DEVELOPMENT OF RAPID GRADING METHOD FOR QUALITY EVALUATION OF TURMERIC RHIZOMES USING FT-NIR SPECTROSCOPY

By

Er. K. DHIVYA, B.Tech. (Agrl. Engg.)

I.D.NO.13-541-005

DEPARTMENT OF FOOD AND AGRICULTURAL PROCESS ENGINEERING

AGRICULTURAL ENGINEERING COLLEGE AND RESEARCH INSTITUTE

TAMILNADU AGRICULTURAL UNIVERSITY

COIMBATORE-641 003

2015

DEVELOPMENT OF RAPID GRADING METHOD FOR QUALITY EVALUATION OF TURMERIC RHIZOMES USING FT-NIR SPECTROSCOPY

Thesis submitted in partial fulfillment of the requirements for the award of the degree of **MASTER OF TECHNOLOGY in AGRICULTURAL PROCESSING AND FOOD ENGINEERING** *to the Tamil Nadu Agricultural University, Coimbatore.*

By

Er. K. DHIVYA, B.Tech. (Agrl. Engg.)

I.D.NO.13-541-005

DEPARTMENT OF FOOD AND AGRICULTURAL PROCESS ENGINEERING

AGRICULTURAL ENGINEERING COLLEGE AND RESEARCH INSTITUTE

TAMILNADU AGRICULTURAL UNIVERSITY

COIMBATORE-641 003

2015

CERTIFICATE

This is to certify that the thesis entitled **"DEVELOPMENT OF RAPID GRADING METHOD FOR QUALITY EVALUATION OF TURMERIC RHIZOMES USING FT-NIR SPECTROSCOPY"** submitted in partial fulfillment of the requirements for the award of the degree of **MASTER OF TECHNOLOGY** in **AGRICULTURAL PROCESSING AND FOOD ENGINEERING** to the Tamil Nadu Agricultural University, Coimbatore is a record of bonafide research work carried out by **Er. K. DHIVYA,** under my supervision and guidance and that no part of the thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles or prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

Place: Coimbatore

Date : **(Dr. K. THANGAVEL)**

Chairman

Approved by

Chairman : (Dr. K. THANGAVEL)

Members : (Dr. M. BALAKRISHNAN)

: (Dr. D. AMIRTHAM)

: (Dr. C. INDU RANI)

Acknowledgement

ACKNOWLEDGEMENT

I am extremely happy to take this opportunity to acknowledge my debts of gratitude to those associated in the preparation of this thesis.

First and foremost, my most sincere gratitude and thanks to the almighty. His grace and tender mercies have renewed me everyday throughout my journey in the research work.

I wish to place my deep sense of gratitude and heartfelt thanks to ***Dr. K. Thangavel****, Professor, Dept. of Fruit Crops, Horticultural College and Research Institute, Periyakulam for his technical guidance, valuable suggestions, keen interest, sustained encouragement, personal affection and care throughout my research work.*

I feel immense pleasure in extending my heartfelt gratitude to the members of the advisory committee ***Dr. D. Amirtham, Dr. M. Balakrishnan****, Assistant Professors, Dept. of Food and Agricultural Process Engineering and* ***Dr. C. Indu Rani****, Assistant Professor (Horticulture) Dept. of Food and Agricultural Process Engineering for their valuable guidance, timely help, suggestions and encouragements throughout the study.*

It is privilege to express my sincere regards to ***Dr. T. Pandiyarajan****, Professor and Head, Dept. of Food and Agricultural Process Engineering for his constant support and timely help rendered during the study period.*

I express my whole hearted thanks to ***Dr. D. Amirtham****, P.G. Co-ordinater for her cordiality, technical guidance and kindly help rendered during the entire course period.*

I express my sincere thanks to ***Dr. C. Indu Rani****, Assistant Professor (Horticulture) Dept. of Food and Agricultural Process Engineering for taking efforts in arranging turmeric samples from Erode.*

I place my profound sense of gratitude to ***Dr. V. Thirupathi, Dr. S. Ganapathy,*** *Professors,* ***Dr. I. P. Suthakar, Dr. R. Arulmari****, Assistant Professors,* ***Dr. N. Varadharaju****, Professor and Head, Post Harvest Technology Centre,* ***Dr. G. Thangamani****, Assistant Professor, (Microbiology) for their suggestions, valuable advice rendered in various stages of the study.*

I wish to express my deep regards and whole hearted thanks to ***Dr. R. Kasthuri*** *Retd. Professor (biochemistry) for her kindly help, care, encouragement and theoretical support extended throughout my research work.*

*I place my sincere thanks to the Director of '****Ulavan Producer Company'****, Erode for providing samples for the research work and his ideas and suggestions regarding the work.*

I humbly express my whole hearted thanks to my seniors ***Dr. M. Pragalyashree, Er. V. Eyarkai nambi, Er. Pandiselvam, Er. Ganesan, Er. V.Chandrasekar, Er. A. Anies rani delfia, Er. Preetha, Er. Gomathy, Er. Jeevarathinam, Er. Sunoj sajahan*** *for their untired help and valuable guidance during my study period.*

I express my deep regards and sincere thanks to my beloved friends ***Aswini, Amreena, Lilly, Puteu, Vidhya, Preethi, Kiran, Ganesh and Rajkumar*** *for their moral support and timely help rendered throughout the study period.*

I also wish to thank all the ***non-teaching staff*** *and* ***workshop staffs*** *for their cooperation and valuable help during my research work.*

Finally I have boundless pleasure in placing my gratitude to my beloved ***parents and sister*** *for their constant support and care, affection and encouragement throughout my academic carrier.*

K. Dhivya

Abstract

ABSTRACT

DEVELOPMENT OF RAPID GRADING METHOD FOR QUALITY EVALUATION OF TURMERIC RHIZOMES USING FT-NIR SPECTROSCOPY

By

Er. K. DHIVYA

Degree : **Master of Technology in Agricultural Processing and Food Engineering.**

Chairman : **Dr. K. Thangavel, Ph.D.,**
Professor (Engineering)
Department of Fruit Crops,
Horticultural College and Research Institute,
Periyakulam.

