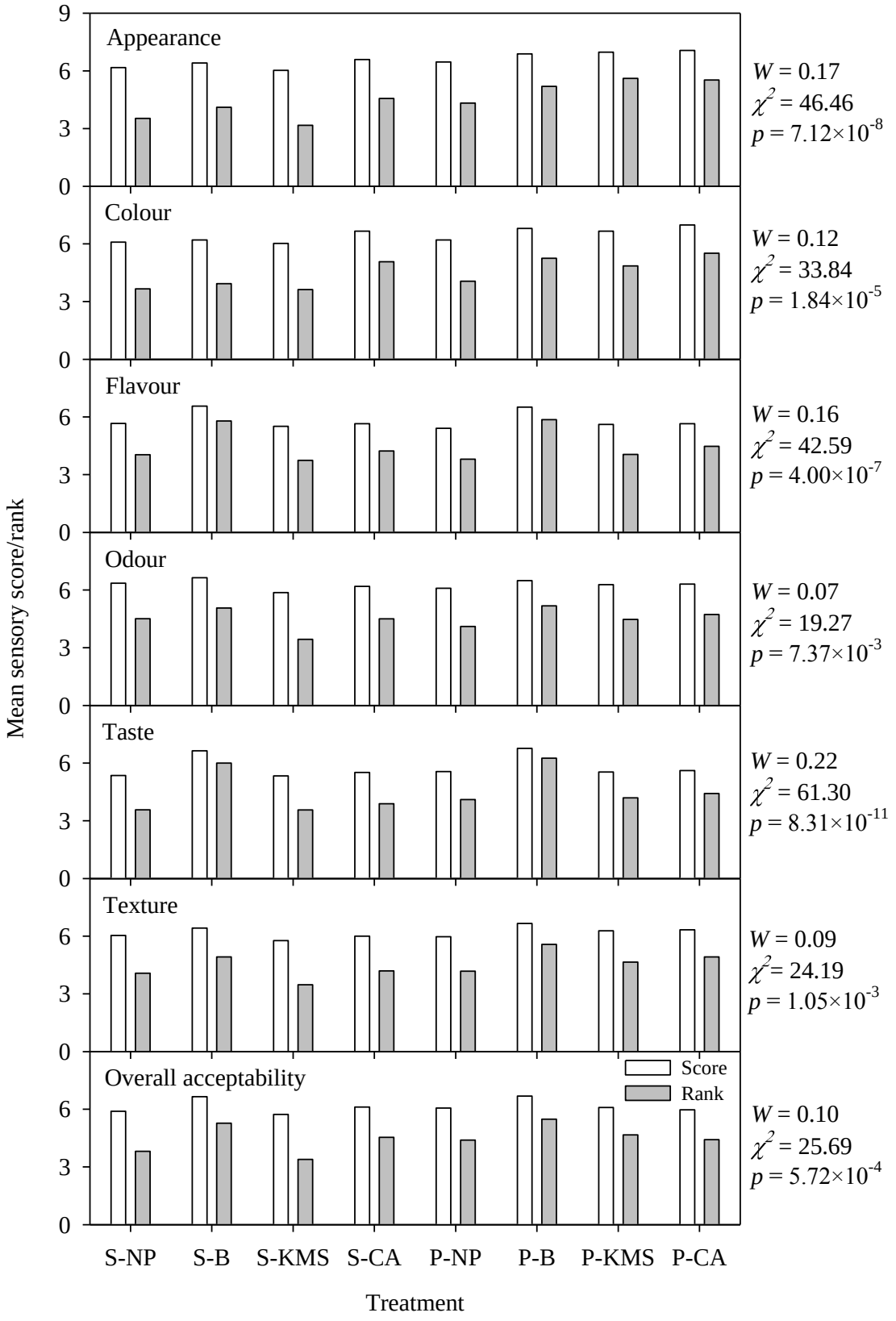

Fig. 4.12 Mean scores and ties corrected ranks of organoleptic traits of canned tender jackfruit subjected to different treatments. *W*: Kendall's coefficient of concordance; χ^2: chi square test statistic; *p*: probability value; S: sterilization; P: pasteurization; NP: no preservative; B: brine; KMS: potassium metabisulphite; CA: citric acid.

In case of canned and fresh tender jackfruit curry (Plate F2 of Appendix F), some level of agreement ($p < \alpha$) existed among judges on their scores on organoleptic traits (Fig. 4.13). The sterilization treatments which yielded the highest mean rank for different organoleptic traits were S-CA (appearance, colour and odour), S-KMS (flavour, taste and overall acceptability) and S-NP (texture). Similarly, P-CA (appearance, flavour, texture and overall acceptability) and P-NP (colour, odour and taste) were found to have high mean rank values among pasteurization treatments. The mean rank of best sterilization treatments were less than pasteurization counterparts (Pritty and Sudheer, 2020) and their percent difference (across organoleptic traits) was computed to be 14.61 (appearance), 14.02 (colour), 18.47 (flavour), 20.08 (odour), 0.66 (taste), 1.10 (texture) and 18.61% (overall acceptability). Interestingly, it was observed that all the best pasteurized treatments (across organoleptic traits) managed to have higher mean rank than fresh tender jackfruit curry (Fig. 4.13). The observation remained consistent for all the organoleptic traits (except appearance and overall acceptability) of curry made of sterilized tender jackfruit as well. This may be attributed to the conjunctive effects of thermal processing (together with blanching) including enzyme inactivation (prevent enzymatic browning, remove harsh flavour, colour retention) and texture modification in a way more pleasing to the consumers. From the sensory analysis results, it may also be implied that the curry based on thermal processed canned tender jackfruit have more consumer preference than that of fresh tender jackfruit.

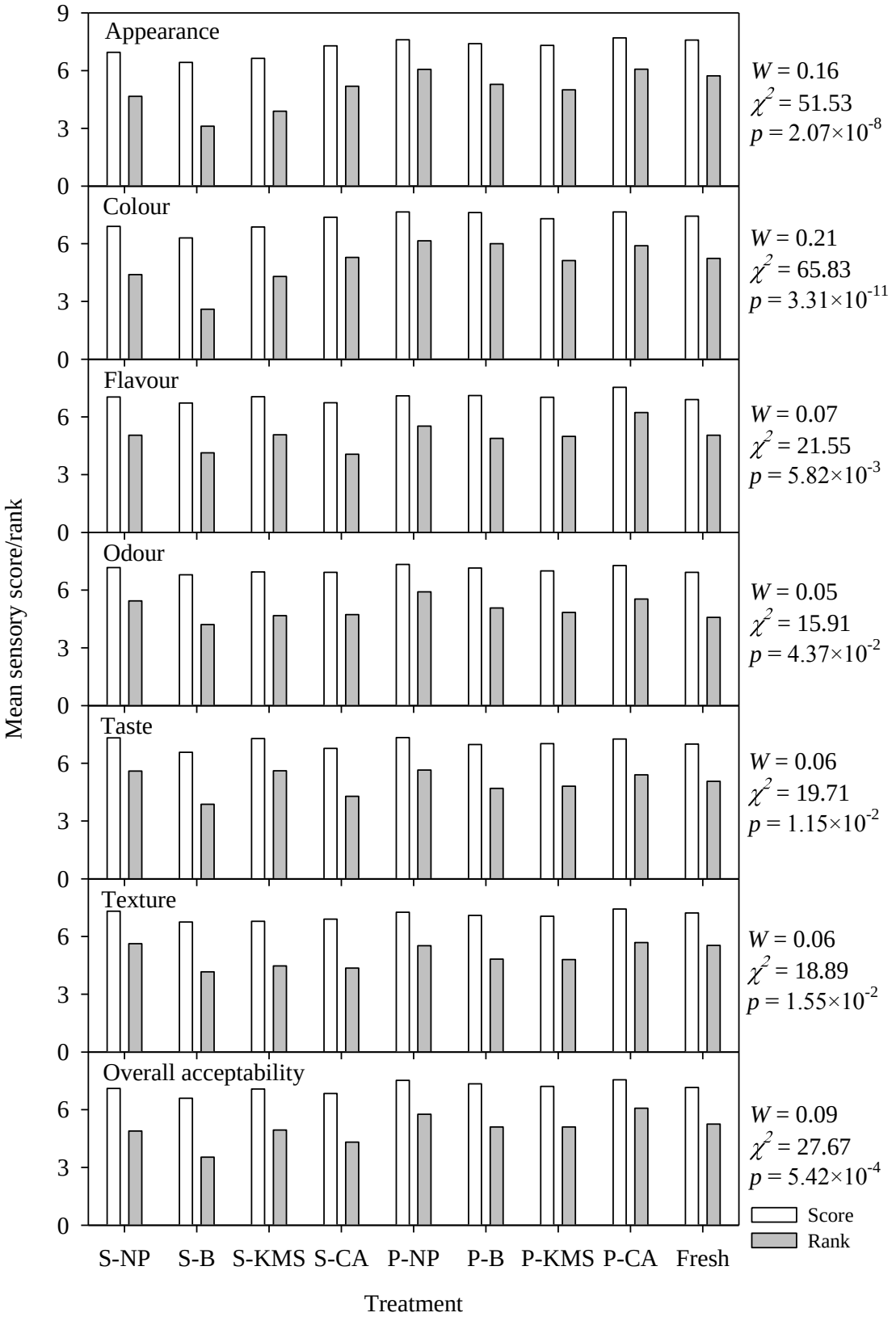

Fig. 4.13 Mean scores and ties corrected ranks of organoleptic traits of curry made from canned tender jackfruit subjected to different treatments. *W*: Kendall's coefficient of concordance; χ^2: chi square test statistic; *p*: probability value; S: sterilization; P: pasteurization; NP: no preservative; B: brine; KMS: potassium metabisulphite; CA: citric acid.

4.2.12 Cost estimation

The cost of production of thermally processed tender jackfruit per TFS can was estimated to be Rs. 25.45 with assumption of one working shift of 8 h duration in a day for a period of 150 days (assumed duration of raw tender jackfruit availability in Kerala). If the number of working shifts of the same duration increases to two, the cost of production decreases to Rs. 23.23 (Appendix G). The estimated annual profit for different assumed selling prices (excluding costs related to transport, storage and taxes) together with the minimum number of cans to be produced per year at which total revenue equals production cost (breakeven point) are shown in Fig. 4.14.

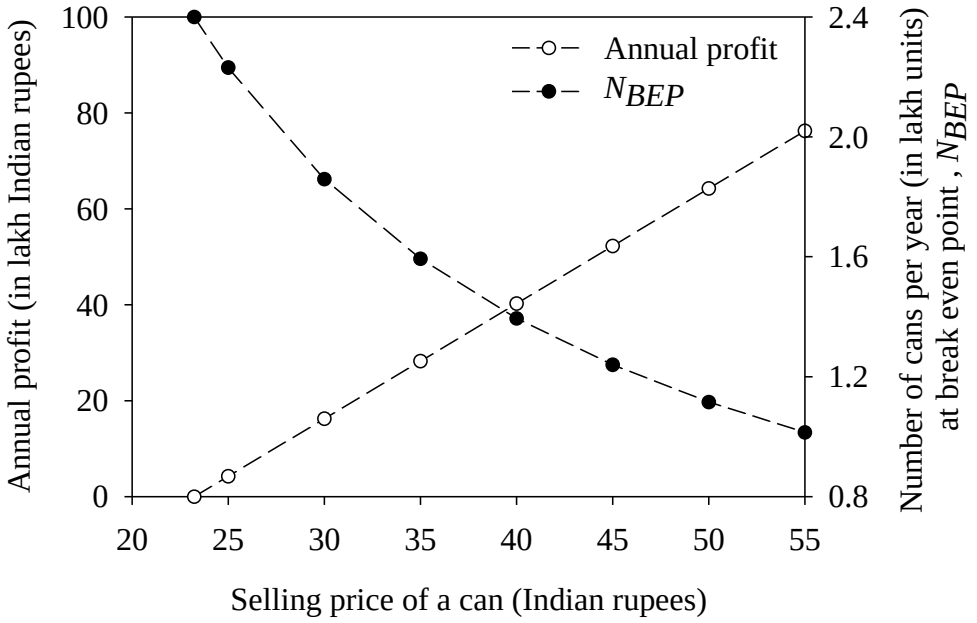

Fig. 4.14 Estimated annual profit and number of cans to be produced at breakeven point for different selling prices of thermal processed tender jackfruit units

4.3 QUALITY ASSESSMENT OF FRESH TENDER JACKFRUIT USING NEAR INFRARED REFLECTANCE SPECTROSCOPY

4.3.1 Descriptive statistics of quality attributes of fresh tender jackfruit

To ensure high variability in the database, tender jackfruit samples (about 50-70 days of maturity) were collected from different geographical locations irrespective of their variety (soft or hard) and other physical attributes. The length, diameter, geometric mean diameter, and sphericity of samples vary in the range 11.40–27.60 cm, 4.93–11.87 cm, 8.36–15.32 cm, 0.33–0.80 (unit less) respectively (Table B1 of Appendix B). The descriptive statistics of chemical and textural attributes of tender jackfruit examined in the study are given in Table 4.9.

Table 4.9 Descriptive statistics of quality attributes of fresh tender jackfruit samples (Set-1; n = 58)

Attribute (unit)	Range	Mean	CV†
pH	5.13 – 6.37	5.79	3.79
TSS (^{o}Brix)	3.70 – 8.00	5.06	16.84
TA (%)	0.13 – 0.51	0.22	42.55
L*	27.43 – 42.80	32.70	12.09
a*	12.11 – 17.21	14.97	8.20
b*	17.73 – 23.12	21.22	6.65
F_c (N)	5.52 – 12.41	8.25	18.86
F_t (N)	1.69 – 8.33	4.30	35.72
F_s (N)	8.35 – 15.15	10.75	13.73
T_c (N.s)	16.67 – 36.25	25.51	19.66
T_t (N.s)	3.87 – 20.69	10.42	42.24
T_s (N.s)	22.17 – 42.06	31.36	12.72

†Coefficient of variation in percentage

The pH value represents low acidic nature of tender jackfruit while TA represent an estimate of its citric acid content. The TSS content being a proxy of sugar content, its low values noted for tender jackfruit samples in this study against that of mature jackfruit (19.03–32.53°Brix) reported by Shamsudin *et al.*(2009) may be ascribed to non-conversion of starch to sugars. Both the textural components appeared to be higher in the skin portion followed by core and tendril. Among these attributes, pH and

TA has low (3.79%) and high (42.55%) values of coefficient of variability, respectively. The variability of attribute values observed in this study was similar to that reported for NIRS analysis of fruits and vegetables (De Oliveira *et al.*, 2014; Maniwara *et al.*, 2014).

4.3.2 Spectral characteristics of fresh tender jackfruit

Figure 4.15 depicts the mean spectrum of fresh tender jackfruit samples examined in this study. Typically, spectral features in the NIRS operational wavelength domain are broad due to overlapping of complex absorption patterns allied with the overtones and combinations of spectrally active functional groups. This is evident in case of spectrum of fresh tender jackfruit as noted in this study (Fig. 4.15). It consists of broad and distinct characteristic absorptions around 970, 1200, 1450 and 1930 nm. The absorption around 970 nm may be associated with second overtone of water while that around 1200 nm may have been caused due to C–H stretching vibration (Fu and Ying, 2016) related to cellulose. The spectral characteristics around 1400–1450 nm band may be linked with the first overtone of water and may also be related to sucrose (Cen and He, 2007). The broad absorption around 1930 may be indicative of combination mode related to water (Fu and Ying, 2016). Apart from these features, small absorptions around 670 and 1790 nm were also noted which may be attributed to chlorophyll-a (Yang *et al.*, 2011) and fructose content of tender jackfruit, respectively.

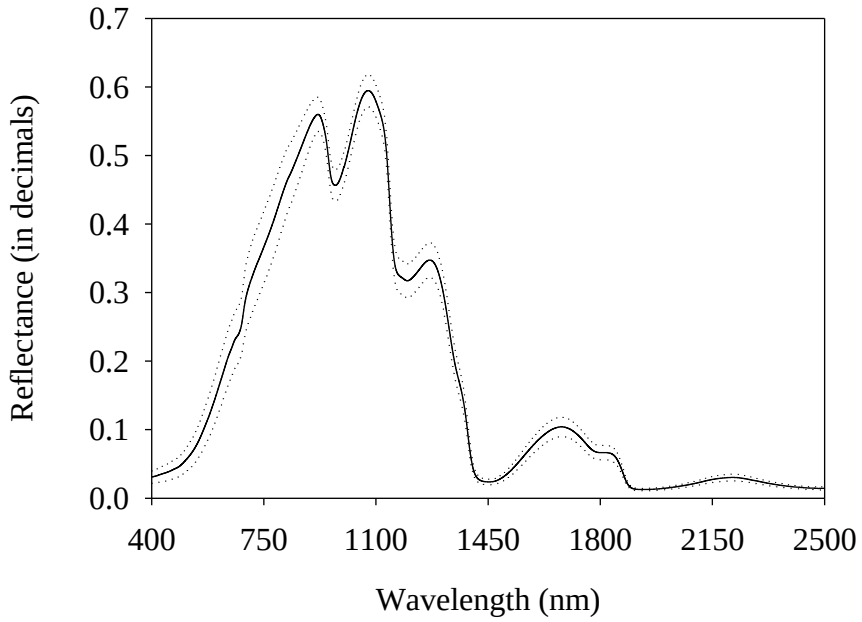

Fig. 4.15 Mean spectral reflectance of fresh tender jackfruit samples (dotted lines represent standard deviation of reflectance spectra)

4.3.3 Selection of best wavelength range and pre-processing combination

The study implemented PLSR algorithm to establish linkage (calibration function or regression model) between pre-processed spectra (average values are shown in Fig. H1 and H2 of Appendix H) and quality attributes of tender jackfruit. Initially, PLSR models of quality attributes were built with different combinations of wavelength range and spectral pre-processing methods (Section 3.4.3). The wavelength range included, visible (VIS, 401–700 nm), near-infrared (NIR, 701–1000 nm), shortwave infrared (SWIR, 1001–2450 nm), VIS–NIR (401–1000 nm), NIR–SWIR (701–2450 nm) and VIS–NIR–SWIR (401–2450 nm). The regression statistics of cross-validation of the PLSR models in terms of R^2, RMSE and RPD varied drastically across different wavelength range and spectral pre-processing combinations (Table H1 of Appendix H). Among them, the selection of best wavelength range and pre-processing combination was based on AIC statistic of associated PLSR models. The ability of AIC to account for both accuracy and complexity together while measuring information loss of statistical model justified its use as a criteria for model selection. High AIC values indicate large information loss and hence poor statistical models. On the other hand, low AIC values denotes good statistical models with less information loss. Thus, minimum AIC was used to identify the best wavelength range and spectral pre-processing combination in two steps. In the first step, the best pre-processing with minimum AIC value was identified for each wavelength range as shown in Fig. 4.16 (case of TA) as an illustrative example. In the figure, it may be noted that $A^*+MSC+SD$ has minimum AIC value among other spectral pre-processing methods when used in conjunction with VIS and VIS-NIR wavelength ranges while R^*+SD appeared to be the best in case of other wavelength ranges. Similarly, best pre-processing for each wavelength region of all the attributes were examined. In the next step, AIC value of the PLSR models with best spectral pre-processing (as identified in the first step) were compared across different wavelength ranges. Among them, the PLSR model with lowest AIC value was chosen as the best among the set of wavelength range and spectral pre-processing combinations considered in this study.