2015

Turmeric (*Curcuma longa L.*) known as the Indian saffron is a rhizomatous herbaceous perennial plant belonging to the family Zingiberaceae. India is the largest producer and exporter of turmeric. With its inherent qualities and high content of the important bioactive compound curcumin, Indian turmeric is considered to be the best in the world. Erode, a city in the South Indian state of Tamil Nadu, is the world's largest producer and the most important trading center for turmeric. Erode local and Salem local are the popular cultivars of Tamil Nadu. Turmeric is known for its antibacterial, antiviral, anti-inflammatory, antitumor, antioxidant, antiseptic, cardioprotective, hepatoprotective, nephroprotective, radioprotective, and digestive activities.

Rhizomes of *C. longa* consists of protein, fat, minerals, carbohydrates, moisture content, essential oil, curcumin and oleoresins. Major quality parameters in turmeric are curcumin, oleoresin and essential oil content. Generally these quality parameters vary depending on the variety, area of cultivation and post harvest operations. Post harvest operations includes curing, drying and polishing. Commercially polished rhizomes are graded manually or using machines based on their dimensions. These rhizomes are

separated as fingers, bulbs and brokens. Whereas, Spices grading and marking rules are based on the quality parameters.

Most conventional and instrumental techniques, measuring these properties are accurate, but destructive, slow and involve a considerable amount of manual work. A rapid, non destructive method for quality assessment is the need of the day.

Hence, a research work was undertaken with the objectives to study the existing grading techniques for turmeric rhizomes, analyse the physical properties and quality parameters for two different varieties of turmeric rhizomes and develop a non destructive grading method using FT- NIR Spectroscopy based on quality parameters.

In the present study the physical and frictional properties were studied and compared for both fingers and bulbs of Erode local and Salem local cultivar samples. In the physical properties, highest length of 64.33 mm was recorded by Salem finger samples. Highest breadth of 27.19 mm and thickness of 24.68 mm were recorded by Salem bulb samples. Highest Geometric mean diameter of 5.59 mm, arithmetic mean diameter of 32.56 mm, square mean diameter of 55.16 mm and equivalent diameter of 35.11 mm were observed for Salem bulb samples. Higher bulk density of 647.79 kg m^{-3} and true density of 1266.4 kg m^{-3} were found in Salem bulb samples and lower bulk density of 384.66 kg $m^{-3}$and true density of 1225.5 kg m^{-3} were found in Erode finger samples. Porosity of 68.6 per cent was higher for Erode finger samples. Unit volume of 0.33 mm^3 and surface area of 9.36 mm^2 were higher for Erode bulb samples. In the frictional properties, maximum angle of repose of 49.35° was recorded by Salem finger samples and minimum angle of repose of 40.56° was recorded by Salem bulb samples. Among the different surfaces used mild steel recorded maximum coefficient of friction and stainless steel recorded minimum coefficient of friction in all four samples.

The quality parameters such as curcumin, starch and moisture content were evaluated in turmeric rhizomes. Each 30 of all four turmeric samples (totally 120 samples) were assessed for its quality parameters by the conventional analytical methods. The curcumin content analysed for 120 samples were in the range of 2.82 to 4.91 per cent, moisture content ranged from 7 to 9.5 per cent and starch varied from 56.68 to 57.81 per cent.

A non destructive method of quality evaluation was developed using FT-NIR Spectroscopy. The Calibration models describing the relationship between quality parameters and the NIR spectra of the sample were developed and evaluated. The results obtained from the conventional analysis for curcumin, starch and moisture content were used for calibrating and validating the instrument. The model was examined using partial least square regression method. The spectral pre processing methods such as vector normalization, first derivative and first derivative + vector normalization were used to eliminate interferences and facilitate information extraction from spectral data. The performance of the final model was evaluated in terms of root mean square error of cross validation (RMSECV) and coefficient of determination (R^2).

For curcumin estimation, first derivative with vector normalisation showed maximum R^2 value of 0.919 and minimum RMSECV value of 0.178. For starch estimation vector normalisation showed maximum R^2 value of 0.968 and minimum RMSECV value of 0.076. For moisture content estimation vector normalisation showed maximum R^2 value of 0.811 and minimum RMSECV value of 0.328. High R^2 values and low RMSECV values showed that the models developed were robust. Thus from the above results FT-NIR could be used as a reliable non destructive method to determine the quality parameters of turmeric rhizomes. Based on these quality parameter values obtained turmeric rhizomes can be classified according to their respective grades and the unknown samples could be analysed within 22 seconds for the estimation of curcumin, moisture and starch contents.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF SYMBOLS AND ABBREVIATIONS

%	-	per cent
±	-	plus or minus
=	-	equal to
ºC	-	degree Celcius
º	-	degree
α	-	alpha
β	-	beta
AGMARK	-	Agricultural Marketing and Grading
AMD	-	Arithmetic Mean Diameter
ANN	-	Artificial Neural Network
AOTF	-	Acousto-Optic Tunable Filter
AR	-	Aspect ratio
BDMC	-	bisdemethoxycurcumin
BIS	-	Bureau of Indian Standards
cm	-	centimeter
COE	-	Constant Offset Elimination
DMC	-	demethoxycurcumin
DON	-	deoxynivalenol
EC	-	epicatechin
ECG	-	epicatechin gallate
EGC	-	epigallocatechin
EGCG	-	epigallocatechin gallate
EOQ	-	Equivalent diameter

ESA	-	European Spice Association
et al.	-	*et alia,* and others
FT-NIR	-	Fourier Transform Near Infrared Spectroscopy
Fig.	-	Figure
FSSAI	-	Food safety and standards authority of India
g	-	Gram
GAE	-	Gallic Acid Equivalents
GMD	-	Geometric Mean Diameter
HCl	-	Hydrochloric acid
HPLC	-	High-Performance Liquid Chromatography
HPTLC	-	High Performance Thin Layer Chromatography
i.e.	-	*id est,* that is
IS	-	Indian standards
ISI	-	Indian Standards Institution
kg	-	kilogram
LDA	-	Linear Discriminant Analysis
m^3	-	cubic metre
MADS	-	Microwave Accelerated Dean–Stark
mg	-	milligram
min	-	minute
ml	-	milliliter
mm	-	millimeter
mm^2	-	square millimeter
MMN	-	Min Max Normalization

MSC	-	Multiplicative Scatter Correction
ng	-	nanogram
NIRS	-	Near Infrared Spectroscopy
nm	-	nanometer
PbS	-	lead sulfide
PCR	-	Principal Component Regression
PFA	-	Prevention of Food adulteration Act
PLS	-	Partial Least Square
PVC	-	Polyvinyl chloride
R^2	-	Coefficient of determination
RMSECV	-	Root Mean Square Error for Cross Validation
RMSEE	-	Root Mean Square Error of Estimation
RMSEP	-	Root Mean Square Error of Prediction
RPD	-	Residual Predictive Deviation
SD	-	Standard Deviation
SLS	-	Straight Line Subtraction
SMD	-	Square Mean Diameter
SNV	-	Standard Normal Variate
SSE	-	Sum of Squared Errors
TLC	-	Thin-Layer Chromatography
viz.	-	namely

Introduction

CHAPTER I

INTRODUCTION

Turmeric is the rhizome of *Curcuma longa L*, a herbaceous perennial plant belongs to the family Zingiberaceae. India is the largest producer and exporter of turmeric and it ranks fourth in production among the spices. The major turmeric producing states in India are Andhra Pradesh, Tamil Nadu, Orissa, Karnataka, West Bengal, Gujarat and Kerala. In India the annual production of turmeric is 9,71,000 tonnes from an area of 1,94,000 hectares during the year 2012-2013 (Agricultural statistics, 2012). In Tamil Nadu the annual production is 1,74,775 tonnes from an area of 46,151 hectares during the year 2012-2013, where Erode takes the first place followed by Dharmapuri and Salem. Indian turmeric is considered as the best in the world and it is named as “Indian saffron”.

The bright yellow colour of turmeric comes mainly from fat- soluble, polyphenolic pigments called curcuminoids which has curcumin as its principal component. Turmeric contains a wide variety of phytochemicals including curcumin, demethoxycurcumin, bisdemethoxycurcumin, zingiberene, curcumenol, curcumol, eugenol, tetrehydrocurcumin, triethylcurcumin, turmerin, turmerones and turmeronols (Chattopadhyay *et al*., 2004). The structure of curcumin ($C_{21}H_{20}O_6$) was first described in 1910 by Lampe and Milobedeska (Himesh *et al*., 2011).Curcumin has antioxidant, anti-inflammatory, antiviral and antifungal actions.

Turmeric is popularly used in foods for its typical colour and flavour and as a preservative. It is a principal ingredient in food preparations and in many pharmaceutical industries. The medicinal uses of turmeric and curcumin are indeed diverse, ranging from cosmetic face cream to the prevention of Alzheimer’s disease. Indian ayurvedics use turmeric to treat liver problems, high cholesterol and digestive problems. It helps to inhibit blood clotting, strengthens the gall bladder and treats skin diseases. Turmeric is widely used in traditional Indian medicine to cure biliary disorders, anorexia, cough, diabetic wounds, heptic disorders, rheumatism and sinusitis (Ravindran *et al*., 2007). It is also used in textile industry, in thepreparation of oils, ointments and poultice, in cosmetic product to prepare natural and herbal creams, lotion and hair dye (Kamble *et al*., 2011).

Generally turmeric consists of 6.3 per cent protein, 5.1 per cent fat, 3.5 per cent minerals, 69.4 per cent carbohydrates, 13.1 per cent moisture content, 3.5 per cent essential oil, 2.5 to 6 per cent curcumin and 5.7 per cent oleoresins (Kamble *et al*., 2011). Major quality parameters in turmeric are curcumin, oleoresin and essential oil contents. More than 70 turmeric types belong to *Curcuma longa* and a few cultivars that belong to *Curcuma aromatica* are known to be under cultivation in India. Most of these cultivars go by local names, derived mostly from the place of occurrence (Nair *et al*., 1980). Erode local and Salem local are the popular cultivars of Tamil Nadu (Ravindran *et al*., 2007).

After harvesting, processing of turmeric includes boiling, drying and polishing. These polished rhizomes are separated as fingers, bulbs and brokens to various grades which are stored in the co-operative marketing society in their respective places, where storage facilities are provided by the state or central warehousing corporations to enable farmers as well as traders to store produce. Turmeric in whole or powder form can be exported only after grading and pre-shipment inspection. Government of India introduced the scheme of compulsory pre-shipment inspection and quality control in 1963. Spices are graded based on the standards fixed for the purpose. Indian Standards for turmeric follow the Agmark specification to ensure quality and purity. Turmeric for export are graded based on the European Spice Association (ESA) and Food Safety and Standards Authority of India (FSSAI) (Balakrishnan, 2007).

Grading of turmeric is commonly done manually or using machines based on their size and shape, whereas the Spices Grading and Marking Rules recommend grading based on the quality parameters. Most instrumental techniques measuring these properties are destructive, slow and involve a considerable amount of manual work. Therefore, there is a demand for new and rapid analytical techniques for quality assessment. Optical multispectral measurements have recently become more popular in food measurements due to their non destructive, fast, real time, online monitoring of samples (Alander *et al*., 2013).

Among the optical methods, Near Infrared Spectroscopy has been tested for non-destructive evaluation of firmness, dry matter, soluble solids, acidity and other physiological properties of many fruits and vegetables and is found successful in analysis (Bureau *et al*., 2009). NIR spectra are the result of relatively weak and broad overtone

and combination bands of fundamental vibrational transitions associated mainly with C-H, N-H, and O-H functional groups. The major strength of Fourier Transform- Near Infrared Spectroscopy (FT-NIR) includes fast and easy equipment operation, high accuracy, precision, the potential to perform non-destructive analysis and prediction of physical and chemical sample parameters from a single spectrum enabling several components to be determined simultaneously with the use of multivariate calibration (Tripathi *et al*., 2010).