Figure 4.17 (colour and chemical attributes) and 4.18 (textural attributes) depicts the AIC value of PLSR models subjected to best spectral pre-processing (as identified in the first step) across different wavelength ranges of all the attributes examined in this

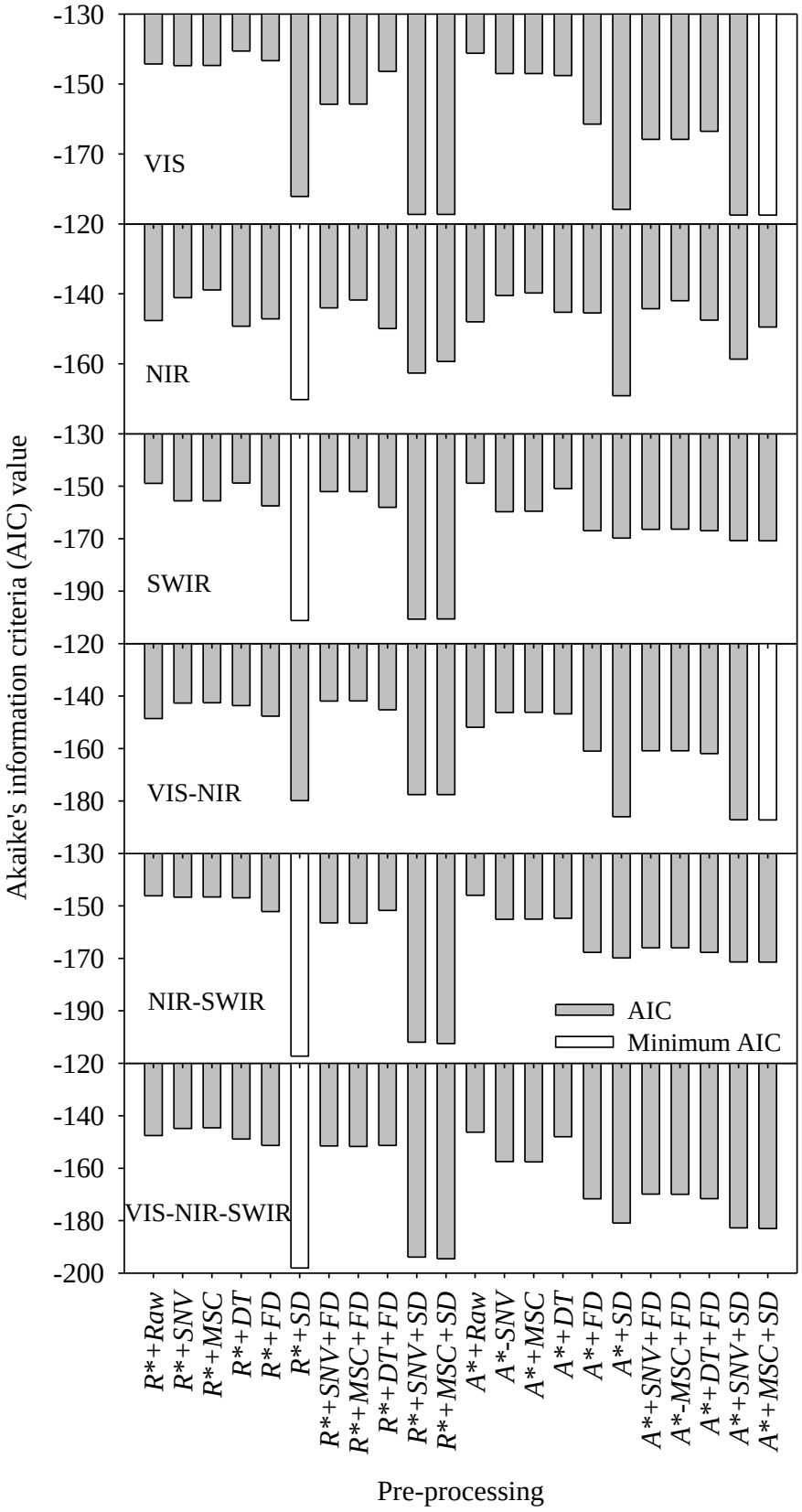

Fig. 4.16 Selection of best pre-processing based on Akaike's Information Criteria (AIC) in case of titrable acidity of tender jackfruit samples. VIS: visible; NIR: near infrared; SWIR: shortwave infrared; *R**: reflectance; *A**: absorbance; *SNV*: standard normal variate; *MSC*: multiplicative scatter correction; *DT*: de-trend; *FD*: first derivative; *SD*: second derivative

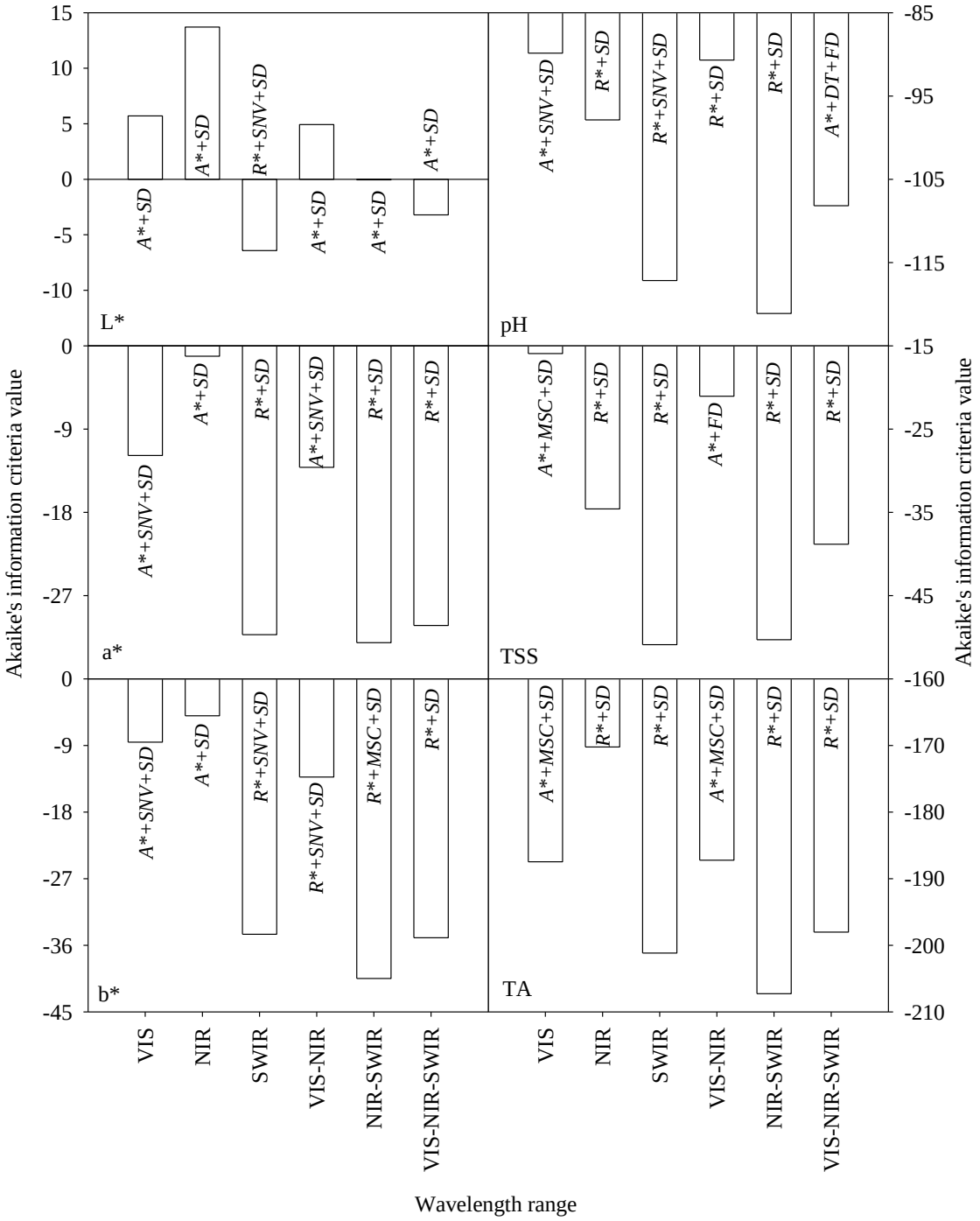

Fig. 4.17 Selection of best wavelength range and spectral pre-processing combination for colour and chemical compositional attributes of tender jackfruit samples. *R**: reflectance; *A**: absorbance; *SNV*: standard normal variate; *MSC*: multiplicative scatter correction; *DT*: de-trend; *FD*: first derivative; *SD*: second derivative; VIS: visible; NIR: near infrared; SWIR: shortwave infrared.

study. Among the different wavelength regions examined, PLSR models developed using NIR-SWIR were found to have low AIC value for most of the attributes (9 out of 12 cases) and hence regarded as the best for fresh tender jackfruit analyses. The exceptions included TSS, F_t and L* for which SWIR appeared to be more relevant based

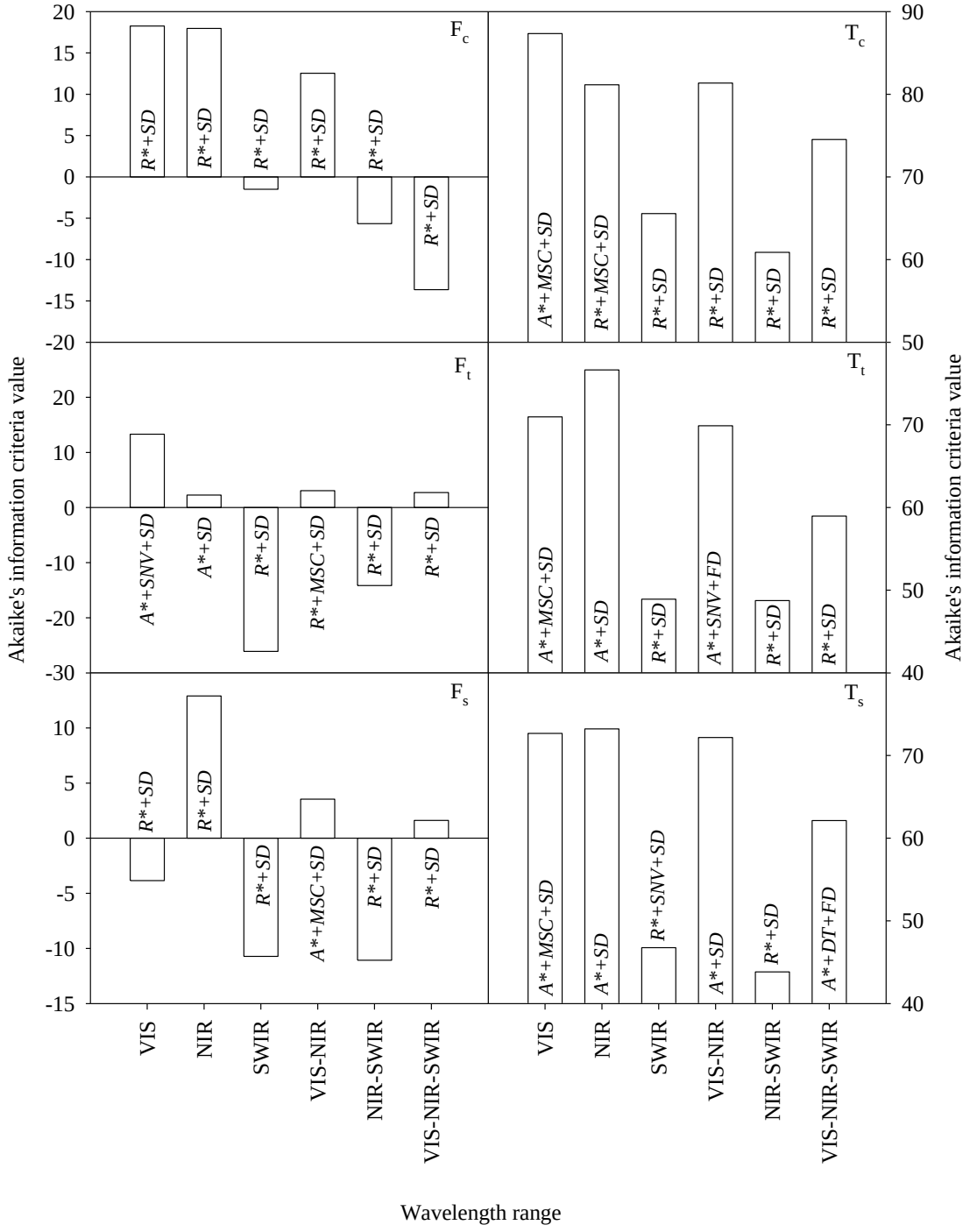

Fig. 4.18 Selection of best wavelength range and spectral pre-processing combination for textural attributes of tender jackfruit samples. *R**: reflectance; *A**: absorbance; *SNV*: standard normal variate; *MSC*: multiplicative scatter correction; *DT*: de-trend; *FD*: first derivative; *SD*: second derivative; VIS: visible; NIR: near infrared; SWIR: shortwave infrared.

on minimum AIC value criteria. Interestingly, it was noted that the best PLSR model of almost all the attributes (10 out of 12 cases) examined was based on spectra subjected to R^*+SD pre-processing. An additional *SNV* and *MSC* transformation of R^* prior to *SD*

was found to yield better results in case of L* (*R+SNV+SD*) and b* (*R+MSC+SD*), respectively. It may be inferred that a) the conventional use of entire spectrum (VIS-NIR-SWIR) may not be necessary and one may discard VIS wavelengths for improved PLSR models of colour, pH, TSS, TA and textural attributes of tender jackfruit and b) R^**+SD* with its ability to account for additive and multiplicative effects in the spectra (Rinnan *et al.*, 2009), the linkage between spectral signature and quality attributes of tender jackfruit have improved. Thus, the overall results of the analysis suggest the use of spectra in the NIR-SWIR wavelength region in conjunction with R^**+SD* pre-processing to yield better NIRS models of fresh tender jackfruit quality attributes.

4.3.4 Performance of models based on best wavelength range and pre-processing

The regression statistics of cross-validation of best performing PLSR models of different quality attributes of tender jackfruit examined in this study are listed in Table 4.10. The performance of best PLSR model of colour attributes (L*, a* and b*) and TA was found to be **e**xcellent (RPD > 3.0) based on the accuracy criteria suggested by Williams and Norris (2001). It may be noted that the NIRS analyses for colour attributes in this study were performed using a small dataset and the consistency of results has to be further examined with large number of samples. However, high accuracy noted for colour attributes favour the utility of NIRS for their successful characterization. The best PLSR models of TSS, F_t, T_t and T_s yielded an accuracy level suited for their coarse quantitative assessment (2.0 < RPD < 2.5). The best models of pH, F_c, F_s and T_c were able to distinguish low and high values and hence found appropriate for screening purpose (1.5 < RPD < 2.0). As limited literature is available on NIRS analysis of tender jackfruit, the performance of best PLSR models obtained in this study were compared with that of other fruits and vegetables subject to the variability in spectral measurements (instrument type, wavelength range), sample representation (intact, chopped, homogenized) and data modelling approach. The performance of best models in this study are comparable or even better than those reported in the literature for pH (Shao *et al.*, 2011; Česonienė *et al.*, 2019), TSS (García-Martínez *et al.*, 2012; Saad *et al.*, 2016; Entrenas *et al.*, 2020), TA (García-Martínez *et al.*, 2012; De Oliveira *et al.*, 2014; Maniwara *et al.*, 2014), colour (Torres *et al.*, 2015) and texture (Kjølstad *et al.*, 1990; Lu, 2001; Sirisomboon *et al.*, 2012).

Table 4.10 Regression statistics of cross-validation of quality attributes of tender jackfruit samples using best wavelength range and spectral pre-processing combination

Attribute	Range	Pre-process	LV	R^2	RMSE	RPD
pH	NIR-SWIR	*R*+SD*	2	0.72	0.12	1.90
TSS	SWIR	*R*+SD*	2	0.79	0.39	2.20
TA	NIR-SWIR	*R*+SD*	3	0.93	0.03	3.68
L*	SWIR	*R*+SNV+SD*	3	0.98	0.54	7.36
a*	NIR-SWIR	*R*+SD*	3	0.98	0.15	8.24
b*	NIR-SWIR	*R*+MSC+SD*	3	0.99	0.10	14.43
F_c	NIR-SWIR	*R*+SD*	2	0.70	0.85	1.84
F_t	SWIR	*R*+SD*	3	0.86	0.57	2.67
F_s	NIR-SWIR	*R*+SD*	2	0.72	0.77	1.91
T_c	NIR-SWIR	*R*+SD*	2	0.71	2.67	1.88
T_t	NIR-SWIR	*R*+SD*	2	0.75	2.16	2.04
T_s	NIR-SWIR	*R*+SD*	2	0.75	1.99	2.01

LV: number of latent variables; R^2: coefficient of determination; RMSE: root mean squared error; RPD: residual prediction deviation

The regression coefficient values of best PLSR models of tender jackfruit quality attributes are shown in Fig. 4.19 and 4.20. The most significant wavelengths identified as three times standard deviation of regression coefficient values are also represented in the figure as black colour bars. The wavelengths around 1000 nm and those in 2200-2450 nm range have prominent influence in the estimation of all the quality attributes of tender jackfruit examined in this study. The spectral features in the former wavelength range may linked with the second overtone of O–H and H_2O at 950 and 960 nm, respectively. The latter wavelength range may be attributed to characteristic absorptions associated with cellulose, especially CH_3 combination, C–H stretching & bending around 2260 nm, second overtone of O–H bending around 2364 nm and combination of C–H stretching & C–C stretching vibrations around 2430 nm (Cen and He, 2007; Xu *et al.*, 2013; Guimarães *et al.*, 2014). Apart from these wavelengths, those around 1800 nm appeared to be most prominent in case of TSS, TA, F_c and T_c which may be associated with first overtone of C–H stretching (Fu and Ying, 2016) of cellulose. In addition, in case of TA, spectral features around 1400 nm due to first overtone of O–H stretching (Guimarães *et al.*, 2014) was also found to be prominent.

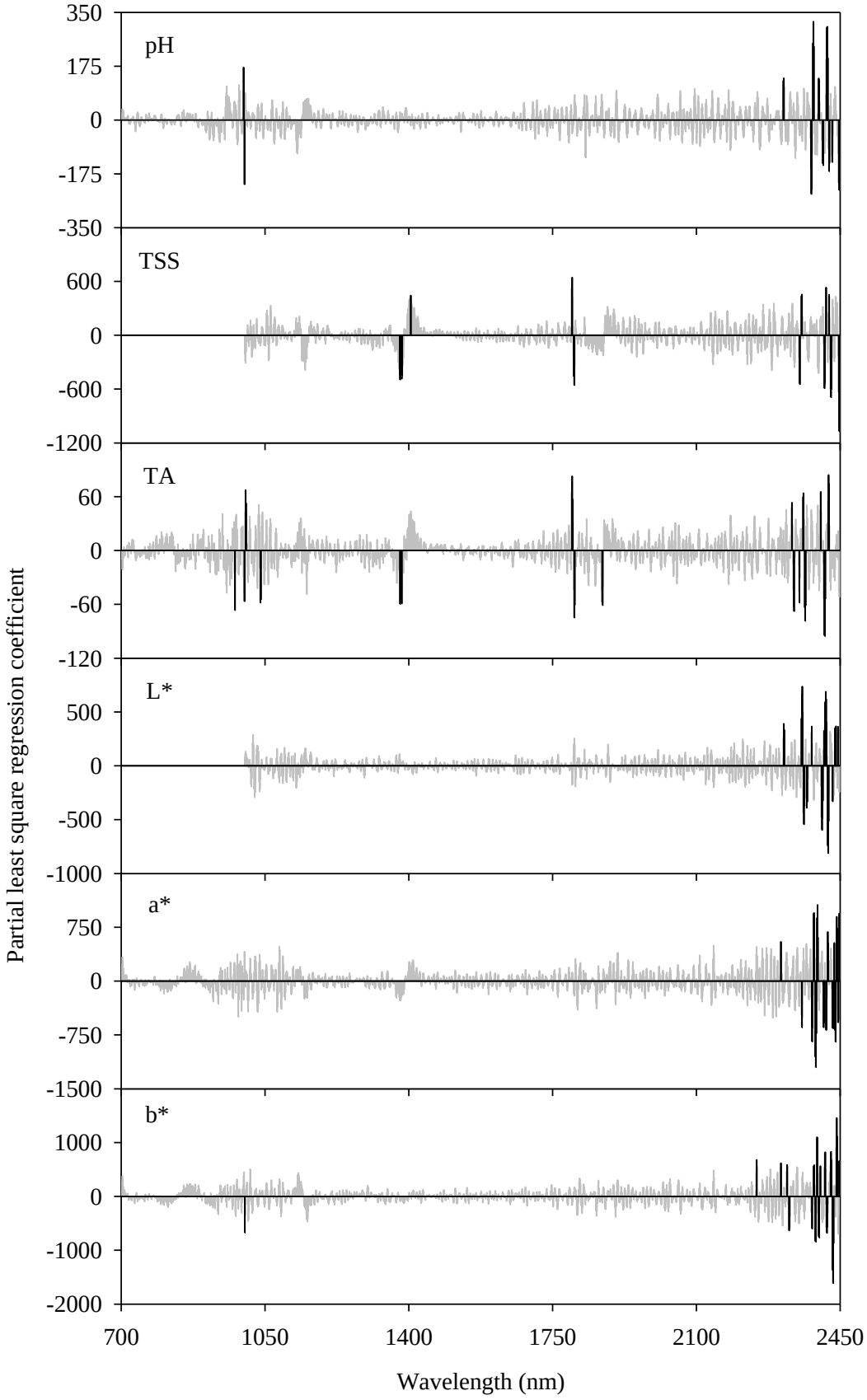

Fig. 4.19 Significant wavelengths for the estimation of chemical composition and colour attributes of fresh tender jackfruit samples

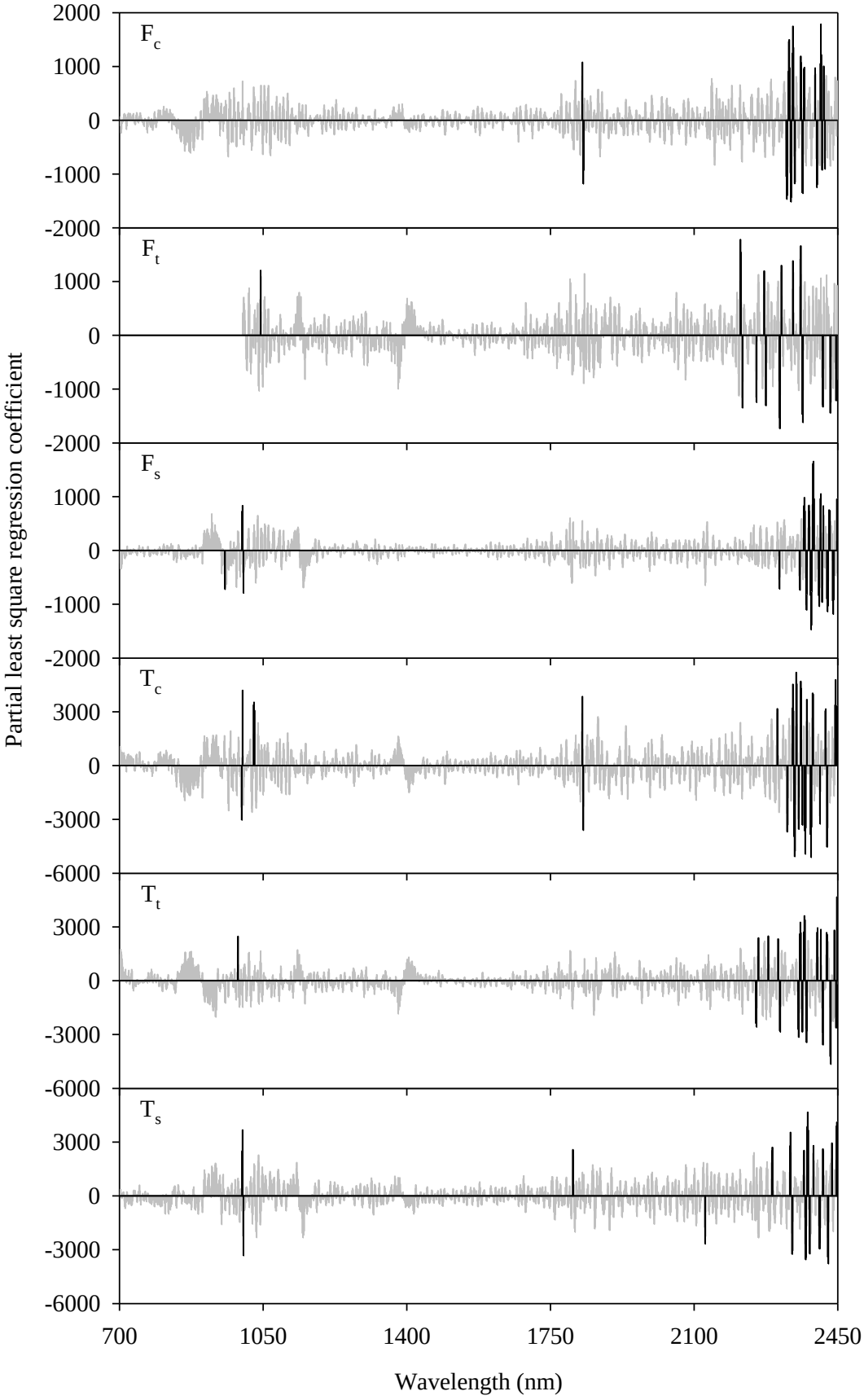

Fig. 4.20 Significant wavelengths for the estimation of textural attributes of fresh tender jackfruit samples

The present study is the first attempt to use NIRS in conjunction with PLSR for quality evaluation of tender jackfruit. Among different attributes examined, best performance was noted for colour followed by TA. The performance of PLSR models was found to be primarily influenced by the overtones and combinations of C–H functional group which may be related to cellulose composition. The overall result of the study endorse NIRS as a rapid, non-destructive, non-invasive and reliable approach to estimate multiple quality attributes of fresh tender jackfruit.