FT-NIR can be developed by calibrating and validating the method using the results of quality parameters obtained from biochemical analysis. Hence by developing a non-destructive FT-NIR method for the analysis of quality parameters in turmeric will help in online grading of the turmeric.

The proposed objectives of the research work are

1. To study the available grading techniques and the quality parameters of turmeric fingers and bulbs.
2. To study the physical and chemical properties of turmeric fingers and bulbs.
3. Acquiring the NIR reflectance spectra and development of spectral data bank of turmeric.
4. To analyse the spectral data with the studied chemical properties of turmeric fingers and bulbs using PLS (Partial Least Square Regression).
5. To develop a rapid non-destructive quality assessment method and validate the method using FT-NIR Spectroscopy for turmeric rhizomes.

Review of Literature

CHAPTER II

REVIEW OF LITERATURE

This chapter deals with comprehensive review of the research work done by various research workers related to the present study namely physical and frictional properties, turmeric processing, grading, quality analysis and grades of turmeric rhizomes been reviewed. Principle, construction and applications of Fourier Transform Near Infrared Spectroscopy for the quality analysis of turmeric rhizomes are also reviewed in a detailed manner.

2.1. Physical Characteristics of Turmeric Rhizomes

Curcuma longa L. is typical of the herbaceous plant with thick and fleshy rhizomes and leaves in sheaths that characterize the family Zingiberaceae. The plants reach a height of up to 1m (Govindarajan, 1980). The turmeric plant needs temperatures between 20°C and 30°C and a considerable amount of annual rainfall to thrive. Turmeric grows in all elevations ranging from sea level to an altitude of 1200m. Fresh turmeric rhizome has a brown skin and bright orange flesh (Benzie and Wachtel, 2011). The underground rhizome, which is processed into the spice, consists of two distinct parts; the egg-shaped primary or mother rhizome, an extension of the stem and several long cylindrical multi-branched secondary rhizomes growing downward from the primary rhizome.

2.2. Varieties of Turmeric

The important turmeric varieties grown in India are, 'Alleppey Finger' (Kerala), 'Erode and Salem turmeric' (Tamil Nadu), 'Raja pore' and 'Sangli turmeric' (Maharashtra) and 'Nizamabad bulb' (Andhra Pradesh). Erode local and salem local are the two important varieties grown and exported from Tamilnadu (Ravindran *et al*., 2007) Turmeric is exported in the form of fresh turmeric, dry turmeric, turmeric powder and oleoresin.

2.3. Physical and Frictional Properties of Turmeric

Physical and frictional properties help in analysis of the product behaviour in handling the material (Mohsenin, 1986). These properties play an important role in

designing equipments for post harvest operations such as dryers, cleaners and graders (Balasubramanian *et al*., 2012). The physical properties such as size, shape, volume, surface area, bulk density, true density, porosity and frictional properties such as angle of repose and coefficient of friction as reported by different researchers are reviewed and reported below.

2.3.1. Physical properties

2.3.1.1. *Size*

The size of many biological materials is determined by measuring their dimensions in three principal mutually perpendicular axes as length, width and thickness. The geometric mean diameter (GMD) is considered as the size criterion and is expressed as the cube root of all three dimensions. Similarly length, breadth and thickness can be used to determine sphericity, arithmetic mean diameter (AMD), square mean diameter (SMD), equivalent diameter (EQD) and aspect ratio (AR).

Athmaselvi and Varadharaju (2002) reported the size of the turmeric rhizomes for BSR I, BSR II and Erode local varieties. Length and breadth of the rhizomes were measured at different moisture contents and their reduction in size was compared. The BSR I had higher primary finger length followed by Erode and BSR II at initial and final moisture contents. BSR II recorded the highest breadth at initial moisture content and least breadth for primary and secondary fingers at final moisture content (10 per cent, w.b.). The reduction in the breadth of the fingers was 64 per cent for BSR II and 36 per cent for BSR I and Erode varieties.

The size of Nigerian yellow bark ginger (*Zingiber officinale Rose*) was studied by Onu and Okafor (2002) and reported that longitudinal length varied from 12.5 to 5.4 cm and diameter along the major and minor axes varied from 6.4 to 3.3 and 2.9 to 1.64 cm, respectively when the moisture content decreased from 81 to 45.6 per cent (w.b.) respectively.

Sinkar *et al*. (2005) conducted preliminary evaluation of 21 varieties of turmeric rhizomes. It was reported that the longest mother rhizome was Rajapuri (9.23 cm) and the maximum weight of mother rhizomes (90.35g) and primary rhizomes (208.92g) were recorded by Salem variety.

Chaudhary *et al*. (2006) conducted studies on the size of 5 different turmeric varieties, *viz*. Krishna, Suvarna, Rajendra Sonia, Suguna and Sudarshana. It was concluded that variety Krishna had the maximum length (10.2 cm) and breadth (2.45 cm) followed by Rajendra Sonia.

Kibar and Ozturk (2008) determined the physical and mechanical properties of soyabean at moisture levels of 8 to 16 per cent d.b. It was found that length, breadth, thickness, arithmetic mean diameter and geometric mean diameter increased from 7.24 to 8.19 mm, 6.79 to 7.12 mm, 5.78 to 6.23 mm, 6.6 to 7.18 mm, 6.57 to 7.14 mm respectively with increase in moisture content. Surface area and volume increased linearly with the moisture content.

Jayashree (2009) reported the size of the ginger rhizomes before and after drying. The average length, width and thickness of fresh ginger rhizome at the moisture content of 81.70 per cent (w.b.) were found to be 14.99, 8.17 and 4.49 cm respectively and for the dried rhizome at moisture content of 8.85 per cent (w.b.) it was 9.74, 5.56 and 3.06 cm, respectively. There was 35.02 per cent reduction in the average length, 31.95 per cent in the average width and 31.85 per cent in the average thickness of ginger rhizome during drying.

Jilani *et al*. (2012) conducted experiments to evaluate the performance of three different turmeric cultivars (Duggirala, Zedory and Krishna). Cultivar Krishna recorded the highest number of fingers per plant (31.43), finger length (7.11cm) and finger width (2.75cm) followed by Zedory and Duggirala.