4.3.5 Effect of sample presentation on NIRS performance

Tender jackfruit typically consists of an outer skin, inner core and tendrils in between. As these components vary in composition and texture, their natural proportion has to be maintained while sample preparation for spectral measurements. This can be easily achieved (no sample preparation) by using intact sample for NIRS measurements. But, due to the aforesaid inter component variability, it is difficult to generate representative spectrum of the whole intact sample using point based NIRS sensors. This issue can be addressed using NIRS instruments with bidirectional measurement facility. Another approach to maintain the proportion of tender jackfruit components is to grate the sample and mix thoroughly prior to its presentation to NIRS sensor. Spectral variability of grated samples can be characterized by suitable replicated measurements using both point based and bidirectional measurements. However, grating fresh tender jackfruit samples prior to NIRS measurements can be labour intensive, time consuming and hence reduce the number of spectral measurements per working hour of the instrument. To select an appropriate sample presentation method among those mentioned above, their NIRS performance would be a decisive factor. As no reports are available in this regard, the study compared the NIRS performance using intact and grated fresh tender jackfruit samples (n = 38).

Figure 4.21 shows the mean spectral reflectance of intact and grated fresh tender jackfruit samples. Although, the mean spectrum of both intact and grated fresh tender jackfruits samples have similar pattern, they differ in terms of spectral reflectance values. Their similar pattern arise due to characteristic absorptions around 970, 1200, 1450 and 1930 nm. More details on spectral features of fresh tender jackfruit in NIRS range has discussed in Section 4.3.2 of this document. The intact spectrum appeared to have high spectral reflectance than the grated counterpart which is more prominent in

the VIS-NIR segment of the spectra. The low reflectance of grated samples may cause due to its low packing density (compared to intact samples) which resulted in higher scattering of the electromagnetic radiation in the void space.

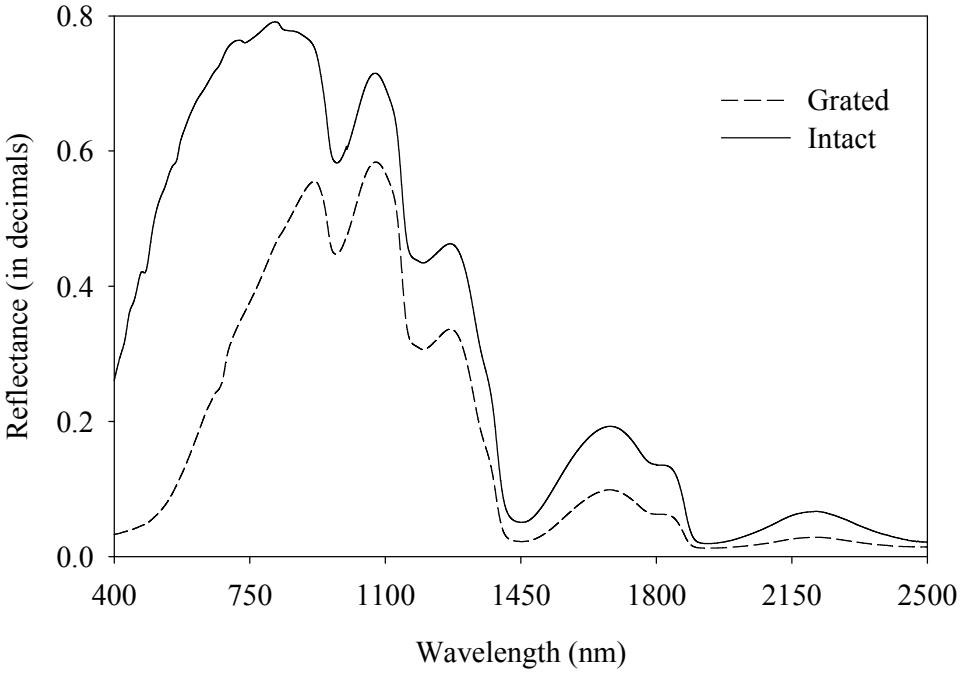

Fig. 4.21 Mean spectral reflectance of intact and grated fresh tender jackfruit samples

The cross-validation performance of PLSR models generated using *R**+*SD* spectra of 38 number of intact and grated samples was examined. Figure 4.22 shows the RPD in the cross-validation of PLSR models of compositional attributes of intact and grated samples. Interestingly, it was noted that PLSR models developed using intact samples have remarkably higher RPD values compared to that of grated samples. This was evident in case of all the attributes examined except F_c. The better results noted in case of intact samples against grated counterparts may be ascribed to a) uniform and flat cut surface of intact samples resulted in low scattering and b) less spectral variation across samples with regard to orientation of particles. These may have imposed relatively less complexity in the spectral information related to the attribute in case of intact samples.

Further, the statistical significance of improved performance noted in case of intact samples as compared to that of grated samples was assessed. For the purpose, we generated the RMSE distribution in the cross-validation of PLSR models of both intact and grated samples by bootstrapping approach (Sarathjith *et al.*, 2016). It involved

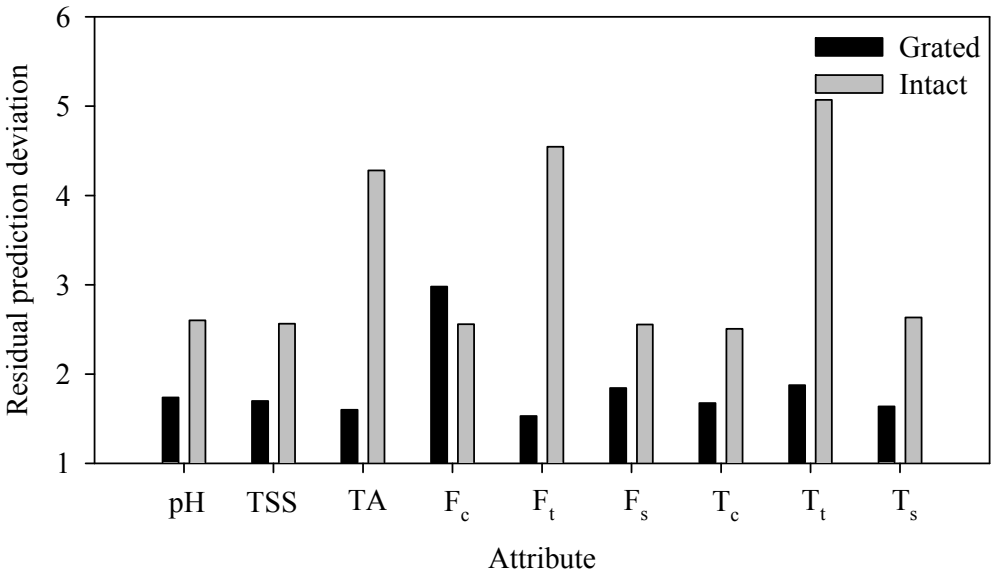

Fig. 4.22 Residual prediction deviation in the cross-validation of partial least square regression models of intact and grated fresh tender jackfruit samples. TSS: total soluble solids; TA: titrable acidity; F_c: firmness of core; F_t: firmness of tendril; F_s: firmness of skin; T_c: toughness of core; T_t: toughness of tendril; T_s: toughness of skin.

resampling of the dataset with replacement for 500 times. Then, for each attribute, the generated RMSE distributions of grated and intact samples were compared for their similarity or dissimilarity at 5% level of significance ($\alpha = 0.05$) by executing a left-tail Student's *t*-test. The H_0 of the test was that both the distributions have equal mean values. Additional assumption for the test included normality of the distributions with equal and unknown variances.

Figure 4.23 illustrates the RMSE distributions (in terms of kernel smoothing density estimates) of all the attributes estimated via NIRS using spectral reflectance from intact and grated fresh tender jackfruit samples. The result of the Student's *t*-test revealed that the mean value of RMSE distribution of intact samples was found to be significantly lower than that of grated samples for all the attributes (except F_c) at the defined level of significance. This was evident with high *t*-statistic and $p < \alpha$ (in fact, the *p*-value of different attributes were found to be very close to zero) noted for these attributes. In case of F_c, grated samples outperformed intact measurements. It may be noted that the intact samples yielded superior results for majority (8 out of 9 cases) of the attributes examined. Thus, the overall result of the analysis favour intact spectral measurements

against grated counterpart to develop NIRS models of compositional attributes of fresh tender jackfruit with improved accuracy.

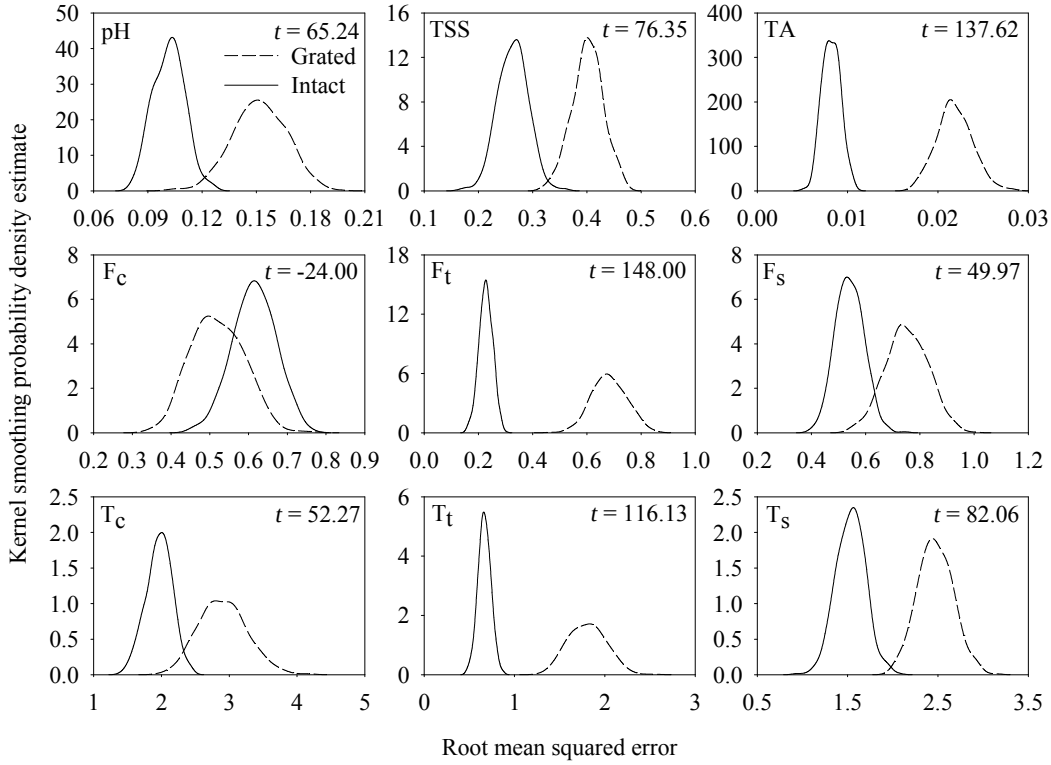

Fig. 4.23 Kernel smoothing density estimates of root mean squared error distribution of cross-validation

4.4 QUALITY ASSESSMENT OF THERMAL PROCESSED TENDER JACKFRUIT USING NEAR INFRARED REFLECTANCE SPECTROSCOPY

4.4.1 Descriptive statistics of quality attributes of thermal processed tender jackfruit

The descriptive statistics of quality attributes of thermal processed canned tender jackfruit sample dataset examined in this study are listed in Table 4.11. It was noted that the attributes namely, moisture, pH, crude fibre, L* and b* values do not vary much across different treatments over the storage period as indicated by the respective coefficient of variation values. On the other hand, remarkable variation in F_s followed by a* were also observed in the dataset. The variability of attribute values noted in this dataset is comparable to that reported for other fruits and vegetables (De Oliveira *et al.*, 2014; Maniwara *et al.*, 2014).

Table 4.11 Descriptive statistics of quality attributes of thermal processed canned tender jackfruit samples (Set-2; n = 48)

Attribute	Range	Mean	SD	CV
L*	45.41 – 72.73	58.47	7.30	12.49
a*	1.29 – 13.44	6.56	3.61	55.02
b*	14.08 – 25.24	18.19	2.34	12.85
ΔE	11.21 – 39.75	26.26	7.80	29.69
Firmness of skin, N	0.79 – 11.63	3.95	2.72	68.78
Moisture, %	76.28 – 90.63	87.78	4.35	4.95
pH	3.56 – 5.12	4.48	0.45	10.11
Total soluble solids, ^{o}Brix	1.40 – 4.35	2.74	0.75	27.27
Titrable acidity, %	0.13 – 0.42	0.22	0.08	36.72
Crude fibre content, %	2.26 – 2.89	2.62	0.17	6.54
Carbohydrate content, mg/100 g (fresh wt.)	1.33 – 4.43	2.37	0.80	33.59
Ascorbic acid, mg/100 g	3.13 – 9.20	5.93	1.20	20.27
Total flavonoid content, mg RE/g (dry wt.)	19.75 – 55.88	37.73	8.92	23.65
Total phenol content, mg GAE/g (dry wt.)	0.40 – 1.07	0.78	0.14	17.64

SD: standard deviation; CV: coefficient of variation in percentage

4.4.2 Spectral characteristics of thermal processed canned tender jackfruit

The R^* spectra of the pulp of sample in four replications were acquired using the DLP NIRscan Nano device (Texas Instruments) over 901.03 – 1701.04 nm (228 data points) wavelength range. The pulp was then oven dried for 24 hours and powdered and its four replicated spectra were acquired. The replicated measurements of each sample were later averaged to generate its representative spectrum. The steps mentioned above yielded both wet (spectra of pulp) and dry (spectra of powder) spectra of thermal processed canned tender jackfruit samples. Due to the concern related to spectral noise at extreme wavelengths in the operational domain of the instrument, the R^* before 910 nm (3 data points) and after 1700 nm (1 data point) were excluded from further analyses. Figure 4.24 shows the mean and standard deviation of both wet and dry spectra of thermal processed canned tender jackfruit samples used in this study. The R^* spectrum of wet and dry samples appeared to be distinctly different in terms of a)

overall R^* and b) spectral features located around 970 and 1200 nm. The overall R^* of the mean spectrum of wet and dry samples varied in the range of 0.02–0.32 and 0.30–0.57, respectively. The relative low R^* of wet samples can be attributed to the absorption of electromagnetic radiation by water molecules. The characteristic absorption around 970 nm due to second overtone of water (Jie *et al.*, 2004; Fu and Ying, 2016) appeared to be prominent in case of wet samples while no such feature was noted in case of dry counterpart. The absorption around 1200 nm was observed to be common in both wet and dry samples spectra which may be linked to C–H stretching of cellulose (Fu and Ying, 2016) and the combination of O–H stretching (first overtone) and O–H bending vibrations (Büning-Pfaue, 2003). But, the latter has a relatively sharp and distinct absorption peak (dip in R^* spectrum) which may be due to its least interference with water than that of the former. Apart from these dissimilarities, both the wet and dry samples have similar spectral pattern especially beyond 1300 nm. A common characteristic absorption was noted around 1450 nm for wet and dry samples which may be attributed to the first overtone of water (Büning-Pfaue, 2003; Cen and He, 2007; Pritty *et al.*, 2020). In both wet and dry spectra, the spectral variation (in terms of standard deviation) appeared to be the least in the wavelength region around 1400 nm compared to other segments.

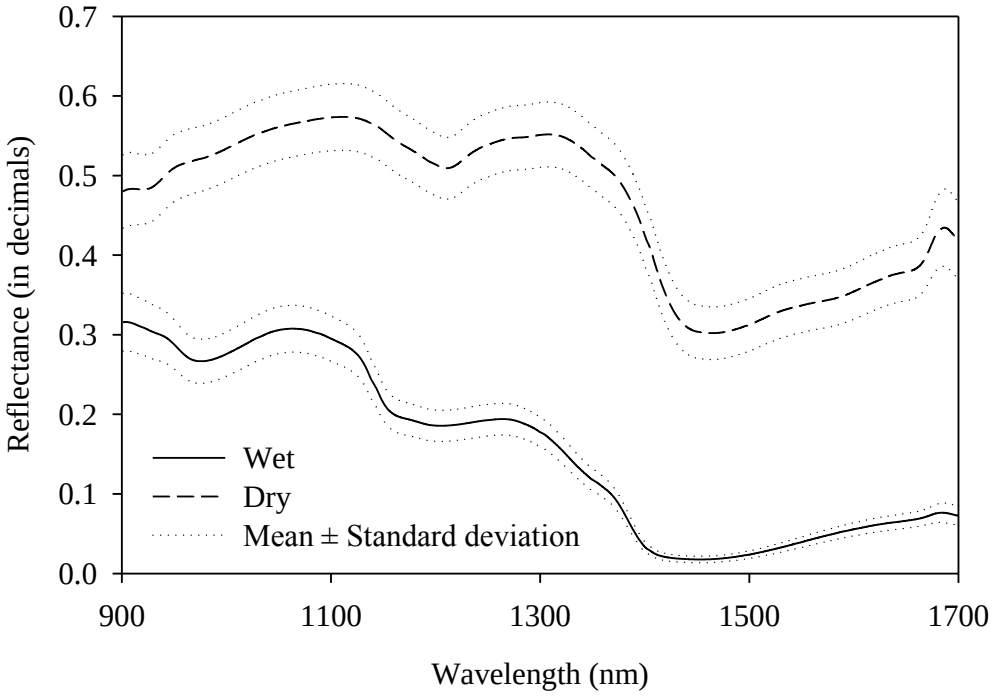

Fig. 4.24 Mean reflectance spectrum of wet and dry samples of thermal processed canned tender jackfruit

4.4.3 Partial least square regression modelling

Both the wet and dry spectra of thermal processed canned tender jackfruit samples were separately related with different quality attributes under PLSR framework. The spectra were subjected to different pre-processing (as mention in Section 3.4.3) and PLSR models were developed for each quality attribute. The AIC value of the PLSR models based on wet and dry spectra were computed as listed in Table H2 and H3 of Appendix H, respectively. Then, the best pre-processing technique was identified based on minimum AIC value of the PLSR models. Accordingly, R^*+*SD* was found to be the best pre-processing for wet spectra to estimate a*, b*, pH, TSS, TPC while R^*+*MSC*+*SD* yielded best result for L*. The pre-processing R^*+*SNV*+*SD* was found to be the best to estimate all the remaining attributes using wet spectra. In case of pre-processing of dry spectra, R^*+*FD* appeared to be prominent in case of all colour attributes and MC while R^*+*SD* yielded best results in case of F_s, AA, TFC and TPC. The R^*+*MSC*+*SD* was chosen as the best in case of both pH and CC estimation while R^*+*SNV*+*FD*, R^*+*MSC*+*FD*, R^*+*SNV*+*SD* was found appropriate for TSS, TA and CFC, respectively.

The regression statistics in the cross-validation of PLSR models based on best pre-processing of both wet and dry spectra are listed in Table 4.12. Based on the RPD criteria (Williams and Norris, 2001), good level of accuracy (2.5 < RPD < 3.0) was noted in the estimation of MC using wet spectra. The accuracy level suitable for discriminating low and high values (1.5 < RPD < 2.0) was noted in case of L*, ΔE and TFC. The NIRS approach using wet spectra was not successful (RPD < 1.5) to yield better accuracy for all the remaining attributes. On the other hand, the PLSR approach in conjunction with dry spectra yielded good estimation accuracy in case of TFC and TPC. An accuracy level suitable for coarse quantitative estimation (2.0 < RPD < 2.5) was noted for MC, CC and AA. Estimation accuracy of best PLSR models using dry spectra was found to be poor (RPD < 1.5) for all the remaining attributes except TSS (RPD = 1.53). The observed versus predicted value plots of quality attributes of thermal processed canned tender jackfruit are shown in Fig. 4.25.

Table 4.12 Cross-validation performance of partial least square regression models of quality attributes based on best pre-processing

Attribute	Pre-process	LV	R^2	RMSE	RPD
	Wet spectra				
L*	*R*+MSC+SD*	3	0.61	4.49	1.63
a*	*R*+SD*	3	0.51	2.50	1.44
b*	*R*+SD*	2	0.48	1.67	1.40
Total colour difference	*R*+SNV+SD*	3	0.60	4.85	1.61
Firmness of skin	*R*+SNV+SD*	2	0.46	1.97	1.38
Moisture content	*R*+SNV+SD*	4	0.86	1.59	2.74
pH	*R*+SD*	2	0.33	0.37	1.23
Total soluble solids	*R*+SD*	2	0.33	0.61	1.23
Titrable acidity	*R*+SNV+SD*	2	0.38	0.06	1.28
Crude fibre content	*R*+SNV+SD*	2	0.45	0.13	1.36
Carbohydrate content¶	*R*+SNV+SD*	2	0.50	0.55	1.44
Ascorbic acid	*R*+SNV+SD*	2	0.34	0.97	1.24
Total flavonoid content	*R*+SNV+SD*	3	0.63	5.34	1.67
Total phenol content	*R*+SD*	2	0.47	0.10	1.39
	Dry spectra				
L*	*R*+FD*	4	0.48	5.23	1.40
a*	*R*+FD*	3	0.40	2.76	1.31
b*	*R*+FD*	2	0.38	1.82	1.28
Total colour difference	*R*+FD*	4	0.47	5.61	1.39
Firmness of skin	*R*+SD*	2	0.31	2.24	1.21
Moisture content	*R*+FD*	4	0.80	1.93	2.25
pH	*R*+MSC+SD*	2	0.28	0.38	1.19
Total soluble solids	*R*+SNV+FD*	5	0.56	0.49	1.53
Titrable acidity	*R*+MSC+FD*	5	0.46	0.06	1.37
Crude fibre content	*R*+SNV+SD*	2	0.20	0.15	1.13
Carbohydrate content¶	*R*+MSC+SD*	5	0.76	0.39	2.05
Ascorbic acid	*R*+SD*	5	0.78	0.56	2.14
Total flavonoid content	*R*+SD*	5	0.85	3.40	2.62
Total phenol content	*R*+SD*	5	0.87	0.05	2.78

¶ Carbohydrate value of three samples were missing (n = 45)

n: number of samples; LV: number of latent variables; R^2: coefficient of determination; RMSE: root mean squared error; RPD: residual prediction deviation; *R**: reflectance; *SNV*: standard normal variate: *MSC*: multiplicative scatter correction; *FD*: first derivative; *SD*: second derivative.

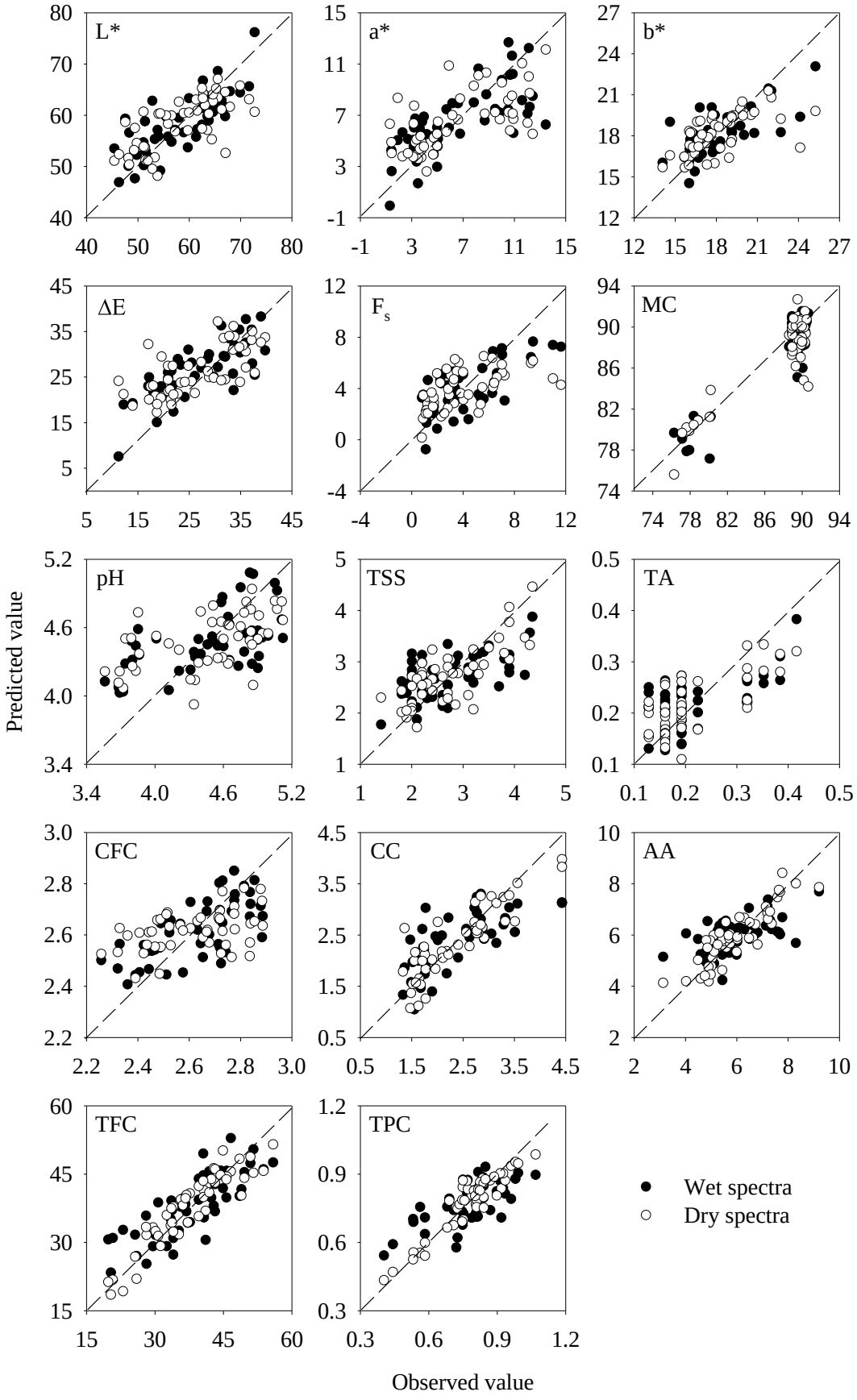

Fig. 4.25 Observed versus predicted values of quality attributes of thermal processed canned tender jackfruit

The PLSR coefficient values describing spectra-attribute linkage of thermal processed canned tender jackfruit samples are shown in Fig. 4.26. The plots of those attributes with RPD > 2 are only shown in the figure.

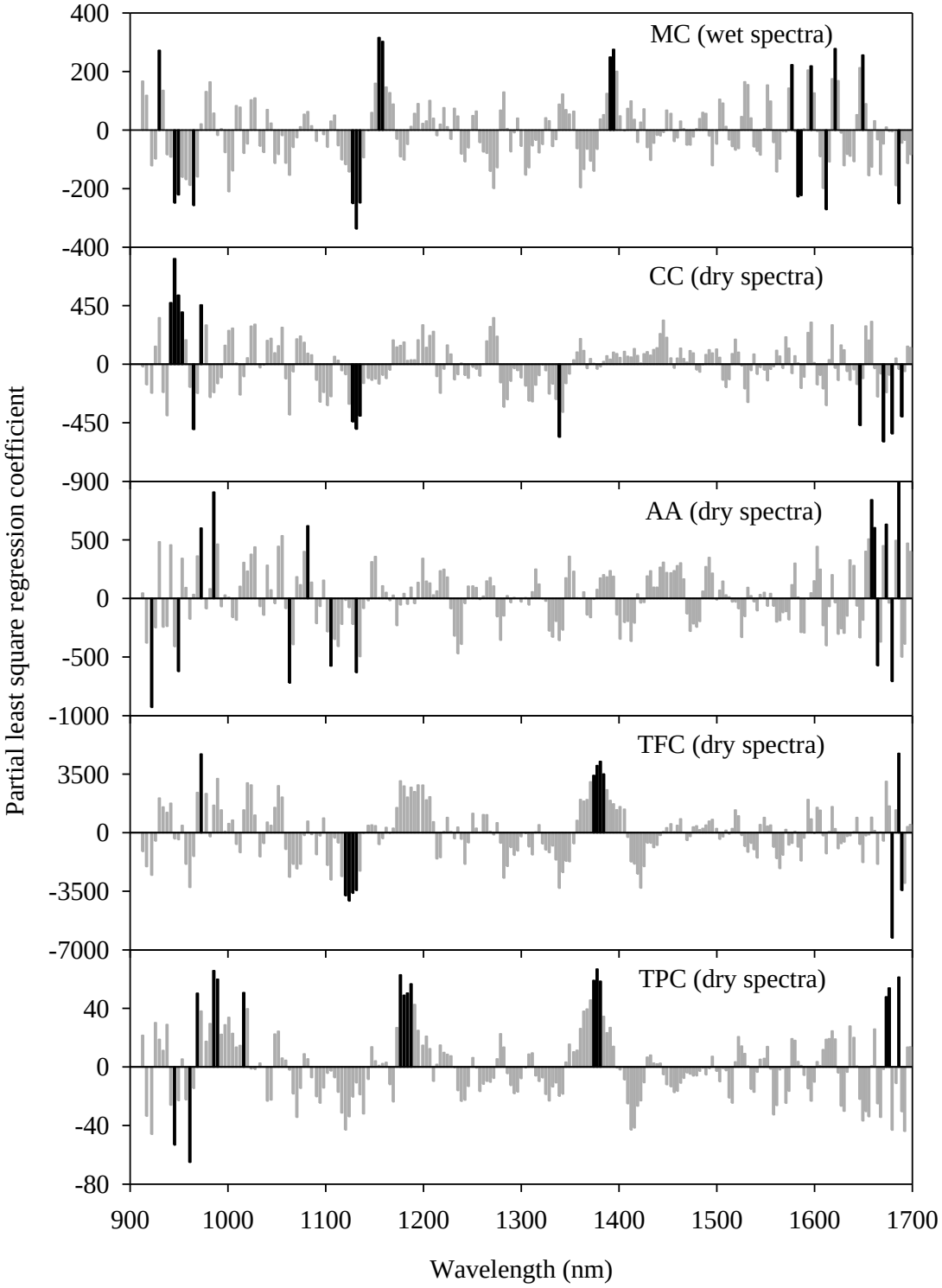

Fig. 4.26 Significant wavelengths for the estimation of quality attributes of thermal processed canned tender jackfruit samples

The wavelengths with absolute magnitude of the regression coefficient value greater than three times its standard deviation were regarded as most prominent for the characterization of quality attributes of thermal processed canned tender jackfruit samples (represented as black colored bars in the figure). The most prominent spectral features identified across these attributes typically occurred in 922–930, 942–953, 961–989, 1016–1082, 1105–1187, 1339, 1374–1394, 1577–1621 and 1646–1689 nm wavelength bands. The spectral features in 922–930 nm range may be related to the third overtone of C–H stretching (Jie *et al.*, 2004; Xu *et al.*, 2012) while 942–953 nm signifies second overtone of O–H stretching (Fu and Ying, 2016). The characteristic absorptions within 961–989 nm may be linked with second overtone of H_2O (Fu and Ying, 2016) or O–H stretching vibrations (Xu *et al.*, 2012) while 1016–1082 nm correspond to second overtone of N–H bond (Kar *et al.*, 2018). The third overtone (De Oliveira *et al.*, 2014) and combination band of C–H bonds (Tamburini *et al.*, 2017; Toledo-Martín *et al.*, 2018) constituted most prominent spectral features of thermal processed tender jackfruit quality attributes in 1105–1187 and around 1339 nm, respectively. The prominent spectral features noted in this study in 1374–1394, 1577–1621 and 1646–1689 nm wavelength ranges may occur due to first overtone of O–H, N–H and C–H bonds, respectively (Sinelli *et al.*, 2008; Ding *et al.*, 2016).

Further, the estimation accuracy of PLSR models of quality attributes based on wet and dry spectra in terms of AIC value was compared (Fig. 4.27). Low AIC represent a better model with regard to both accuracy and complexity together. The wet spectra based PLSR models of L*, a*, b*, ΔE, F_s, MC, TA and CFC yielded low AIC value than those of dry spectra. On the other hand, PLSR models of CC, AA, TFC and TPC yielded low AIC values in conjunction with dry spectra. The relatively poor performance of wet spectra based PLSR models of these attributes may be due to presence of moisture as a major chromophore masking absorption characteristics relevant for their estimation.

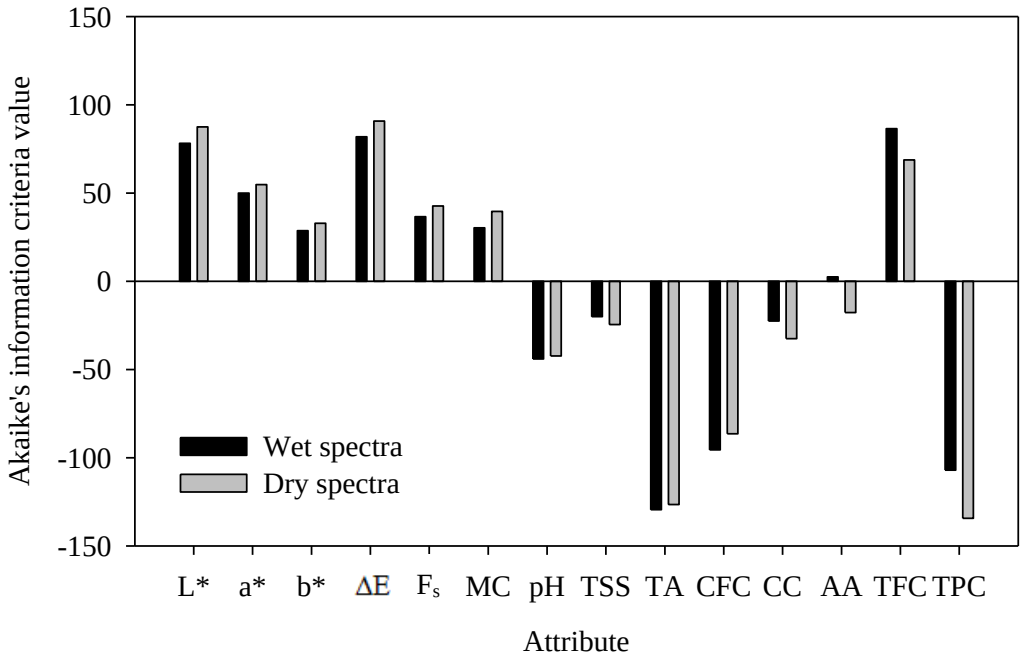

Fig. 4.27 Akaike's information criteria value of partial least square regression models of thermal processed canned tender jackfruit

4.5 ASSESSMENT OF TOTAL FLAVONOID AND PHENOL CONTENTS OF FRESH TENDER JACKFRUIT COMPONENTS USING NEAR INFRARED REFLECTANCE SPECTROSCOPY

The importance of phytochemicals in vegetables to lower the risks associated with cancer, stroke, heart and pulmonary diseases is largely recognized (Turkmen *et al.*, 2005; Daduang *et al.*, 2011; Chandra *et al.*, 2014; Tang *et al.*, 2017). In this regard, the phytochemical characterization of tender jackfruit is very much essential in promoting its consumption as a vegetable. However, limited studies have characterized phytochemicals of tender jackfruit. In this investigation, two major phytochemicals namely TFC and TPC across different components (skin, tendril and core) of fresh tender jackfruit has been characterized. The Set-3 samples were collected exclusively for this purpose.

The distribution of analysed TFC and TPC values of tender jackfruit components are approximately represented by means of histogram together with respective descriptive statistics (Fig. 4.28). Above each histogram a boxplot with whiskers is also illustrated to display the minimum, maximum, median (50^{th} percentile), first (25^{th} percentile) and

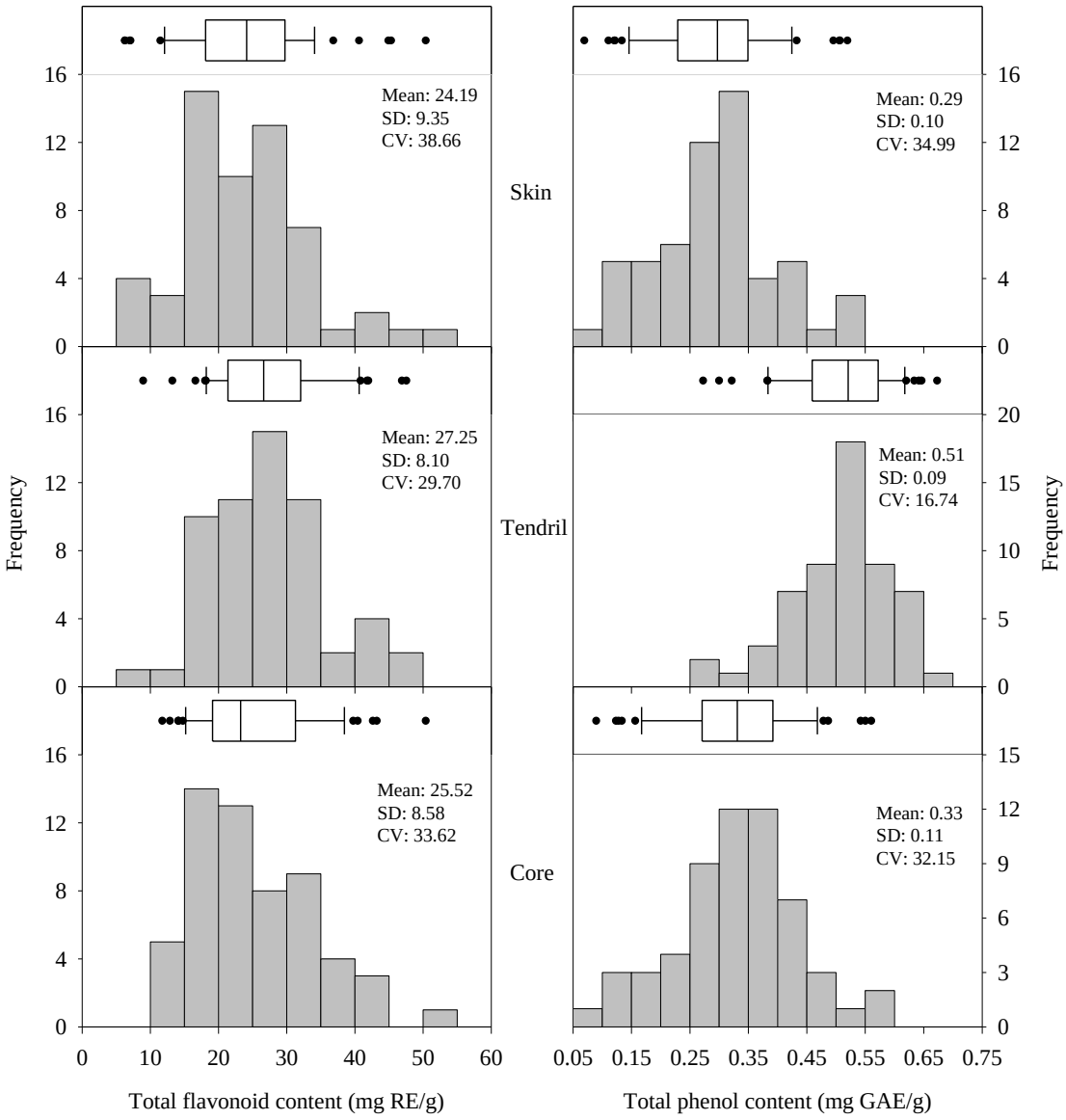

Fig. 4.28 Histograms and boxplots of the distribution of total flavonoid and phenol contents of tender jackfruit components (SD and CV represents standard deviation and coefficient of variation in percentage, respectively)

third (75th percentile) quartiles of the attribute values. The TFC values varied in the range of 6.27–50.39, 8.95–47.55 and 11.75–50.39 mg RE/g while that of TPC was noted to be 0.07–0.52, 0.27–0.67 and 0.09–0.56 mg GAE/g across skin, tendril and core of tender jackfruit samples, respectively. The coefficient of variability of the attribute values appeared to be higher for skin followed by core and tendril. On the other hand, the mean values of both TFC and TPC appeared to be higher in case of tendril followed by core and skin. For a more meaningful interpretation, pairwise comparison of the distribution of attribute values across two different components was

performed using statistical tests. For the purpose, two-sample *t*- and *F*-tests were executed ($\alpha = 0.05$) with equality of means and variances as the H_0, respectively. The results of these tests are given in Table 4.13. The result of the statistical tests revealed that both the mean and variance of TFC values were not significantly different across tender jackfruit components as evident with high probability values (*p*) than the desired level of significance (α). Similar result was obtained with respect to the variance of the distribution of TPC values. In contrast to these findings, a statistically significant difference in the mean value of the distribution of TPC of tendril was noted when compared to that of both skin and core components. The TPC of tendril was found to be superior to that of other components of tender jackfruit samples.

Table 4.13 Results of statistical tests for pairwise comparison of the distribution of total flavonoid and phenol content values across tender jackfruit components

Components	Two sample *t*-test		Two sample *F*-test	
	p	Decision	*p*	Decision
		Total flavonoid content		
Skin-Tendril	0.06	Accept H_0	0.28	Accept H_0
Skin-Core	0.43	Accept H_0	0.52	Accept H_0
Tendril-Core	0.27	Accept H_0	0.67	Accept H_0
		Total phenol content		
Skin-Tendril	1.67×10^{-22}	Reject H_0	0.18	Accept H_0
Skin-Core	0.06	Accept H_0	0.81	Accept H_0
Tendril-Core	2.86×10^{-17}	Reject H_0	0.11	Accept H_0

H_0: null hypothesis; *p*: probability value

4.5.1 Spectral characteristics of tender jackfruit components

The mean R^* of both fresh and dried (pulverized before spectra acquisition) tender jackfruit components are shown in Fig. 4.29. In both fresh and dry cases, spectral pattern appeared to be similar across the components. The characteristic absorptions noted in case of fresh and dry spectra of tender jackfruit components resemble that of whole sample as can be seen in Fig. 4.15 and 4.24, respectively. More details on these absorption features are discussed in Section 4.3.2 (fresh samples) and 4.4.2 (dry samples).

Although tender jackfruit components have similar spectral pattern, they differ in terms of overall R^*. In case of fresh samples, tendril was found to have higher overall R^* which could be due to its lower moisture content than other components. In case of overall R^*values of skin and core, the former bear higher values which can be related to its higher density than the latter. In case of dried samples, core was found to have high overall R^* followed by skin and tendril which could be related to the fineness of the pulverized samples.