Balasubramanian *et al*. (2012) studied the physical properties of turmeric rhizomes (IISR allepey supreme var). Samples were divided into three grades (I: 25–35 mm, II: 35–45 mm, III: 45–55 mm) according to its length. Average values of length, breadth, thickness, geometric mean diameter, arithmetic mean diameter, square mean diameter, equivalent diameter, sphericity and aspect ratio of the turmeric rhizome were 30.38–50.60 mm, 9.77–10.64 mm, 5.18–6.44 mm, 12.77–13.76 mm, 15.82–21.91 mm, 24.24–28.58 mm, 17.61–21.41 mm, 0.27–0.42 and 0.20–0.35mm respectively.

Lokandhe *et al*. (2013) reported the length, width and weight of the fresh rhizomes for three cultivars *viz*. Salem, Krishna and Tekurpetha. Length and width of the fingers were found higher in Krishna and lower in Tekurpetha.

2.3.1.2. *Bulk density and true density*

Bulk density is the ratio of rhizome mass to the volume of the sample container. The true density is defined as the ratio of the mass of a sample to its volume. The sample volume is determined using the liquid (toluene) displacement method.

Athmaselvi and Varadharaju (2002) reported the relationship between moisture content with bulk density and true density for turmeric varieties. The bulk density of BSR I, BSR II and Erode varieties increased from 779 to 809 kg m^{-3}, 693 to 853 kg m^{-3} and 753 to 801 kg m^{-3} respectively with the increase in moisture content from 10 to 70 per cent. Similarly true density increased from 1295 to 1315 kg m^{-3} for BSR I, 1282 to 1317 kg m^{-3} for BSR II and 1293 to 1315 kg m^{-3} for Erode variety.

Coskuner and Karababa (2006) reported the relationship between moisture content with bulk density and true density for coriander seeds. True density increased nonlinearly with moisture content from 332 to 349 kg m^{-3} whereas bulk density decreased linearly from 234.1 to 220.2 kg m^{-3} in the moisture content range of 7.1 per cent and 18.94 per cent (d.b.).

Chandrasekar (2007) reported that the bulk density and true density of coleus tubers decreased from 432.26 to 233.65 kg m^{-3} and 484.03 to 299.123 kg m^{-3} respectively, as the moisture content decreased from 466.62 to 21.52 per cent (d.b.).

Kibar and Ozturk (2008) reported the bulk and true density of soyabean at different moisture levels (8 – 16 per cent d.b.). The bulk and true density was found to decrease from 766 to 719 kg m^{-3}, 983 to 905 kg m^{-3} respectively as moisture content increased from 8 to 16 per cent.

Balasubramanian *et al*. (2012) reported the bulk density and true density of IISR allepey supreme variety for three grades (I 25–35 mm, II: 35–45 mm, III: 45–55 mm) of turmeric rhizomes. The values reported were 260 to 348 kg m^{-3} and 1341 to 1354 kg m^{-3} respectively.

2.3.1.3. *Porosity*

Porosity (ε) is defined as the volume fraction of a bulk volume that contains air or void fraction that is present in the given sample volume. It is expressed as the ratio of void volume to total volume.

Kibar and Ozturk (2008) reported the porosity of soyabean at different moisture levels (8 to 16 per cent d.b.). The porosity decreased linearly from 22.58 to 20.61 per cent with the increase in moisture content from 8 to 16 per cent.

Balasubramanian *et al*. (2012) reported the porosity of IISR allepey supreme variety for three grades (I 25–35 mm, II: 35–45 mm, III: 45–55 mm) of turmeric rhizomes. The porosity increased from 74.53 to 80.93 per cent with the increase in dimension of sample.

2.3.2. Frictional properties

The angle of repose is the angle between the base and the slope of the cone formed on a free vertical fall of granular materials over a horizontal plane. The size, shape, moisture content and orientation of the grains affect the angle of repose (Sahay and Singh, 1994).

Kibar and Öztürk (2008) reported the angle of repose of soyabean at different moisture levels (8 – 16 per cent d.b.). The angle of repose increased linearly from 27.37º to 31.81º with the increase of moisture content.

Balasubramanian *et al*. (2012) reported the angle of repose of IISR allepey supreme variety for three grades (I: 25–35 mm, II: 35–45 mm, III: 45–55 mm) of turmeric rhizomes. The angle of repose of grades I, II and III were 37.57, 38.44 and 38.90º respectively.

The coefficient of friction between granular materials is equal to the tangent of the angle of internal friction for the material. The frictional coefficient depends on grain shape, surface characteristics and moisture content (Chakraverty, 1995).

Athmaselvi and Varadharaju (2002) determined the static coefficient of friction of turmeric rhizomes of BSR I, BSR II and Erode variety with respect to moisture content on four metallic surfaces (aluminium, mild steel, galvanised iron and stainless steel). The static coefficient of friction increased with increase in moisture content of rhizomes in all the surfaces.

Balasubramanian *et al*. (2012) reported the static coefficient of friction of IISR allepey supreme variety for three grades (I: 25–35 mm, II: 35–45 mm, III: 45–55 mm) of

turmeric rhizomes. The coefficient of friction for these grades on aluminum surface, mild steel sheet and plywood sheet were 0.81 to 0.69, 0.94 to 0.84 and 0.86 to 0.8 respectively. It was observed that the coefficient of friction for aluminum surface was the lowest.

2.4. Chemical Composition of Turmeric

Rhizomes of *C. longa* consists of 6.3 per cent protein, 5.1 per cent fat, 3.5 per cent minerals, 69.4 per cent carbohydrates, 13.1 per cent moisture content, 3.5 per cent essential oil, 2.5 to 6 per cent curcumin and 5.7 per cent oleoresins (Kamble *et al*., 2011). The coloring matter, which represents 2 to 6 per cent of turmeric, consists mainly of curcumin and small amounts of its analogues, mainly demethoxycurcumin and bisdemethoxycurcumin. The essential oil, which is present up to 5 per cent, is composed mainly of sesquiterpenes, many of which are specific for the species. Most important for the aroma are α- and β-turmerones and ar –turmerone (Ravindran *et al*., 2007).