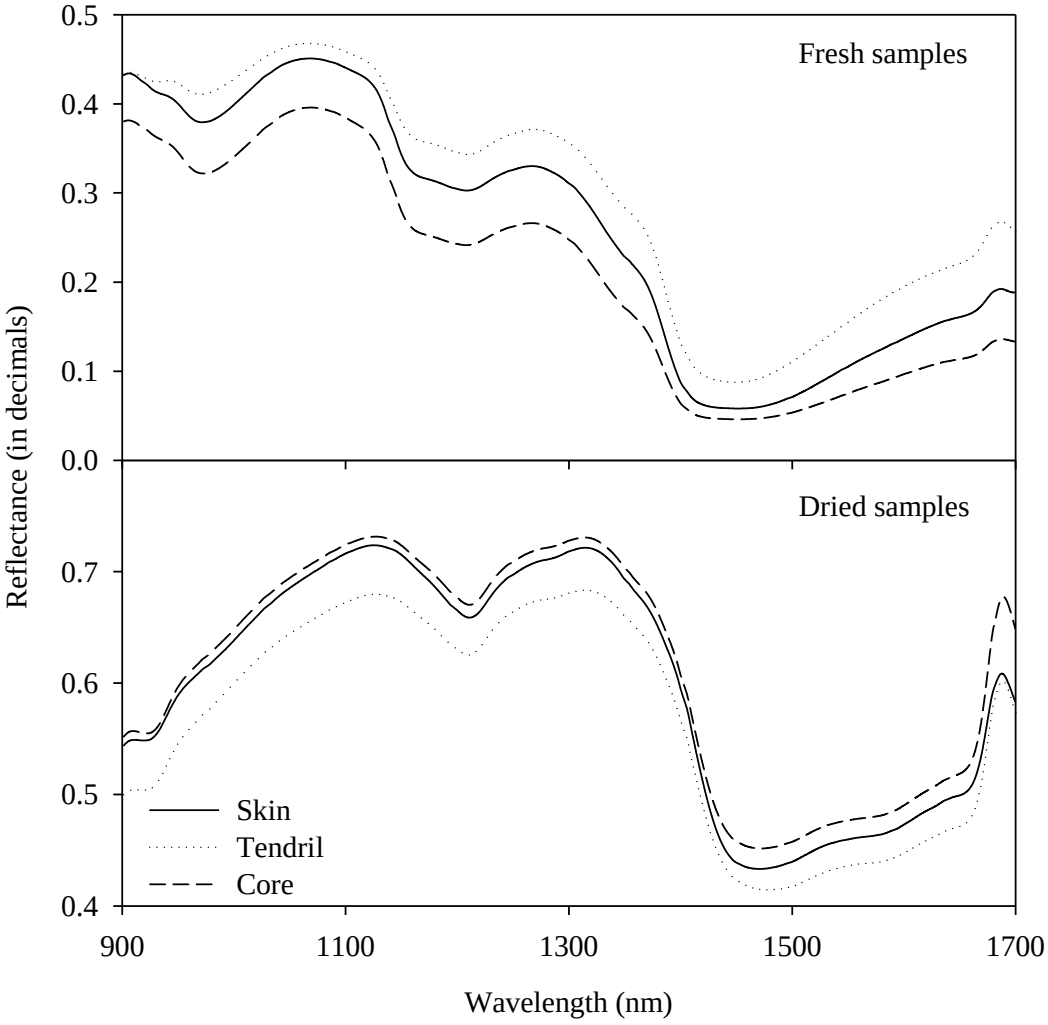

Fig. 4.29 Mean spectral reflectance of tender jackfruit components

4.5.2 Partial least square regression modelling

Initially, the PLSR models of TFC and TPC were built using different pre-processed spectra of each component and corresponding AIC values were computed. Then, the best pre-processing/PLSR model was identified based on minimum AIC value (Table

H4 and H5 of Appendix H). The pre-processing and regression statistics of the best PLSR models of TFC and TPC based on spectra of fresh and dried tender jackfruit components are listed in Table 4.14. The corresponding observed versus predicted plots are shown in Fig. 4.30. Among the best PLSR models of TFC based on fresh spectra, better cross-validation performance was noted in case of tendril compared to other components (Table 4.14). It yielded an accuracy level suitable for coarse quantitative estimation (2.0 < RPD < 2.5) of TFC based on RPD criteria suggested by Williams and Norris (2001). Similarly, better regression statistics were noted in case of best PLSR model of core samples to estimate TPC, however, its accuracy was found to be capable of discriminating low and high values (1.5 < RPD < 2.0). All the other models of TFC and TPC based on fresh spectra were found to have poor level of accuracy (RPD < 1.5).

Table 4.14 Cross-validation performance of best partial least square regression models of total flavonoid and phenol contents of tender jackfruit components

Sample type	Component	Pre-process	LV	R^2	RMSE	RPD
		Total flavonoid content				
Fresh	Skin	A^*+*MSC*+*SD*	2	0.25	8.04	1.16
	Tendril	A^*+*MSC*+*SD*	5	0.81	3.47	2.33
	Core	R^*+*SD*	2	0.37	6.74	1.27
Dried	Skin	A^*+*SD*	5	0.87	3.29	2.84
	Tendril	A^*+*SD*	5	0.91	2.42	3.34
	Core	R^*+*SNV*+*SD*	4	0.74	4.30	2.00
		Total phenol content				
Fresh	Skin	A^*+*SNV*+*SD*	2	0.31	0.08	1.21
	Tendril	A^*+*SNV*+*SD*	2	0.36	0.07	1.26
	Core	A^*+*SD*	5	0.61	0.07	1.62
Dried	Skin	R^*+*SNV*+*SD*	5	0.88	0.04	2.88
	Tendril	A^*+*SNV*+*SD*	5	0.86	0.03	2.70
	Core	A^*+*SD*	3	0.66	0.06	1.72

LV: number of latent variables; R^2: coefficient of determination; RMSE: root mean squared error; RPD: residual prediction deviation; A^*: absorbance; R^*: reflectance; *SNV*: standard normal variate: *MSC*: multiplicative scatter correction; *SD*: second derivative.

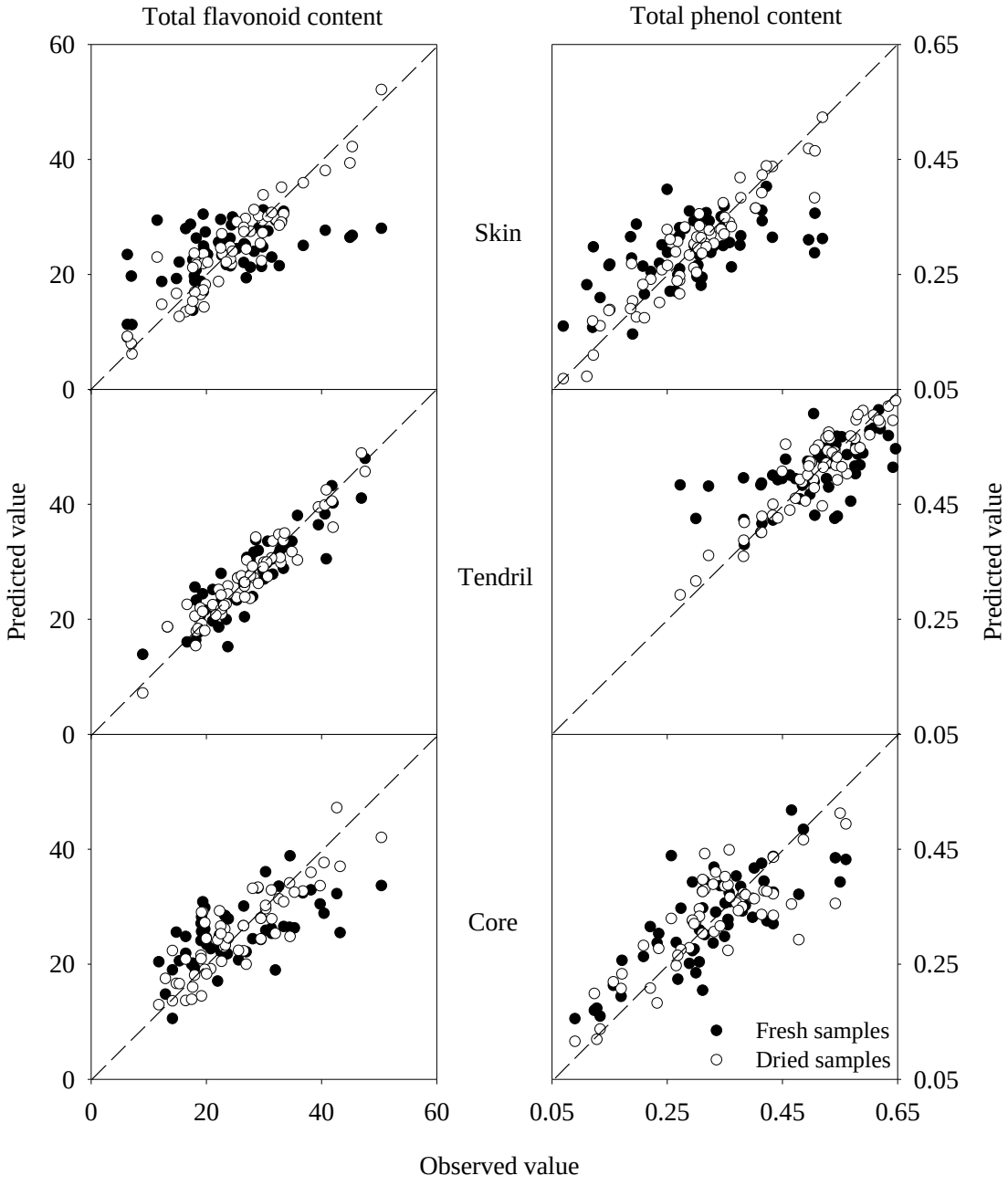

Fig. 4.30 Observed versus predicted values of total flavonoid and phenol contents of tender jackfruit components

On the other hand, best PLSR models based on spectra of dried samples yielded better performance than that of their fresh counterparts. This was found to be consistent across tender jackfruit components and attributes. The percent decrease in RMSE of PLSR models built using dry spectra with that of fresh samples was noted to be 59.09, 30.18, 36.28% (in case of TFC) and 57.98, 53.22, 5.62% (in case of TPC) across skin, tendril and core components of tender jackfruit, respectively. The accuracy of best PLSR models based on dried spectra was found to be excellent (RPD > 3) in case of TFC of

tendril; good (2.5 < RPD < 3.0) in case of TFC of skin, TPC of both skin and tendril; suitable for coarse quantitative estimation (2.0 < RPD < 2.5) in case of TFC of core and capable of discriminating low and high TPC values of core (1.5 < RPD < 2.0).

The PLSR coefficient values of TFC and TPC of tender jackfruit components based on spectra of dried samples are illustrated in Fig. 4.31. Most prominent wavelengths (absolute magnitude greater than three times its standard deviation) are represented as black coloured bars in the figure. The most prominent wavelengths for the estimation of TFC and TPC of different tender jackfruit components were mostly found in 913–934, 942–957, 961–993, 1009–1059, 1098–1195, 1221–1225, 1381–1384, 1583–1636 and 1661–1689 nm. Most of these prominent wavelengths are similar or comparable with those noted in case of thermal processed canned tender jackfruit samples (Section 4.4.3). The spectral features in 913–934 nm range may be related to the third overtone of C–H stretching (Jie *et al.*, 2004; Xu *et al.*, 2012). The second overtone of O–H stretching (Fu and Ying, 2016) might have resulted in characteristic absorptions in 942–957 nm while 961–993 nm may be assigned to second overtone of H2O (Fu and Ying, 2016) or O–H stretching vibrations (Xu *et al.*, 2012). The spectral features in 1009–1059 nm may be due to second overtone of N–H bond (Kar *et al.*, 2018) while third overtone (De Oliveira *et al.*, 2014) and combination band of C–H bonds (Tamburini *et al.*, 2017; Toledo-Martín *et al.*, 2018) resulted in prominent wavelengths in 1098–1195 nm. The third C–H overtone might be responsible for the spectral response in 1221–1225 nm wavelength band (Tamburini *et al.*, 2017; Toledo-Martín *et al.*, 2018). The prominence of spectral features in 1381–1384, 1583–1636 and 1661–1689 nm wavelength ranges may be linked to the first overtone of O–H, N–H and C–H bonds (Sinelli *et al.*, 2008; Ding *et al.*, 2016).

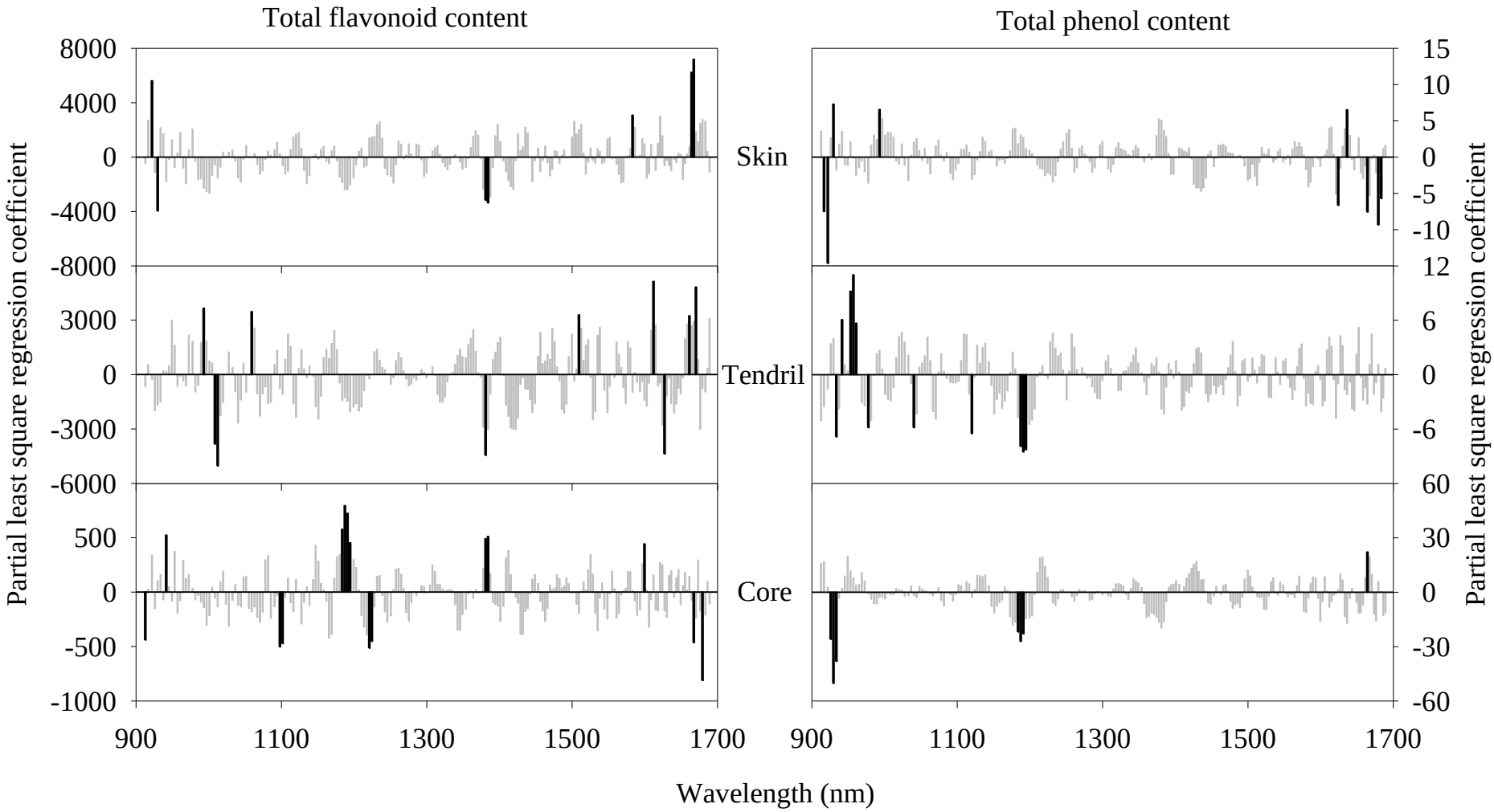

Fig. 4.31 Partial least square regression coefficient of total flavonoid and phenol contents of tender jackfruit components based on spectra of dried samples (most prominent wavelengths are represented as black coloured bars)

CHAPTER 5
SUMMARY AND CONCLUSIONS

The present study mainly focused on techniques for preservation and rapid characterization of tender jackfruit. Preservation of tender jackfruit in either ready-to-eat or ready-to-cook form throughout the year has gained much relevance to avail its health benefits even in off-season. Among different preservation techniques, thermal processing appeared to be the most efficient and economical method that allows commercial scale production with no compromise for microbiological safety of the product. The study has investigated the effect of thermal processing of tender jackfruit in TFS cans on its quality and shelf life. Initially, the time-temperature combination suitable for thermal processing of tender jackfruit was standardized. For the purpose, two different pasteurization (90 and 100^{o}C) and sterilization (110 and 121^{o}C) temperatures were considered. The treatments involved in the analysis consisted of combination of each temperature with time required to attain different lethality as indicated by F and F_0 values in case of pasteurization and sterilization, respectively. The thermal processed canned tender jackfruit samples (irrespective of pasteurization and sterilization treatments) were found to have significantly different quality attribute (colour, texture, AA, TFC and TPC) values as that of fresh sample based on the results of single factor ANOVA ($p < \alpha$). The criteria to adjudge the best treatment among pasteurization and sterilization cases relied primarily on microbiological safety followed by the quality attributes of the thermal processed samples. Accordingly, pasteurization at 90^{o}C for 19 min ($F = 60$) and sterilization at 121^{o}C for 8 min ($F_0 = 3$) were identified as the best treatments.

Later, a new batch of tender jackfruit samples were thermal processed in TFS cans under standardized conditions and subjected to quality evaluation every month for a storage period of 7 months. In this study, the effect of preservatives (2% brine, 0.1% KMS, 0.3% CA) and a control treatment (no preservatives) on the quality of thermal processed tender jackfruit during storage was examined. Based on the results of two factor ANOVA, the quality attributes namely TA, TSS, CC and CFC revealed no significant difference ($p > \alpha$) during the storage period. However, the variation in colour, firmness, pH, AA, TFC and TPC were significant irrespective of preservative and thermal processing (pasteurization and sterilization) treatments. The difference in

quality attribute values across preservative and thermal processing treatments were noted to be significant in many cases irrespective of storage period. Interestingly, the sensory analysis (after 8 months of storage) revealed that treatments without preservatives yielded highest mean rank for texture (in case of sterilization), colour, odour and taste (in case of pasteurization) among different treatments. Although, the treatments with preservatives ranked high for other organoleptic traits, the mean rank observed for treatments without preservatives were comparable with them. More importantly, all the treatments (with and without preservatives) subjected to standardized pasteurization and sterilization conditions were found to be microbiologically safe during the storage period. It might be concluded that the addition of preservatives is not mandatory for safe storage of tender jackfruit when subjected to thermal processing. However, the study advocates the use of any of the standardized thermal processing treatments with or without preservatives for safe storage of tender jackfruit subject to the selection of most appropriate one based on consumer preference.

As part of the investigation for rapid characterization of tender jackfruit, the utility of NIRS as a novel approach was demonstrated. It involved the quality assessment of both fresh (collected from different locations) and thermal processed (stored for 6 months) tender jackfruit. The study made attempt to address the key aspects of NIRS based characterization of tender jackfruit including the 1) selection of best wavelength range and pre-processing combination, 2) effect of sample presentation, 3) comparative performance of PLSR models based on wet and dry spectra and 4) inter component variability of fresh tender jackfruit with regard to TFC and TPC. Spectral measurements related to the first and second analyses were performed using Fieldspec 4 (Analytical System Devices, USA; wavelength range: 350–2500 nm) while DLP NIRscan Nano (Texas Instruments, USA; wavelength range: 900–1700 nm) was used to perform the third and fourth analyses. The calibration functions (spectra-attribute linkage) involved in the above analyses were developed using PLSR and their cross-validation performance was evaluated (in terms of R^2, RMSE and RPD of observed versus predicted values).

The result of the above analyses revealed that the use of spectra in the NIR-SWIR wavelength region in conjunction with R^*+SD pre-processing resulted in better NIRS

models (based on minimum AIC value) of quality attributes of fresh tender jackfruit. Based on the RPD criteria proposed by Williams and Norris (2001), the PLSR models of L*, a*, b* and TA were found to be excellent (RPD > 3.0) while those of TSS, F_t, T_t and T_s yielded accuracy suitable for coarse quantitative assessment (2.0 < RPD < 2.5). The best models of pH, F_c, F_s and T_c were able to distinguish low and high values and hence found appropriate for screening purpose (1.5 < RPD < 2.0). The use of intact samples was found to yield PLSR models of the compositional attributes with improved accuracy than grated counterpart by comparing the mean values of their RMSE distribution. The performance of PLSR models of CC, AA, TFC and TPC of tender jackfruit (raw and thermal processed) yielded better results when dried than in fresh/wet condition. The DLP NIRscan Nano was found to be satisfactory for cost effective characterization of both TFC (R^2: 0.74–0.79; RMSE = 2.42–4.30; RPD = 2.00–3.34) and TPC (R^2 = 0.66–0.88; RMSE = 0.03–0.06; RPD = 1.72–2.88) of skin, tendril and core components of tender jackfruit. The overall results of the analyses advocates the use of NIRS for a rapid, reliable, non-destructive and non-invasive quality assessment of tender jackfruit.

Highlights

- Demonstrated thermal processing of tender jackfruit in TFS cans as a promising technique for its safe storage even without preservatives.
- Novel application of NIRS for quality assessment of fresh and thermal processed tender jackfruit.
- NIRS models of CC, AA, TFC and TPC exhibited better performance using dried tender jackfruit samples than fresh counterparts.
- Tender jackfruit components vary significantly with regard to TPC.
- NIRS device estimate TFC and TPC cost effectively with reasonable accuracy.

Future scope

- The standardized thermal processing parameters identified in this study may be used for commercial scale production of canned tender jackfruit.
- Kinetic modelling to predict physicochemical quality changes during thermal processing of canned tender jackfruit.
- Update the existing spectral library using more diverse samples to develop more robust calibration functions of quality attributes of tender jackfruit.