2.5. Quality Parameters of Turmeric Rhizomes

Major factor that contributes to export demand or potential of a commodity is its quality. The chief factor of good quality in turmeric rhizomes is the high curcumin content, giving a deep yellow color. Price of the turmeric rhizomes also varies depending on the curcumin content (Madan, 2007).

Sivaraman (2007) reported that the moisture content plays a vital role during the entire processing of turmeric. High moisture content in the rhizomes was one of the major reasons for low curing percentage. Moisture level of polished rhizomes above 12 per cent can affect the free-flow characteristics of turmeric powder.

Govindarajan (1980) described the starch as the reserve carbohydrate of the Curcuma rhizomes and considered to be the major component. Some species of the genus *Curcuma. angustifolia* Roxb, *Curcuma. zedoaria* Roscoe are essentially used as sources of starch in remote places or in times of scarcity. Balakrishnan (2007) reported that the starch extracted from rhizome as arrowroot was used for making cakes and as a substitute for barley starch given to children. High content of starch in the spice tends to give excessive fine powder when comminuted.

2.5.1. Moisture content

A convenient method for determination of water and other organic emulsions was first developed by Dean and Stark (1920). An apparatus was designed consisting of round bottom flask, distilling tube receiver and condenser. Water immiscible solvent was used for distillation. Sample was distilled with the solvent for an hour which separates the water content from the mixture. Finally the separated volume of water was noted from the receiver.

Athmaselvi and Varadharaju (2002) reported that the average moisture content of BSR I and Erode local was 82 per cent (w.b.) and the moisture content of BSR II was 86 per cent (w.b.) immediately after harvest.

Jose and Joy (2009) reported the moisture content of turmeric rhizomes dried by different drying methods. The mean initial moisture content of turmeric was 84.16 per cent and the final moisture content of rhizomes dried under commercial drying, conventional drying and solar tunnel drying was found to be 12.19, 11.81 and 9.98 per cent, respectively.

Veillet *et al*. (2009) developed a new method to measure the water content using a "microwave accelerated Dean–Stark" (MADS) distillation method. Moisture content was estimated by MADS method for olive fruits and compared with the conventional Dean – stark distillation method. Water determination from olives with MADS was better than that with conventional dean-stark method in terms of energy saving, rapidity (10 min versus 120 min), reproducibility, and cleanliness.

Bertouche *et al*. (2012) used alpha pinene as green solvent instead of toluene for moisture determination in Dean-stark distillation method. Moisture content was determined for onions, garlic, carrots, leeks, olives, caraway and coriander seeds, oregano and minced meat and compared with conventional Dean – stark distillation method. Alpha pinene Dean –stark distillation method allowed a substantial savings in term of extraction time (30 min vs 105 min) and energy consumption.

Veillet *et al*. (2010) used limonene instead of toluene in the Dean–Stark procedure for moisture estimation, to reduce the influence of chemicals and use of green

solvents. Moisture determination on wide range of food matrices was performed using toluene and limonene. Water content (per cent) using limonene and toluene in carrot was 89.3±0.5 and 89.5±0.7, in garlic 68.0±0.7 and 68.6±1.9 and in minced meat 64.1±0.5 and 64±0.3 respectively. Hence limonene could be used as a good alternative solvent in the Dean–Stark procedure.

2.5.2. Curcumin

Curcumin is the phytochemical that gives a yellow colour to turmeric. It is an orange–yellow crystalline powder which is hydrophobic in nature and freely soluble in ethanol, dimethylsulfoxide, acetone and oils. Curcumin was first isolated by Vogel and Pelletier (1815) and identified as 1,6-heptadiene-3,5-dione-1,7-bis(4-hydroxy-3-methoxyphenyl)-(1E,6E) or diferuloylmethane. This skeleton of curcumin was confirmed by the work of Lampe *et al*. (1910).

Curcumin has a melting point of 183ºC, molecular formula of $C_{21}H_{20}O_6$ and molecular weight of 368.37 g/mol. Turmeric contains curcumin along with other chemical constituents known as the "curcuminoids" (Srinivasan, 1952). The major curcuminoids present in turmeric are demethoxycurcumin (curcumin II, DMC), bisdemethoxycurcumin (curcumin III, BDMC).

Mehta *et al*. (1980) estimated the curcumin content in leaves and rhizomes of three cultivars of *C. longa* and one type of *C. amada* during various stages of growth, starting from the 100^{th} day of planting up to final harvest. With increasing maturity, curcumin content of leaf decreased while that of rhizome increased, which indicated that the site of biosynthesis of curcumin was the leaves, from where it got translocated to rhizome. Cheng *et al*. (2001) reported that curcumin was nontoxic to humans at up to 8000 mg/day when taken by mouth for 3 months.

Curcumin is used as a treatment in wide variety of ailments. Medicinal properties of curcumin include antiangiogenic, antioxidant, anti-inflammatory, anticancer and antimutagen. It helps in curing diabetes, mulitiple sclerosis, Alzheimer disease, HIV replication, septic shock, cardiovascular diseases, cardiotoxicity, gallstone formation, arthritis, liver injury, cataract formation. (Ravindran *et al*., 2007).

Qualitative and quantitative analyses of curcuminoids in turmeric samples are very important in order to determine the quality of the raw materials or its finished products (Jiang *et al*., 2009).

Balashanmugam (1991) reported that curcumin could be extracted by solvent extraction, high performance liquid chromatography and super critical carbondioxide extraction method.

Krishnamoorthy *et al*. (1976) compared the extraction of curcuminoids by soxhlet extraction method, batch and counter-current cold percolation methods. Results showed that curcuminoid yield was poor (1.5-2 per cent) in soxhlet extraction method, while cold percolation method gave a higher yield (5.7-5.9 per cent). Acetone as an extraction solvent was slightly superior to alcohol and ethylene dichloride.