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APPENDIX A

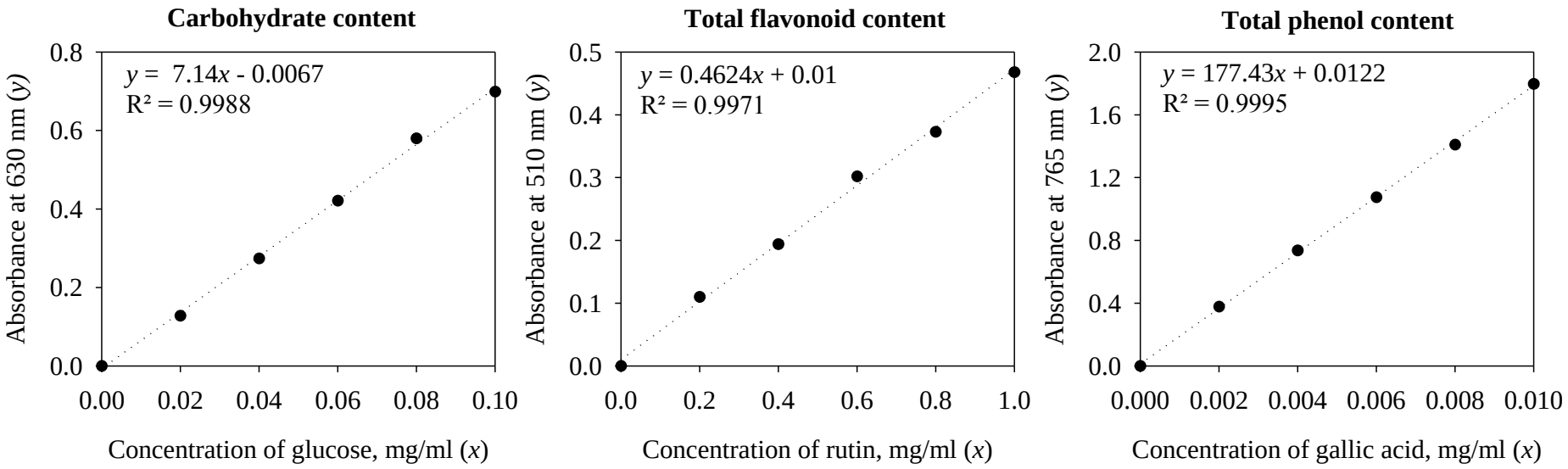


Fig. A1 Standard curve used for the determination of carbohydrate, total flavonoid and phenol contents of tender jackfruit samples

APPENDIX B

Table B1 Sample collection details of Set-1 dataset used for near infrared reflectance spectroscopic analyses

ID	Latitude (deg-min-sec)	Longitude (deg-min-sec)	District	Variety	*L* (cm)	*C* (cm)	*D* (cm)	*AMD*	*GMD*	*f*	*AR*	d_c (cm)	t_t (cm)	t_s (cm)
1	10 51 12	75 59 12	Malappuram	*Varikka*	19.00	28.40	9.04	14.02	11.58	60.97	0.48	3.90	1.00	0.80
2	10 51 46	75 59 17	Malappuram	*Koozha*	11.40	22.50	7.17	9.28	8.37	73.38	0.63	3.00	0.70	0.75
3	10 50 37	76 00 16	Malappuram	*Varikka*	15.80	25.60	8.15	11.98	10.16	64.33	0.52	3.20	1.00	0.60
4	10 50 37	76 00 16	Malappuram	*Varikka*	12.70	25.20	8.03	10.36	9.35	73.64	0.63	4.70	0.45	0.70
5	10 51 08	75 59 19	Malappuram	*Varikka*	18.50	29.20	9.30	13.90	11.70	63.22	0.50	2.90	1.10	0.70
6	10 51 06	76 00 09	Malappuram	*Varikka*	21.90	27.10	8.63	15.27	11.77	53.75	0.39	3.65	1.00	0.60
7	10 51 06	76 00 09	Malappuram	*Varikka*	26.00	27.50	8.76	17.38	12.59	48.41	0.34	4.70	0.70	0.70
8	10 51 06	76 00 09	Malappuram	*Varikka*	27.60	27.20	8.66	18.13	12.75	46.18	0.31	4.30	0.50	1.10
9	10 51 08	75 59 19	Malappuram	*Varikka*	27.30	16.80	5.35	16.33	9.21	33.74	0.20	3.60	0.70	1.00
10	10 51 08	75 59 19	Malappuram	*Varikka*	26.00	24.40	7.77	16.89	11.62	44.70	0.30	3.70	0.50	1.00
11	10 50 18	76 00 09	Malappuram	*Varikka*	18.00	29.50	9.39	13.70	11.67	64.83	0.52	3.40	1.10	0.80
12	10 50 37	76 00 16	Malappuram	*Varikka*	27.20	26.69	8.50	17.60	12.45	46.64	0.32	3.70	1.40	0.60
13	10 50 37	76 00 16	Malappuram	*Varikka*	24.00	27.10	8.63	16.32	12.14	50.57	0.36	3.50	0.90	0.60
14	10 50 03	75 59 41	Malappuram	*Varikka*	17.00	30.10	9.59	13.29	11.60	68.25	0.56	5.70	0.70	0.60
15	10 49 41	75 59 39	Malappuram	*Koozha*	11.00	24.50	7.80	8.75	79.54	0.71	0.00	3.10	1.10	0.70
16	10 49 41	75 59 39	Malappuram	*Koozha*	23.40	32.30	10.29	16.84	13.53	57.81	0.44	3.60	1.00	1.00
17	10 49 41	75 59 39	Malappuram	*Varikka*	23.00	26.00	8.28	15.64	11.64	50.61	0.36	3.90	1.00	0.40
18	10 49 55	75 59 42	Malappuram	*Koozha*	15.60	31.20	9.94	12.77	11.55	74.03	0.64	3.00	1.90	0.70

Table B1 continued

ID	Latitude	Longitude	District	Variety	*L*	*C*	*D*	*AMD*	*GMD*	*f*	*AR*	d_c	t_t	t_s
19	10 49 55	75 59 42	Malappuram	*Varikka*	19.00	35.00	11.15	15.07	13.32	70.08	0.59	3.40	1.70	0.80
20	10 47 41	75 59 44	Malappuram	*Varikka*	19.50	27.10	8.63	14.07	11.32	58.08	0.44	2.50	1.40	0.70
21	09 02 51	76 55 09	Kollam	*Koozha*	23.70	29.40	9.36	16.53	12.76	53.84	0.40	3.80	0.80	0.90
22	09 02 45	76 55 10	Kollam	*Koozha*	19.90	31.30	9.97	14.93	12.55	63.07	0.50	4.20	0.90	1.00
23	09 02 45	76 55 10	Kollam	*Koozha*	17.60	30.90	9.84	13.72	11.95	67.87	0.56	3.80	1.20	0.70
24	09 01 51	76 55 22	Kollam	*Koozha*	14.70	32.90	10.48	12.59	11.73	79.79	0.71	5.10	1.10	0.80
25	09 01 51	76 55 22	Kollam	*Varikka*	16.70	37.30	11.88	14.29	13.31	79.68	0.71	3.10	2.00	0.70
26	09 04 58	76 52 38	Kollam	NA	17.60	32.50	10.35	13.98	12.35	70.19	0.59	4.00	1.20	0.70
27	09 04 59	76 52 38	Kollam	NA	23.20	30.70	9.78	16.49	13.04	56.21	0.42	3.50	1.40	0.80
28	09 04 59	76 52 38	Pathanamthitta	*Varikka*	22.10	33.10	10.54	16.32	13.49	61.05	0.48	4.50	1.20	1.00
29	09 08 30	76 47 22	Pathanamthitta	*Varikka*	19.70	31.90	10.16	14.93	12.67	64.31	0.52	3.50	2.00	1.20
30	09 09 43	76 43 15	Pathanamthitta	NA	16.20	30.30	9.65	12.92	11.47	70.79	0.60	4.60	0.90	0.90
31	09 09 39	76 43 09	Pathanamthitta	NA	18.10	30.20	9.62	13.86	11.87	65.60	0.53	3.70	1.20	0.90
32	09 09 53	76 41 27	Pathanamthitta	*Varikka*	19.20	31.90	10.16	14.68	12.56	65.42	0.53	4.40	1.50	1.00
33	09 09 57	76 40 28	Alappuzha	*Koozha*	16.70	27.60	8.79	12.74	10.89	65.19	0.53	3.90	1.00	0.70
34	09 09 58	76 40 22	Alappuzha	*Koozha*	16.20	32.20	10.25	13.23	11.94	73.72	0.63	4.00	1.10	1.30
35	09 09 58	76 40 22	Alappuzha	NA	22.40	35.50	11.31	16.85	14.20	63.39	0.50	4.40	1.80	0.70
36	09 10 10	76 39 18	Alappuzha	*Varikka*	19.30	28.90	9.20	14.25	11.78	61.04	0.48	3.10	1.20	0.80
37	09 10 10	76 39 18	Alappuzha	*Varikka*	19.70	31.10	9.90	14.80	12.46	63.23	0.50	3.50	1.30	1.10
38	09 10 10	76 39 18	Alappuzha	NA	19.60	34.60	11.02	15.31	13.35	68.12	0.56	3.40	1.90	0.70
39	09 10 10	76 39 18	Alappuzha	*Varikka*	15.20	27.20	8.66	11.93	10.45	68.74	0.57	4.50	0.70	0.70

Table B1 continued

ID	Latitude	Longitude	District	Variety	*L*	*C*	*D*	*AMD*	*GMD*	*f*	*AR*	d_c	t_t	t_s
40	09 10 19	76 38 56	Alappuzha	*Koozha*	14.20	31.60	10.06	12.13	11.29	79.49	0.71	3.90	1.90	1.40
41	09 10 20	76 38 56	Alappuzha	*Koozha*	25.90	37.00	11.78	18.84	15.32	59.15	0.45	5.60	1.40	0.90
42	09 10 01	76 39 11	Alappuzha	*Varikka*	22.30	32.70	10.41	16.36	13.42	60.19	0.47	4.00	1.10	1.10
43	09 10 36	76 38 14	Alappuzha	*Koozha*	18.30	35.50	11.31	14.80	13.27	72.54	0.62	5.00	1.50	0.70
44	09 10 49	76 31 47	Alappuzha	*Varikka*	22.90	33.00	10.51	16.70	13.62	59.50	0.46	3.50	1.50	0.70
45	09 10 49	76 31 30	Alappuzha	NA	19.70	30.70	9.78	14.74	12.35	62.68	0.50	4.30	1.10	0.70
46	09 10 49	76 31 30	Alappuzha	NA	18.30	27.40	8.73	13.51	11.17	61.04	0.48	3.50	1.20	0.70
47	09 13 10	76 28 42	Alappuzha	*Koozha*	17.90	30.50	9.71	13.81	11.91	66.53	0.54	5.20	0.70	0.80
48	09 21 58	76 21 45	Alappuzha	*Varikka*	16.70	36.40	11.59	14.15	13.09	78.40	0.69	3.40	2.60	0.70
49	09 29 12	76 20 20	Alappuzha	NA	24.50	30.30	9.65	17.07	13.16	53.73	0.39	3.70	1.80	0.70
50	09 33 44	76 19 48	Alappuzha	*Varikka*	20.30	34.50	10.99	15.64	13.48	66.41	0.54	3.40	1.90	0.80
51	10 51 12	75 59 15	Malappuram	NA	21.60	27.50	8.76	15.18	11.83	54.78	0.41	3.20	1.20	0.50
52	10 51 12	75 59 15	Malappuram	NA	19.10	32.00	10.19	14.65	12.56	65.78	0.53	4.50	1.20	0.50
53	10 51 12	75 59 15	Malappuram	NA	24.00	31.60	10.06	17.03	13.45	56.02	0.42	4.40	1.30	0.60
54	10 50 01	75 58 13	Malappuram	*Varikka*	17.00	31.60	10.06	13.53	11.99	70.50	0.59	4.60	1.20	NA
55	10 49 21	75 57 42	Malappuram	*Varikka*	21.10	31.00	9.87	15.49	12.72	60.27	0.47	5.40	1.00	NA
56	10 49 24	75 58 02	Malappuram	*Varikka*	22.60	29.00	9.24	15.92	12.45	55.07	0.41	3.00	1.40	NA
57	10 50 18	75 59 48	Malappuram	*Varikka*	14.50	27.50	8.76	11.63	10.36	71.45	0.60	3.00	1.60	NA
58	10 50 20	75 59 50	Malappuram	*Varikka*	17.40	28.00	8.92	13.16	11.14	64.04	0.51	4.10	1.00	NA

L: length; *C*: circumference; *D*: outer diameter; *AMD*: arithmetic mean diameter; *GMD*: geometric mean diameter; *f*: sphericity; *AR*: aspect ratio; d_c: core diameter; t_t: thickness of tendril; t_s: thickness of skin; NA: not available during sample collection

Table B2 Sample collection details of Set-3 dataset used for near infrared reflectance spectroscopic analyses

ID	Latitude (deg-min-sec)	Longitude (deg-min-sec)	District	Variety	*L* (cm)	*C* (cm)	*D* (cm)	*AMD*	*GMD*	*f*	*AR*	d_c (cm)	t_t (cm)	t_s (cm)
1	10 35 59	76 02 24	Thrissur	*Varikka*	22.40	31.10	9.90	13.00	58.02	0.44	4.00	1.20	0.90	16.15
2	10 36 09	76 02 15	Thrissur	*Koozha*	21.50	29.50	9.39	12.38	57.56	0.44	5.00	0.90	0.80	15.45
3	10 35 38	76 02 17	Thrissur	*Varikka*	21.50	33.50	10.67	13.47	62.66	0.50	4.60	1.70	1.40	16.08
4	10 36 28	76 04 40	Thrissur	*Varikka*	14.00	32.00	10.19	11.33	80.89	0.73	5.20	1.10	0.70	12.09
5	10 36 26	76 04 40	Thrissur	*Koozha*	17.60	25.00	7.96	10.37	58.91	0.45	4.40	0.80	0.60	12.78
6	10 36 32	76 04 54	Thrissur	*Varikka*	16.50	30.10	9.59	11.48	69.60	0.58	4.50	1.40	0.80	13.04
7	10 36 49	76 05 07	Thrissur	*'Thamara'*	14.00	33.00	10.51	11.56	82.57	0.75	5.00	1.30	0.80	12.25
8	10 36 49	76 05 07	Thrissur	NA	15.20	30.50	9.71	11.27	74.17	0.64	3.50	1.50	1.20	12.45
9	10 35 31	76 5 22	Thrissur	*Varikka*	20.20	30.50	9.71	12.39	61.36	0.48	5.00	1.40	0.50	14.95
10	10 36 49	76 05 03	Thrissur	*Koozha*	19.00	32.00	10.19	12.54	65.99	0.54	5.00	0.80	1.00	14.59
11	10 36 50	76 05 01	Thrissur	*Koozha*	21.50	31.00	9.87	12.79	59.50	0.46	4.60	1.30	1.10	15.68
12	10 36 49	76 05 00	Thrissur	*Varikka*	18.20	26.00	8.28	10.76	59.13	0.45	3.70	1.00	0.60	13.24
13	10 36 49	76 04 60	Thrissur	*Varikka*	18.50	26.80	8.54	11.04	59.69	0.46	3.70	0.80	1.20	13.52
14	10 36 49	76 04 59	Thrissur	NA	15.20	25.00	7.96	9.87	64.96	0.52	4.20	0.80	0.60	11.58
15	10 36 48	76 05 07	Thrissur	*Varikka*	17.30	21.00	6.69	9.18	53.05	0.39	5.10	0.90	0.90	11.99
16	10 48 39	76 00 36	Malappuram	NA	20.60	29.00	9.24	12.06	58.56	0.45	3.80	1.40	0.90	14.92
17	10 48 39	76 00 36	Malappuram	NA	21.50	33.00	10.51	13.34	62.03	0.49	3.60	1.70	0.80	16.00
18	10 49 39	76 02 07	Palakkad	NA	22.70	38.00	12.10	14.92	65.73	0.53	3.70	2.50	0.40	17.40
19	10 49 59	76 02 18	Palakkad	*Varikka*	19.60	30.50	9.71	12.27	62.60	0.50	5.00	1.00	0.80	14.65
20	10 49 53	76 02 37	Palakkad	*Varikka*	25.40	33.00	10.51	14.10	55.51	0.41	5.00	1.60	0.30	17.95

Table B2 continued

ID	Latitude	Longitude	District	Variety	*L*	*C*	*D*	*AMD*	*GMD*	*f*	*AR*	d_c	t_t	t_s
21	10 49 53	76 02 37	Palakkad	*Varikka*	15.60	29.00	9.24	11.00	70.48	0.59	3.50	1.90	0.80	12.42
22	10 53 02	76 04 35	Malappuram	*Koozha*	20.00	30.50	9.71	12.35	61.77	0.49	3.80	1.40	0.70	14.85
23	10 49 46	76 01 18	Malappuram	*Koozha*	19.10	28.00	8.92	11.49	60.16	0.47	4.80	0.50	1.00	14.01
24	10 49 45	76 01 18	Malappuram	*Koozha*	16.80	32.00	10.19	12.03	71.64	0.61	5.20	1.30	0.90	13.49
25	10 49 45	76 01 19	Malappuram	*Varikka*	17.80	32.00	10.19	12.27	68.93	0.57	3.90	1.50	0.40	13.99
26	10 49 45	76 01 19	Malappuram	*Varikka*	17.00	27.50	8.76	10.92	64.24	0.51	3.90	0.90	1.10	12.88
27	10 51 13	75 59 17	Malappuram	NA	16.20	31.50	10.03	11.77	72.63	0.62	4.30	2.00	0.30	13.11
28	10 51 13	75 59 17	Malappuram	NA	22.80	33.00	10.51	13.60	59.65	0.46	4.90	1.10	1.00	16.65
29	10 51 46	75 59 17	Malappuram	*Koozha*	19.30	28.50	9.08	11.67	60.45	0.47	4.00	0.90	0.60	14.19
30	10 51 12	75 59 21	Malappuram	NA	16.10	27.00	8.60	10.59	65.80	0.53	4.50	0.90	0.40	12.35
31	10 51 12	75 59 21	Malappuram	NA	21.50	25.00	7.96	11.08	51.55	0.37	3.80	0.70	0.40	14.73
32	10 51 12	75 59 21	Malappuram	NA	24.00	27.00	8.60	12.10	50.43	0.36	4.40	0.90	0.60	16.30
33	10 51 36	75 59 19	Malappuram	NA	17.30	27.00	8.60	10.85	62.73	0.50	4.40	1.10	0.50	12.95
34	10 51 36	75 59 19	Malappuram	NA	18.80	28.10	8.95	11.46	60.94	0.48	5.00	1.20	0.40	13.87
35	10 51 13	75 59 17	Malappuram	NA	22.90	34.50	10.99	14.03	61.27	0.48	5.80	1.30	0.80	16.94
36	10 51 13	75 59 17	Malappuram	NA	19.20	29.50	9.39	11.92	62.07	0.49	4.80	0.90	1.10	14.30
37	10 50 29	75 59 50	Malappuram	*Varikka*	18.50	23.00	7.32	9.97	53.90	0.40	3.50	0.30	0.80	12.91
38	10 50 29	75 59 51	Malappuram	NA	14.00	31.50	10.03	11.21	80.05	0.72	3.80	1.00	1.30	12.01
39	10 50 29	75 59 51	Malappuram	*Varikka*	18.10	29.00	9.24	11.55	63.83	0.51	3.70	0.80	1.10	13.67
40	10 50 29	75 59 51	Malappuram	*Varikka*	16.10	28.50	9.08	10.98	68.22	0.56	3.50	0.60	0.90	12.59
41	10 50 30	75 59 53	Malappuram	*Varikka*	15.70	28.00	8.92	10.76	68.56	0.57	3.80	0.80	0.60	12.31

Table B2 continued

ID	Latitude	Longitude	District	Variety	*L*	*C*	*D*	*AMD*	*GMD*	*f*	*AR*	d_c	t_t	t_s
42	10 50 30	75 59 53	Malappuram	*Koozha*	13.40	27.50	8.76	10.09	75.29	0.65	3.10	1.20	0.60	11.08
43	10 50 29	75 59 59	Malappuram	*Varikka*	20.80	30.00	9.55	12.38	59.51	0.46	5.20	1.00	0.60	15.17
44	10 50 29	75 59 59	Malappuram	*Koozha*	16.20	34.00	10.83	12.38	76.42	0.67	4.20	1.20	0.80	13.51
45	10 50 28	76 00 05	Malappuram	*Varikka*	14.20	32.00	10.19	11.38	80.13	0.72	3.80	1.30	0.80	12.19
46	10 50 18	76 00 29	Malappuram	*Varikka*	18.80	33.50	10.67	12.49	66.46	0.54	4.20	1.00	1.10	14.49
47	10 50 18	76 00 29	Malappuram	*Koozha*	17.00	32.00	10.19	12.08	71.07	0.60	5.60	0.70	1.00	13.59
48	10 50 19	76 00 29	Malappuram	*Varikka*	19.60	28.00	8.92	11.59	59.13	0.45	3.80	0.50	1.00	14.26
49	10 50 19	76 00 28	Malappuram	*Koozha*	16.00	26.50	8.44	10.44	65.26	0.53	3.70	0.60	0.90	12.22
50	10 50 56	75 59 15	Malappuram	NA	17.00	29.00	9.24	11.31	66.56	0.54	4.00	0.60	1.30	13.12
51	10 51 42	75 59 22	Malappuram	NA	18.80	32.00	10.19	12.49	66.46	0.54	5.10	1.20	1.10	14.49
52	10 51 42	75 59 22	Malappuram	NA	19.20	32.00	10.19	12.58	65.53	0.53	5.00	1.10	0.70	14.69
53	10 51 42	75 59 22	Malappuram	NA	15.00	30.00	9.55	11.10	74.00	0.64	5.10	0.30	1.10	12.27
54	10 51 12	75 59 15	Malappuram	NA	26.10	34.50	10.99	14.66	56.15	0.42	5.00	1.20	0.80	18.54
55	10 51 12	75 59 15	Malappuram	NA	18.50	32.00	10.19	12.43	67.18	0.55	4.00	1.00	1.00	14.34
56	10 51 12	75 59 15	Malappuram	NA	29.00	32.00	10.19	14.44	49.78	0.35	4.50	1.20	0.70	19.59
57	10 51 12	75 59 15	Malappuram	NA	23.60	27.00	8.60	12.04	51.00	0.36	4.60	0.60	0.50	16.10
58	10 51 12	75 59 15	Malappuram	NA	21.00	29.00	9.24	12.14	57.81	0.44	4.90	0.80	0.60	15.12
59	10 51 12	75 59 15	Malappuram	NA	22.60	32.00	10.19	13.29	58.78	0.45	5.70	0.60	0.80	16.39
60	10 51 12	75 59 15	Malappuram	NA	23.70	30.50	9.71	13.07	55.16	0.41	4.10	1.00	0.60	16.70

L: length; *C*: circumference; *D*: outer diameter; *AMD*: arithmetic mean diameter; *GMD*: geometric mean diameter; *f*: sphericity; *AR*: aspect ratio; d_c: core diameter; t_t: thickness of tendril; t_s: thickness of skin; NA: not available during sample collection

APPENDIX C

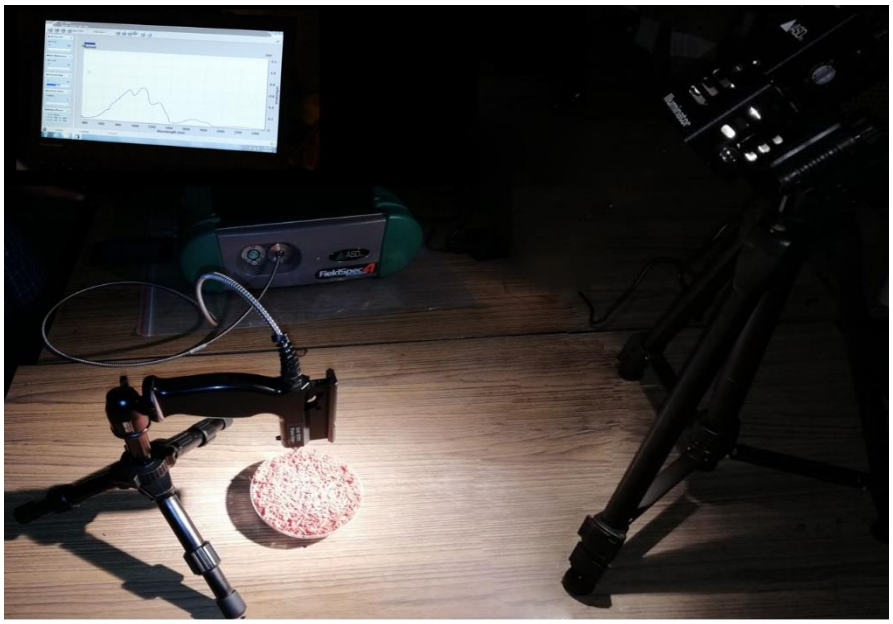


Plate C1. Spectra acquisition using ASD FieldSpec-4 spectroradiometer

Table C1 Specifications of ASD FieldSpec-4 spectroradiometer

Specification[#]		**Details**[#]
Spectral range	:	350-2500 nm
Spectral resolution	:	3 nm @ 700 nm; 8 nm @ 1400/2100 nm
Spectral sampling	:	1.4 nm @ 350-1000 nm; 1.1 nm @ 1001-2500 nm
Scanning time	:	100 milliseconds
Stray light specification	:	VNIR 0.02%, SWIR 1 & 2 0.01%
Wavelength reproducibility	:	0.1 nm
Wavelength accuracy	:	0.5 nm
Channels	:	2151
Detectors	:	VNIR detector (350-1000 nm): 512 element silicon array
		SWIR 1 detector (1001-1800 nm): Graded Index InGaAs Photodiode, Two Stage TE Cooled
		SWIR 2 detector (1801-2500 nm): Graded Index InGaAs Photodiode, Two Stage TE Cooled
Input	:	1.5 m fibre optic (25° field of view). Optional narrower field of view fibre optics available.
Noise equivalent radiance	:	VNIR 1.0×10^{-9} W/cm^2/nm/sr @ 700 nm
		SWIR 1 1.4×10^{-9} W/cm^2/nm/sr @ 1400 nm
		SWIR 2 2.2×10^{-9} W/cm^2/nm/sr @ 2100 nm
Weight	:	5.44 kg (12 lbs)

[#]Source: https://www.malvernpanalytical.com

Plate C2. Spectra acquisition using DLP NIRscan Nano

Table C2 Specifications of DLP NIRscan Nano (Source: http://www.ti.com/)

Specification		**Details**
Spectral range	:	900-1700 nm
Spectral resolution	:	10 nm
Channels	:	228
Lamp power	:	1.4 W
Detectors	:	1-mm single-pixel InGaAs non-cooled detector
Temperature	:	0-50^{o}C

APPENDIX D

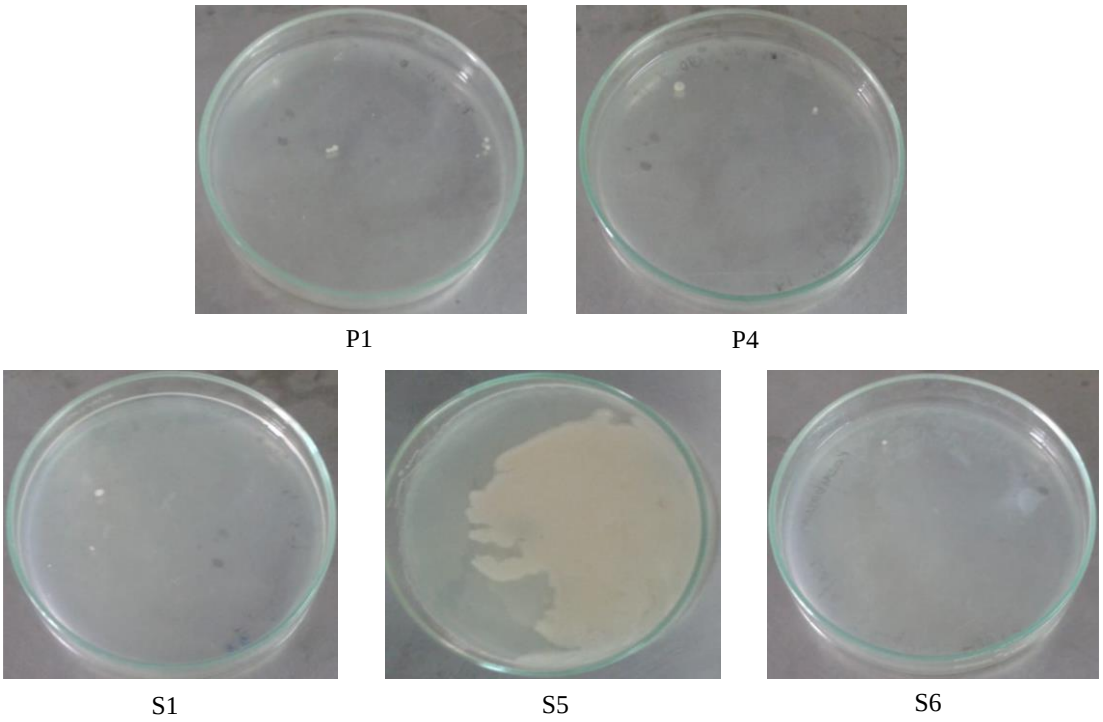
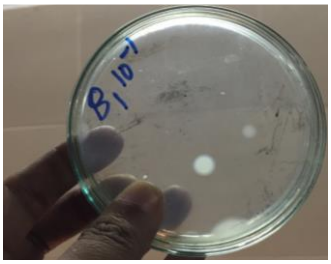
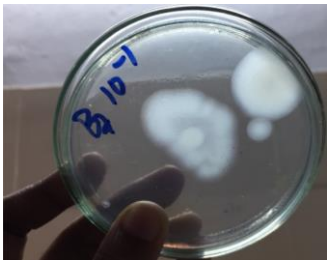


Plate D1. Petri plates (10^{-1} dilution) showing bacterial count in different thermal process treatments. P and S represents pasteurization and sterilization treatments, respectively.

APPENDIX E

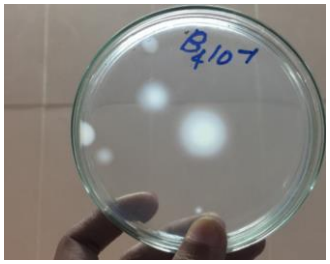


M-NP

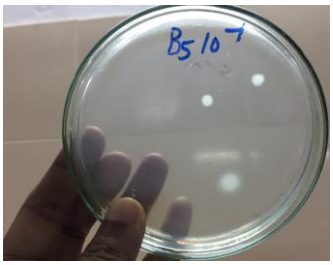


M-B

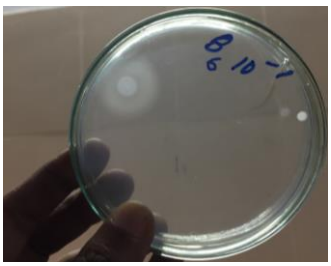
M-KMS



M-CA



M-B+KMS



M-KMS+CA

Plate E1. Petri plates (10^{-1} dilution) showing microbial growth in canned tender jackfruit subjected to mild treatment (M). NP: no preservative; B: brine; KMS: potassium metabisulphite; CA: citric acid.

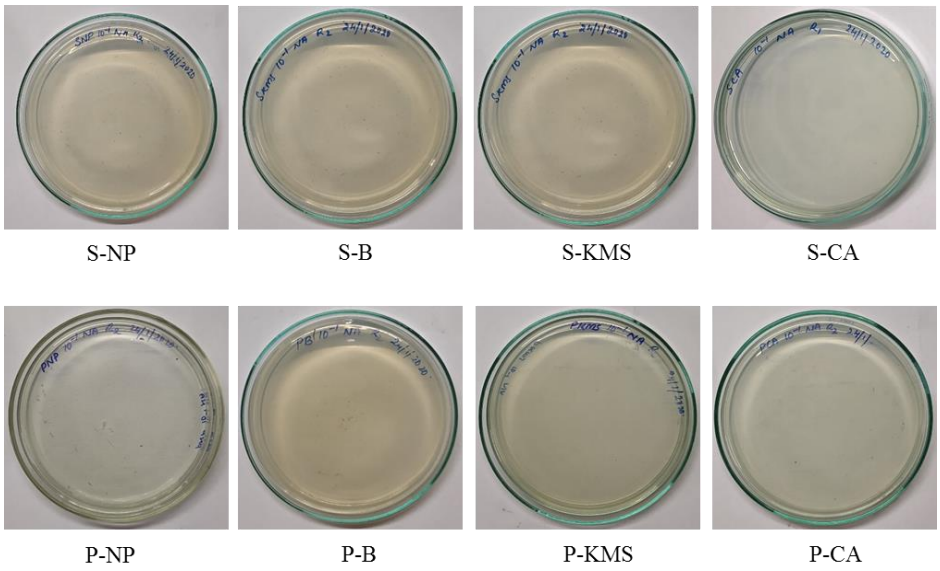


Plate E2. Petri plates with nutrient agar medium (10^{-1} dilution) showing no bacterial growth in thermal processed canned tender jackfruit after 8 months of storage. P and S represents pasteurization and sterilization treatments, respectively. NP: no preservative; B: brine; KMS: potassium metabisulphite; CA: citric acid.

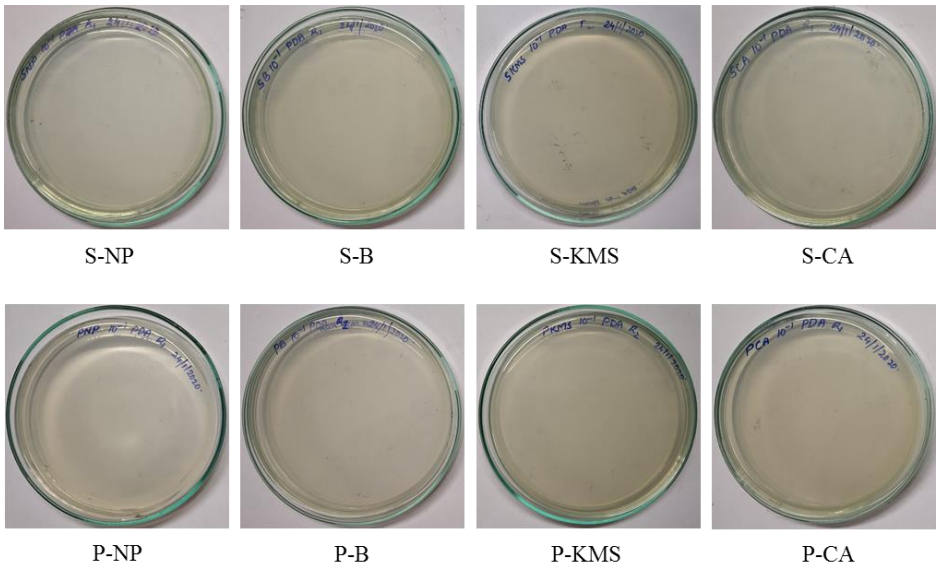


Plate E3. Petri plates with potato dextrose medium (10^{-1} dilution) showing no fungal and yeast growth in thermal processed canned tender jackfruit after 8 months of storage. P and S represents pasteurization and sterilization treatments, respectively. NP: no preservative; B: brine; KMS: potassium metabisulphite; CA: citric acid.

APPENDIX F

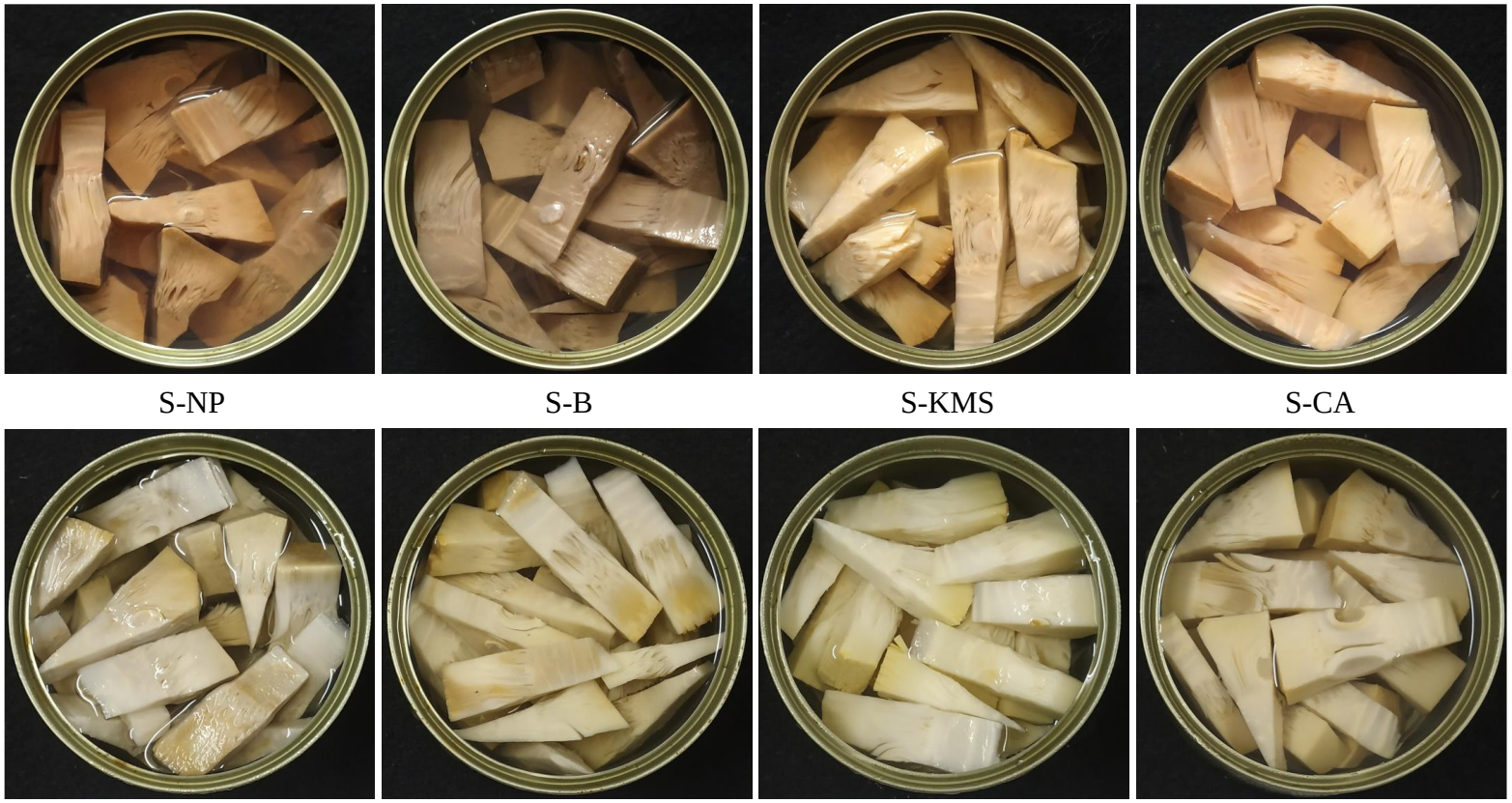


Plate F1. Thermal processed canned tender jackfruit after 8 months of storage. P and S represents pasteurization and sterilization treatments, respectively. NP: no preservative; B: brine; KMS: potassium metabisulphite; CA: citric acid.

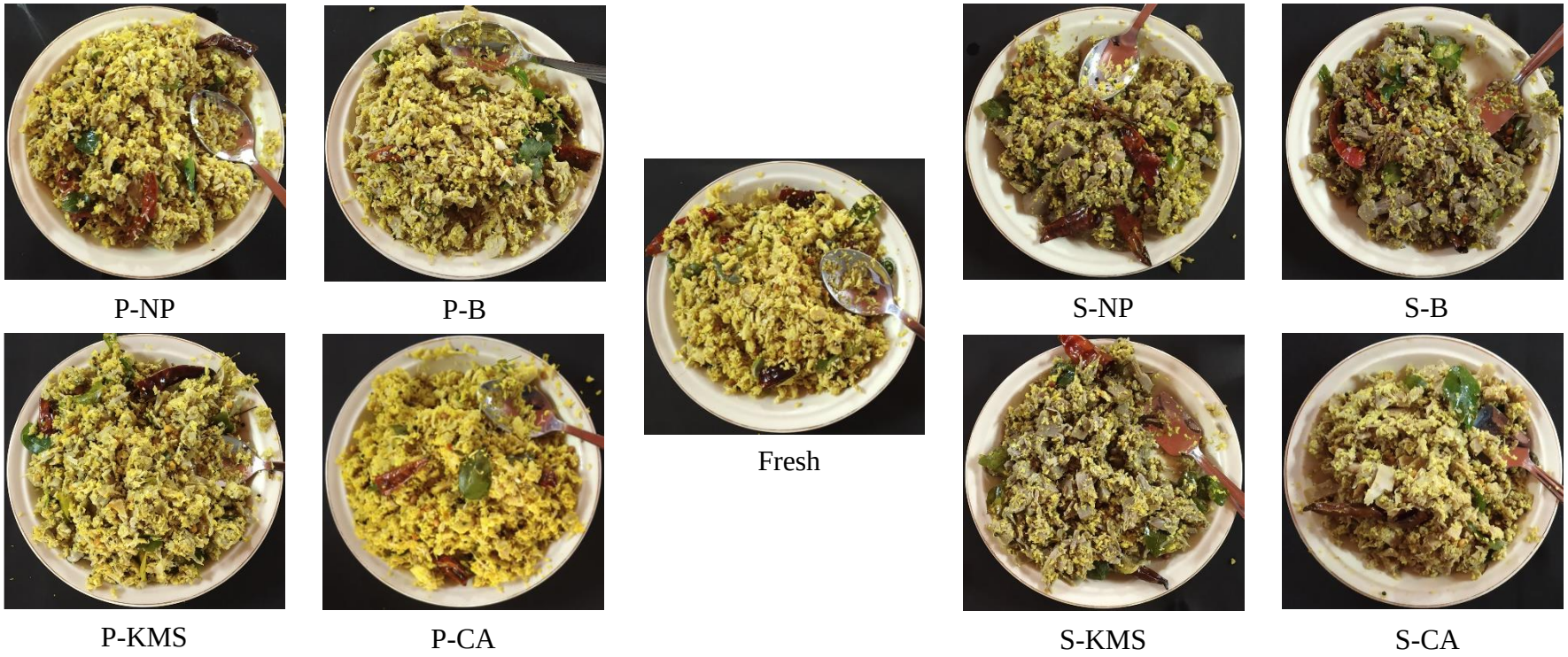


Plate F2. Curry prepared for sensory evaluation using fresh and thermal processed canned tender jackfruit (stored for 8 months). P and S represents pasteurization and sterilization treatments, respectively. NP: no preservative; B: brine; KMS: potassium metabisulphite; CA: citric acid.

APPENDIX G

Cost estimation for the production of thermal processed canned tender jackfruit

Initial cost: Cost of machineries and building

Cost of boiler retort, hydraulic can seamer, installation, weighing balance and utensils	=	Rs. 1500000.00
Building cost (500 sq.ft) @ 1500/sq.ft	=	Rs. 750000.00
Miscellaneous items	=	Rs. 100000.00
Total initial cost (C)	=	Rs. 2350000.00

Assumptions

Useful life (n)	=	10 years
Salvage value (S)	=	$0.10 \times C$
Annual interest (r)	=	$0.12 \times C$
Insurance and taxes (i)	=	$0.02 \times C$
Repair and maintenance (m)	=	$0.05 \times C$
Number of working days per year (D)	=	150
Number of working shifts per day (n_s)	=	2
Duration of a working shift (d_s)	=	8 h
Electricity consumption per shift (E_s)	=	20 KWH
Electricity charge per unit (c_e)	=	Rs. 7.00
Fuel (diesel) required for boiler operation per hour (f)	=	6 L
Cost of diesel per litre (c_f)	=	Rs. 74.00
Labours required per shift (n_l)	=	4
Cost per labour in a working shift (c_l)	=	Rs. 350.00
Cost of a TFS can with lid including 18% GST (c_c)	=	Rs. 12.39
Cost of 1 kg raw tender jackfruit (c_r)	=	Rs. 20.00
Percentage of edible portion in a raw tender jackfruit (p_e)	=	75%

Annual fixed cost

Depreciation (C_D)	=	$\frac{C - S}{n}$
	=	Rs. 211500.00

Interest (C_I) = $\frac{C+S}{2} \times r$

= Rs. 155100.00

Insurance and taxes (C_{IT}) = $C \times i$

= Rs. 47000.00

Annual fixed cost (AFC) = $C_D + C_I + C_{IT}$

= Rs. 413600.00

Annual variable cost

Repair and maintenance (C_{RM}) = $C \times m$

= Rs. 117500.00

Electricity consumption per day (e_d) = $E_S \times n_s$

= 40 KWH

Electricity charge per year (C_E) = $e_d \times c_e \times D$

= Rs. 42000.00

Diesel required per day (F) = $f \times d_s \times n_s$

= 96 L

Diesel cost per year (C_F) = $F \times c_f$

= Rs. 1065600

Labour cost per day (c_{ld}) = $n_l \times n_s \times c_l$

= Rs. 2800.00

Labour cost per year (C_L) = $c_{ld} \times D$

= Rs. 420000.00

Number of cans treated in a single retort operation (n_c) = 200

Quantity of edible portion of tender jackfruit in each can (q_{e1}) = 85 g

Quantity of edible portion require for a single retort operation (q_e) = $n_c \times q_{e1}$

= 17 kg

Quantity of raw tender jackfruit require for a single retort operation (q_r) = $\frac{q_e}{p_e}$

= 22.67 kg

Time require for a person to peel and cut 1 kg of raw tender jackfruit	=	3 min
Time require for two persons to peel and cut the desired quantity of tender jackfruit for a single retort operation (t_{pc})	=	34 min
Blanching (1 min in boiling water) may be performed at every 12 min during sample preparation, number of blanching operations required	=	3
Time require for blanching beyond the sample preparation period (t_b)	=	1 min
Time require for filling and exhausting of cans required for single retort operation (t_{fe})	=	30 min
Time for sealing of cans required for single retort operation (t_s)	=	35 min
Duration of thermal processing (t_{tp})		
t_{tp} at standardized sterilization temperature	≈	8 min
t_{tp} at standardized pasteurization temperature	≈	19 min
Total time for single retort operation (t_r)	=	$t_{pc} + t_b + t_{fe} + t_s + t_{tp}$
t_r at standardized sterilization temperature	≈	2 h (107 min)
t_r at standardized pasteurization temperature	≈	2 h (118 min)
Number of retort operations per day (n_r)	=	$\frac{n_s \times d_s}{t_r}$
	=	8
Quantity of raw tender jackfruit required per day (q_d)	=	$n_r \times q_r$
	=	181.33 kg
Cost of raw tender jackfruit per year (C_R)	=	$q_d \times D \times c_r$
	=	Rs. 544000.00
Number of cans processed per day (n_{cd})	=	$n_r \times n_c$
	=	1600
Number of cans per year (N_C)	=	$n_{cd} \times D$
	=	240000
Cost of cans per year (C_C)	=	$N_C \times c_c$
	=	Rs. 2973600.00
Total cost of materials (C_M)	=	$C_R + C_C$
	=	Rs. 3517600.00