Numerous analytical methods have been reported by researchers for quantitative analysis of curcuminoids. Some of the methods are based on spectrophotometric techniques, expressed as the total color content of the sample. However, using this technique it is not possible to separate and to quantify the curcuminoids individually (Jayaprakasha *et al*., 2002). Hence, chromatography based techniques and electrophoresis are among the methods of choice for determination of curcuminoids attributed to their separation capacities (Rohman, 2012).

Due to the low cost in operation, ease in sample preparation, and the availability of several detection systems, thin-layer chromatography (TLC) is regularly used for the identification, separation, quantification purposes of natural pigments, including curcuminoids (Forgacs and Cserhati., 2002). However, high-performance liquid chromatography (HPLC) is a method of choice for curcuminoids attributed to the high precision and accuracy offered and low detection limit achieved.

Gantait *et al*. (2011) developed a high performance thin layer chromatography (HPTLC) for determination of curcumin in several marketed spices sample of turmeric powder. The HPTLC separation was performed on precoated aluminium backed HPTLC plates of 0.2 mm layer thickness with silica gel 60 F_{254} with dichloromethane and methanol (99:1) combination as mobile phase. The limit of detection and limit of

quantification were found to be 49 ng and 148 ng per spot, respectively. Recovery values from 99.6 to 99.73 per cent showed that the reliability and reproducibility of the method were excellent.

Tanaka *et al*. (2008) investigated the possibility of near infrared (NIR) spectroscopy to quantify the contents of curcuminoids (C, DMC, and BDMC) in turmeric. The results showed that the optimized method offers good prediction model with standard error of prediction of 0.117, 0.061, 0.070, and 0.174 per cent, respectively for C, DMC, BDMC and total curcuminoids.

Pathak *et al*. (2010) reported the variation in curcumin content in *Cucuma longa* procured from different zones of India. Curcumin was estimated by spectrophotometric method. The curcumin content ranged from 0.30 per cent (central zone) to 3.24 per cent (south zone). Average curcumin content was found to be 1.54 per cent on dry weight basis.

Tripathi *et al*. (2010) developed a nondestructive method of measuring curcuminoid content of turmeric powder by fourier transform near infrared (FT-NIR) spectrometer. Calibration was made from 24 samples which were analysed spectrophotometrically and cross validated with another 24 samples. The values of coefficient of determination (R^2) and root mean square error of cross validation (RMSECV) were 0.97 and 0.104, which concluded FT-NIR could be used as an effective, non destructive tool for determining curcuminoid in turmeric.

Patil *et al*. (2011) studied the extraction of curcuminoids from turmeric powder with the help of methanol as solvent and curcuminoids were isolated in the form of crystals with 95 per cent purity and 75 per cent yield.

Himesh *et al*. (2011) reported the quantitative and qualitative determination of curcumin in the ethanolic extract of *C.longa*. Qualitative estimation was carried out by thin layer chromatographic method. Curcuminoids estimation was carried out by spectrophotometric and HPLC techniques, where the detection of curcuminoids were performed at 425 nm. The quantitative determination of phenolic content, per cent curcumin and colour value from ethanolic extract was found to be 11.24 as mg GAE/g, 10.23 per cent and 172 respectively.

2.5.3. Starch content

The method of acid hydrolysis and determination of the liberated glucose was most satisfactory for the starch determination. Sulphuric acid has been chosen as a suitable starch hydrolysing agent as it increases the rate of destruction of glucose by 100 per cent, whereas hydrochloric acid increases by 53 per cent (Pirt and Whelan, 1951).

The viscosity profiles of Curcuma species (*Curcuma. zedoaria and Curcuma longa*) have been studied and was reported to have high thickening and gelling properties, and high stability when agitated (Leonel *et al*., 2003). Hence could be used as a potential raw material for food industry starches.

The turmeric rhizomes can be considered as a rich unconventional source of starch of commercial interest for specialty applications. The microstructure of starch revealed to possess a smooth surface with regular elliptical shape. The high amylose content in turmeric starch is beneficial for the manufacturing of selected products requiring high crispness and low expansion (Kuttigounder *et al*., 2011).

2.6. Processing of Turmeric

Processing of raw rhizomes assumes importance from the point of view of the appearance and color of the end product. The processing consists of three stages *viz*. curing, drying, and polishing.

2.6.1. Curing

Curing essentially involves boiling fresh rhizomes in water until soft before drying. Boiling destroys the vitality of fresh rhizomes, obviates the raw odor, reduces drying time, and yields a uniformly colored product. Cleaned rhizomes are boiled in copper or galvanized iron or earthern vessels with water just enough to soak them and boiling is stopped when froth comes out with the release of white fumes having the typical turmeric aroma. The boiling lasts for 45 to 60 minutes till the rhizomes become soft (Rao *et al*., 1975).

Govindarajan (1980) described the methods of curing. Fingers and bulbs could be boiled separately and bulbs required longer cooking time than the fingers. Bigger bulbs were split into halves or quarters. Curing was more uniform when done in small batches.

Curing should be done within 2 or 3 days after harvest to avoid rhizome spoilage. Cooking rhizomes prior to drying promotes gelatinization of starch, facilitates uniform drying, and increases the dehydration rate. Other benefits include uniform distribution of pigments inside rhizome and a more attractive product (not wrinkled) that lends itself to easier polishing

Weiss (2002) reported that the stage at which boiling stops largely influences the color and aroma of the final product. Over-cooking spoils the color of the final product while under-cooking renders the dried product brittle. An improved method of curing was studied where the cleaned rhizomes were taken in a perforated trough made of galvanized iron or mild steel sheet with extended parallel handle. Perforated trough containing the raw turmeric was immersed in a pan of boiling water, which can hold three to four troughs at a time. Boiling was continued till the material becomes soft.

A steam boiling unit with capacity of 250-270 kg/batch was developed by the Department of Agricultural Processing, TNAU- Coimbatore to overcome the issue of non-availability of labourers and timely boiling of turmeric (Spice board, 2008).

Kamble and Soni (2009) studied the curing process to reduce the quality losses, time and fuel in turmeric processing. An improved boiling pot with lid were designed and compared with traditional boiling pot. Turmeric boiled for 35 minutes in improved boiling pot retained higher curcumin and essential oil content.