Annual variable cost (*AVC*) = $C_{RM} + C_E + C_F + C_L + C_M$

= Rs. 5162700.00

Total annual cost (C_{total}) = $AFC + AVC$

= **Rs. 5576300.00**

Production cost per can = $\frac{C_{total}}{N_C}$

= **Rs. 23.23**

APPENDIX H

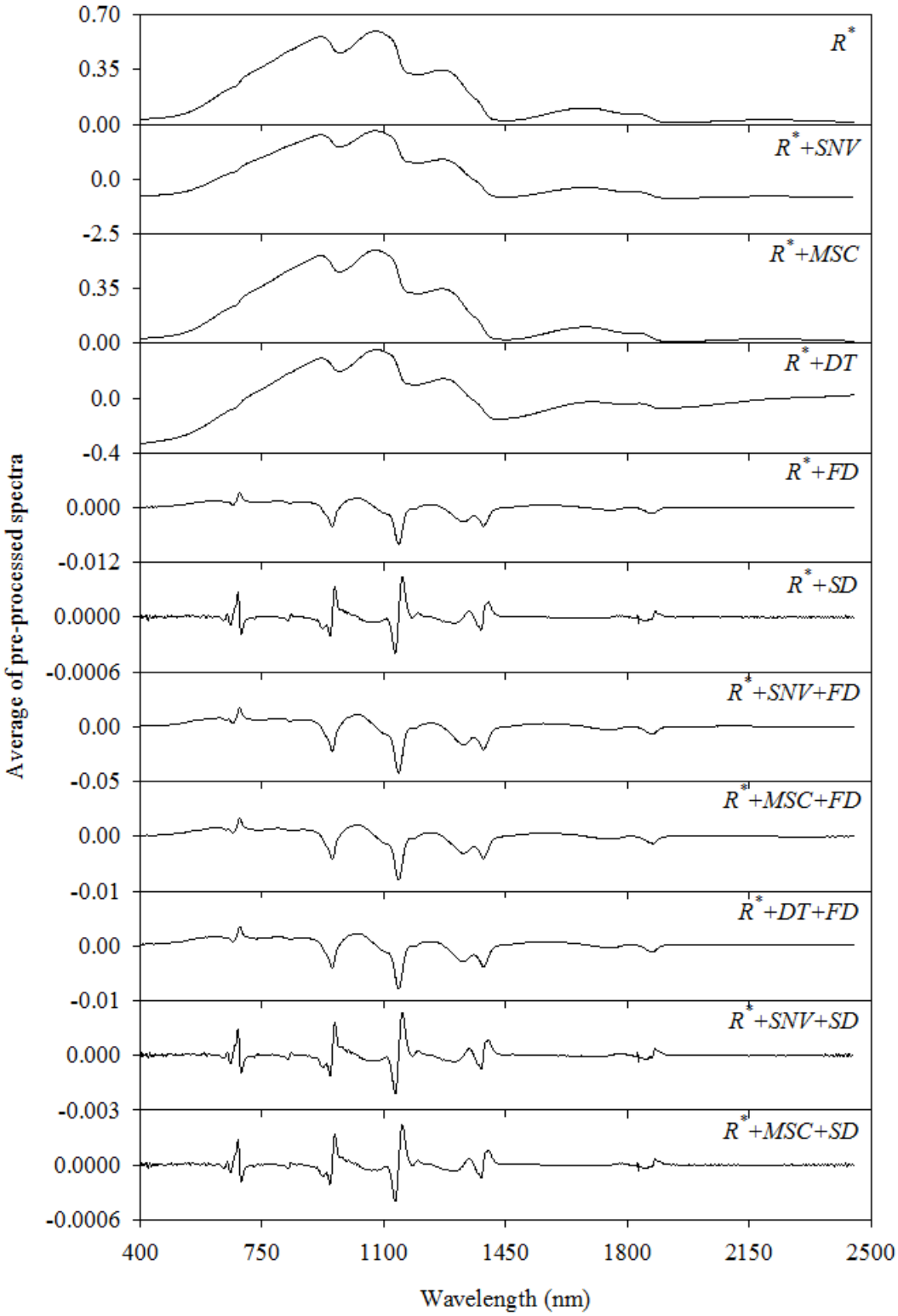


Fig. H1 Average of reflectance spectra subjected to different pre-processing; R^*: reflectance; *SNV*: standard normal variate; *MSC*: multiplicative scatter correction; *DT*: de-trend; *FD*: first derivative; *SD*: second derivative.

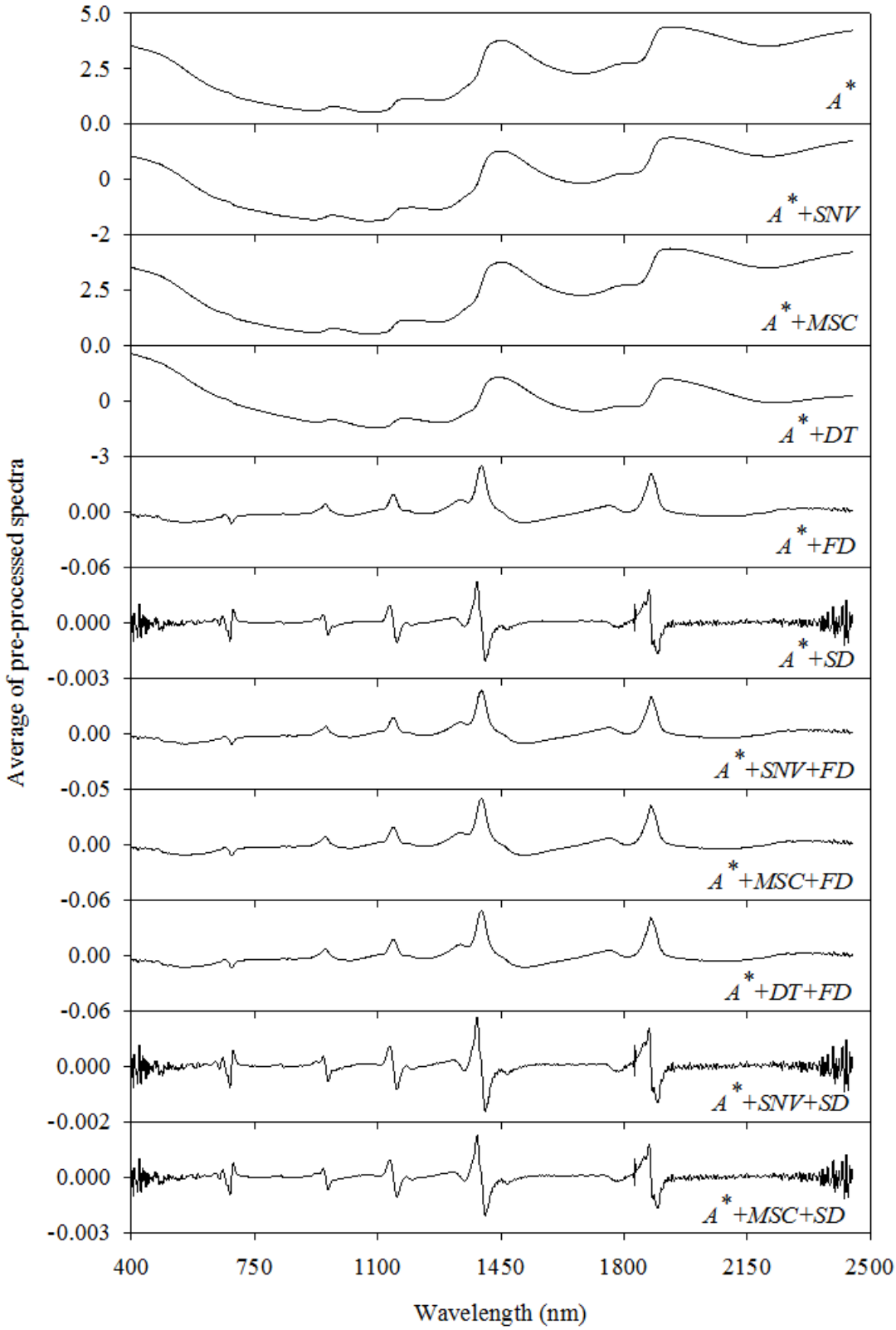


Fig. H2 Average of absorbance spectra subjected to different pre-processing; A^*: absorbance; *SNV*: standard normal variate; *MSC*: multiplicative scatter correction; *DT*: de-trend; *FD*: first derivative; *SD*: second derivative.

Table H1 Range of regression statistics for different wavelength range and pre-processing combinations

Attribute	R^2	RMSE	RPD
pH	0.00 – 0.72	0.12 – 0.22	1.01 – 1.90
Total soluble solids, ^{o}Brix	0.01 – 0.79	0.39 – 0.84	1.01 - 2.20
Titrable acidity, %	0.21 – 0.93	0.03 – 0.08	1.13 – 3.68
Firmness (core), N	0.01 – 0.79	0.71 – 1.53	1.01 – 2.18
Firmness (tendril), N	0.10 – 0.86	0.57 – 1.44	1.07 – 2.67
Firmness (skin), N	0.03 – 0.72	0.77 – 1.44	1.03 – 1.91
Toughness (core), N.s	0.01 – 0.71	2.67 – 4.95	1.01 – 1.88
Toughness (tendril), N.s	0.09 – 0.75	2.16 – 4.16	1.06 – 2.04
Toughness (skin), N.s	0.03 – 0.75	1.99 – 3.89	1.03 – 2.01
L*	0.12 – 0.98	0.54 – 3.61	1.10 – 7.36
a*	0.22 – 0.98	0.15 – 1.06	1.16 – 8.24
b*	0.14 – 0.99	0.10 – 1.28	1.11 – 14.43

R^2: coefficient of determination, RMSE: root mean squared error, RPD: residual prediction deviation

Table H2 Akaike's information criteria value for different pre-processing of wet spectra of thermal processed canned tender jackfruit samples

	L*	a*	b*	ΔE	F_w	MC	pH	TSS	TA	CFC	CC	AA	TFC	TPC
*R**	95.11	63.35	38.89	98.59	45.82	41.25	-36.93	-12.50	-122.23	-81.81	-11.95	9.14	95.34	-103.75
R+SNV*	92.52	59.49	41.84	95.62	49.17	56.28	-38.03	-13.34	-120.93	-82.02	-15.67	8.16	101.00	-96.90
R+MSC*	92.57	59.51	41.84	95.66	49.17	56.39	-38.02	-13.33	-120.93	-82.02	-15.67	8.17	101.01	-96.90
R+DT*	89.58	58.50	38.57	92.82	45.66	43.53	-38.26	-12.70	-122.61	-81.87	-15.51	8.97	94.39	-104.45
R+FD*	92.24	60.09	38.10	95.59	45.25	35.98	-38.58	-13.77	-122.72	-82.69	-15.85	6.99	93.62	-104.74
R+SD*	81.32	**49.99**	**28.69**	84.48	40.54	37.93	**-44.01**	**-20.04**	-127.56	-90.80	-19.10	2.96	87.59	**-107.02**
R+SNV+FD*	91.56	58.87	38.64	94.81	46.65	48.31	-40.55	-15.10	-123.70	-83.92	-16.70	7.04	96.85	-99.74
R+MSC+FD*	91.59	58.89	38.64	94.84	46.65	48.39	-40.53	-15.12	-123.69	-83.92	-16.69	7.07	96.88	-99.69
R+DT+FD*	92.14	59.55	37.17	95.56	45.01	36.11	-38.79	-13.95	-122.86	-83.05	-15.73	7.06	93.92	-103.33
R+SNV+SD*	78.12	51.87	31.88	**81.83**	**36.53**	**30.21**	-43.59	-19.52	**-129.48**	**-95.56**	**-22.54**	**2.46**	**86.40**	-106.25
R+MSC+SD*	**78.11**	51.87	31.88	81.84	36.53	30.41	-43.59	-19.52	-129.48	-95.54	-22.51	2.49	86.43	-106.21

Bold value denotes the column minimum; L*, a*, b*: colour space coordinates, ΔE: total colour difference; F_w: firmness; MC: moisture content; TSS: total soluble solids; TA: titrable acidity; CFC: crude fibre content; CC: carbohydrate content; AA: ascorbic acid; TFC: total flavonoid content; TPC: total phenol content; *R**: reflectance; *SNV*: standard normal variate; *MSC*: multiplicative scatter correction; *DT*: detrend; *FD*: first derivative; *SD*: second derivative.

Table H3 Akaike's information criteria value for different pre-processing of dry spectra of thermal processed canned tender jackfruit samples

	L*	a*	b*	ΔE	F_w	MC	pH	TSS	TA	CFC	CC	AA	TFC	TPC
*R**	91.01	57.65	38.05	94.04	47.39	44.56	-37.14	-14.25	-119.56	-82.47	-9.61	10.59	96.86	-112.02
R+SNV*	92.62	60.99	33.70	96.08	45.67	51.14	-36.93	-17.56	-121.27	-83.12	-13.65	10.14	96.58	-112.46
R+MSC*	92.63	60.99	33.73	96.08	45.71	51.12	-36.93	-17.55	-121.27	-83.11	-13.59	10.15	96.71	-112.46
R+DT*	92.64	60.49	36.73	94.50	48.51	48.97	-36.06	-13.30	-119.31	-82.38	-10.94	10.41	95.55	-113.58
R+FD*	**87.42**	**54.73**	**32.84**	**90.76**	44.77	**39.57**	-38.78	-22.45	-123.04	-84.21	-23.19	6.12	79.64	-123.89
R+SD*	89.17	55.21	36.16	92.10	**42.64**	50.67	-40.70	-15.68	-122.90	-86.17	-28.72	**-17.75**	**68.79**	**-134.31**
R+SNV+FD*	90.10	57.12	33.36	93.28	44.05	48.27	-38.87	**-24.53**	-126.56	-84.97	-20.75	6.43	79.28	-119.47
R+MSC+FD*	90.11	57.12	33.31	93.29	44.11	48.43	-38.89	-24.41	**-126.58**	-84.99	-20.53	6.46	79.36	-119.41
R+DT+FD*	87.78	55.89	34.61	91.11	45.13	43.93	-38.84	-15.14	-122.04	-84.05	-20.64	5.58	82.38	-120.83
R+SNV+SD*	91.14	56.55	36.18	94.10	43.18	55.98	-42.33	-15.25	-125.60	**-86.50**	-32.45	4.97	80.54	-124.10
R+MSC+SD*	91.16	56.55	36.17	94.11	43.23	55.95	**-42.34**	-15.25	-124.78	-86.50	**-32.57**	4.99	80.55	-124.09

Bold value denotes the column minimum; L*, a*, b*: colour space coordinates, ΔE: total colour difference; F_w: firmness; MC: moisture content; TSS: total soluble solids; TA: titrable acidity; CFC: crude fibre content; CC: carbohydrate content; AA: ascorbic acid; TFC: total flavonoid content; TPC: total phenol content; *R**: reflectance; SNV: standard normal variate; MSC: multiplicative scatter correction; DT: detrend; FD: first derivative; SD: second derivative

Table H4 Akaike's information criteria of partial least square regression models of total flavonoid and phenol contents based on spectra of fresh tender jackfruit components

Pre-process	Total flavonoid content			Total phenol content		
	Skin	Tendril	Core	Skin	Tendril	Core
R^*	129.67	120.65	125.47	-130.21	-140.34	-130.31
R^*+*SNV*	127.89	119.65	122.53	-130.88	-141.21	-129.85
R^*+*MSC*	127.91	119.67	122.55	-130.88	-141.16	-129.85
R^*+*DT*	127.30	118.30	123.83	-129.37	-140.24	-131.97
R^*+*FD*	125.87	112.47	120.89	-130.64	-143.56	-134.08
R^*+*SD*	124.51	90.71	**112.78**	-134.18	-145.59	-139.88
R^*+*SNV*+*FD*	126.49	107.17	119.98	-131.93	-142.42	-132.57
R^*+*MSC*+*FD*	126.49	111.48	120.01	-131.96	-142.41	-132.57
R^*+*DT*+*FD*	125.81	112.05	120.99	-130.42	-143.53	-133.88
R^*+*SNV*+*SD*	124.41	81.74	113.62	-135.04	-144.59	-137.75
R^*+*MSC*+*SD*	124.45	82.02	113.65	-135.04	-144.58	-137.77
A^*	129.51	121.20	125.63	-129.02	-139.70	-129.97
A^*+*SNV*	127.53	119.28	123.11	-131.68	-140.44	-128.01
A^*+*MSC*	127.56	119.30	123.12	-131.62	-140.35	-128.00
A^*+*DT*	128.31	119.53	123.28	-129.40	-144.13	-130.20
A^*+*FD*	127.53	116.49	121.69	-130.84	-142.89	-129.87
A^*+*SD*	123.51	84.51	119.04	-135.30	-145.36	**-145.64**
A^*+*SNV*+*FD*	124.87	112.44	121.95	-133.08	-142.05	-129.64
A^*+*MSC*+*FD*	124.79	112.46	121.97	-133.24	-142.04	-129.63
A^*+*DT*+*FD*	127.60	109.59	121.77	-130.69	-142.99	-129.80
A^*+*SNV*+*SD*	122.87	80.94	116.99	**-136.83**	**-149.62**	-136.69
A^*+*MSC*+*SD*	**122.80**	**80.93**	117.02	-136.83	-149.60	-136.64

Bold values denotes the column minimum. R^*: reflectance; *SNV*: standard normal variate; *MSC*: multiplicative scatter correction; *DT*: detrend; *FD*: first derivative; *SD*: second derivative; A^*: absorbance

Table H5 Akaike's information criteria of partial least square regression models of total flavonoid and phenol contents based on spectra of dried tender jackfruit components

Pre-process	Total flavonoid content			Total phenol content		
	Skin	Tendril	Core	Skin	Tendril	Core
R^*	119.97	116.64	123.98	-140.35	-143.93	-134.76
R^*+*SNV*	118.68	115.92	123.40	-141.52	-145.64	-136.55
R^*+*MSC*	116.21	115.86	123.36	-140.89	-145.55	-136.56
R^*+*DT*	120.01	119.32	119.92	-142.88	-146.27	-135.95
R^*+*FD*	105.93	113.17	118.84	-155.99	-147.94	-139.34
R^*+*SD*	85.28	110.22	93.53	-167.20	-154.89	-147.77
R^*+*SNV*+*FD*	107.64	115.10	110.33	-147.48	-147.03	-137.23
R^*+*MSC*+*FD*	108.95	114.88	109.64	-146.11	-147.00	-137.22
R^*+*DT*+*FD*	106.11	115.07	118.58	-153.75	-148.22	-142.17
R^*+*SNV*+*SD*	83.92	74.26	**91.09**	**-180.25**	-177.60	-147.51
R^*+*MSC*+*SD*	82.35	73.82	91.82	-178.21	-150.07	-147.74
A^*	122.83	116.66	124.17	-139.51	-144.21	-134.50
A^*+*SNV*	120.61	116.26	123.22	-140.53	-145.57	-136.46
A^*+*MSC*	116.40	116.21	123.18	-139.50	-145.47	-136.45
A^*+*DT*	120.98	116.70	121.68	-140.13	-147.09	-133.00
A^*+*FD*	111.25	114.44	118.65	-147.73	-148.79	-145.00
A^*+*SD*	**77.86**	**60.45**	103.56	-169.62	-170.18	**-152.94**
A^*+*SNV*+*FD*	107.16	114.82	110.93	-148.13	-146.95	-146.45
A^*+*MSC*+*FD*	104.05	114.46	114.56	-146.16	-146.96	-137.14
A^*+*DT*+*FD*	111.49	114.67	118.47	-148.05	-148.30	-144.04
A^*+*SNV*+*SD*	80.41	65.38	103.38	-179.10	**-186.93**	-151.88
A^*+*MSC*+*SD*	79.20	65.86	103.42	-176.84	-186.73	-151.96

Bold values denotes the column minimum. R^*: reflectance; *SNV*: standard normal variate; *MSC*: multiplicative scatter correction; *DT*: detrend; *FD*: first derivative; *SD*: second derivative; A^*: absorbance

STANDARDIZATION AND NEAR INFRARED REFLECTANCE SPECTROSCOPY BASED QUALITY EVALUATION OF THERMALLY PROCESSED TENDER JACKFRUIT (*Artocarpus heterophyllus* L.)

by

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(2017-28-001)

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the

requirements for the degree of

DOCTOR OF PHILOSOPHY IN AGRICULTURAL ENGINEERING

Faculty of Agricultural Engineering and Technology

Kerala Agricultural University

DEPARTMENT OF PROCESSING & FOOD ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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KERALA, INDIA

2020

ABSTRACT

The present study examined thermal processing in tin free steel cans (TFS) and near infrared reflectance spectroscopy (NIRS) techniques for preservation and rapid characterization of tender jackfruit, respectively. In the thermal processing study, the effect of 16 treatments with different time-temperature combinations on physicochemical and microbiological attributes of canned tender jackfruit were examined. Accordingly, pasteurization at 90^{o}C for 19 min (F = 60 min) and sterilization at 121^{o}C for 8 min (F_0 = 3 min) were identified as the best treatments. During 7 months of storage, these treatments yielded microbiologically safe tender jackfruit with no significant ($p < 0.05$) change in titrable acidity, total soluble solids, carbohydrate and crude fibre contents. In both pasteurization and sterilization treatments with/without preservatives, quality and sensory attributes of canned tender jackfruit were comparable. Hence, the study endorse the use of any of the standardized thermal processing treatments even without preservatives for safe storage of tender jackfruit. The NIRS study was the primary attempt to characterize tender jackfruit (fresh and thermal processed) using its spectral reflectance (R^*) within 400-2500 nm wavelength range by means of partial least square regression (PLSR) algorithm. Based on cross-validation of PLSR models, the study have identified a) second derivative of R^* in 701–2450 nm as the best pre-processing and wavelength combination for the estimation of quality attributes of fresh tender jackfruit, b) spectral measurement of intact tender jackfruit samples outperform grated counterparts, c) dry spectra of thermal processed tender jackfruit yield superior results than wet spectra, d) DLP NIRscan Nano for cost effective characterization of inter component (skin, tendril and core) variability of fresh tender jackfruit with regard to total flavonoid and phenol contents. The overall results of the analyses advocates the use of NIRS for a rapid, reliable, non-destructive and non-invasive quality assessment of tender jackfruit.