2.6.2. Drying

Sankaracharya and Natarajan (1975) described the method of drying. The boiled rhizomes were allowed to dry by spreading out open in 5 to 7 cm thick layers on uncoated plain bamboo mats or concrete drying floor. A thinner layer was not desirable as this may result in surface discoloration.

Turmeric should be dried on clean surfaces to ensure the product's quality against contamination by extraneous matter. Care should be taken to avoid mold growth on the rhizomes. It took 10 to 15 days for the rhizomes to become completely dry. Improved drying methods like mechanical dryers were used. Drying using cross-flow hot air at a maximum temperature of 60ºC was found to give a satisfactory product (Spice board, 1995)

Ravindran *et al*. (2007) compared the drying methods of turmeric. Artificial drying gave a brighter product than the sun drying. Solar driers were also economically used for drying turmeric. The dried condition was attained when the finger breaks cleanly with a metallic sound and with moisture content 5 to 10 per cent. Improperly dried spice would be susceptible to microbial growth and infestation by storage pests. The dry rhizomes possess earthy, slightly unpleasant odor and a bitterish, mild acrid taste; they impart exciting warmth in the mouth and color the saliva yellow

2.6.3. Polishing

Dried turmeric has a rough appearance and dull surface color. The outer surface was polished to give a better finish. Polishing removes the surface roughness by getting rid of the surface scales, the small rootlets, and any remaining soil particles. Polishing is done either by manual or mechanical means.

Anandaraj *et al*. (2001) described the polishing of rhizomes using drums rotated by hand or by power. The drum was made of expanded metal mesh fixed to solid, circular end plates and was mounted on a central axis. The drum was covered with a tight wrapping of woven wire, the mesh of which was small enough to retain the turmeric, but large enough to allow dust, dirt, and rootlets to fall through. When the drum filled with turmeric was rotated, polishing was effected by abrasion of the surface against the mesh as well as by rubbing rhizomes against each other as they roll inside the drum.

Pruthi (1980) recommended different combinations of treatments with emulsions containing alum, turmeric powder, castor seed paste, sodium bisulfite and sulphuric acid or hydrochloric acid to impart attractive surface color. Anandaraj *et al*. (2001) reported the method to improve the surface color of polished rhizomes. Turmeric powder was added to the polishing drum in the last 10 minutes of polishing. The colour of the processed turmeric influences the price of the produce. Turmeric powder mixed with little water would be sprinkled during the last phase of polishing to improve the colour (Spice board, 2008).

2.6.4. Grading

Grading is normally done by the farmers manually splitting the polished rhizomes into bulbs, fingers and brokens, whose dimensions are mentioned in the Table 2.1. In case of industries turmeric bulbs are graded into two grades and turmeric fingers are graded into three grades and the dimensions are mentioned in the Table 2.2

Table 2.1 Dimensions of rhizomes in manual grading

	Length (cm)	Breadth (cm)	Thickness (cm)
Bulbs	2 – 5.5	1.7-2.1	1.6 – 2.6
Fingers	2.5 – 7.9	0.85-1.8	0.6 – 1.6
Brokens	1.5 – 1.9	0.64-0.85	0.3 – 0.85

Table 2.2 Dimensions of rhizomes in industrial grading

	Length (cm)	Breadth (cm)	Thickness (cm)
Bulbs – 1st quality	3.27-6.74	1.68 – 3.52	1.54-3.08
2nd quality	1.47-3.26	1.21-1.67	1.01-1.53
Fingers- 1st quality	3.3-7.5	1.3-1.83	1.21-1.45
2nd quality	2.2- 3.28	0.86-1.29	0.84 -1.2
3rd quality	0.88-2.19	0.64-0.85	0.3-0.85

Mechanical graders are available, where turmeric is graded based on the dimension of rhizomes. Mechanical graders used in the industries consist of bucket elevator, rotating chamber with various sieve size and destoners.

To ensure the quality of spices for export, Government of India introduced the scheme of compulsory Preshipment Inspection and Quality Control in 1963. Spices are graded based on the standards fixed for the purpose. These grades are popularly known as the Agmark Grades. Export Inspection Agency, under the Export Inspection Council of India, held the mandate for preshipment inspection and quality control certification. For turmeric, the grading takes into consideration the hardness of the rhizomes, percentage of small pieces, bulbs, foreign matter, as well as defectives. Indian Standards for turmeric follow the Agmark specifications to ensure quality and purity. Grade designations and respective specifications for Indian turmeric under Agmark are given in Tables 2.3 and 2.4 (Directorate of Marketing and Inspection, 2012). Food Safety and Standards regulations for turmeric rhizome and powder are given in Table 2.5 and 2.6 respectively.

The European Spice Association (ESA) has come out with the "quality minima for herbs and spices." This serves as a guideline specifications for member countries in European Union. ESA specifications with respect to turmeric are summarized as in Table 2.7. Indian Standard (IS) Specifications for whole and ground turmeric are displayed in Table 2.8.

Hence quality analyses of turmeric rhizomes is very important for exporting the rhizomes, but the conventional methods of analysis are time consuming, destructive and involves a considerable amount of manual work. Fourier- transform near infrared spectroscopy has the potential to perform fast, accurate and non destructive analysis.

Table 2.3. Grade designations and quality of turmeric (whole)

Grade designation	Quality				
	Special characteristics				
	Organic extraneous matter, % (m/m) (max.)	Inorganic extraneous matter, % (m/m) (max.)	Defective rhizomes, % (m/m) (max.)	Moisture, % (m/m) (max.)	Curcuminoid content % (m/m) (min.)
Special	0.8	0.2	3	12	2
Standard	1.5	0.5	5	12	Not specified

Table 2.4. Grade designations and quality of turmeric powder

Grade designation	Quality				
	Special characteristics				
	Moisture % (m/m) (Max.)	Total ash % (m/m) (Max.)	Acid insoluble ash, % (m/m) (Max.)	Curcuminoid content %(m/m) (min.)	Starch % (m/m) (Max.)
Special	10	7.0	1.5	2.0	60
Standard	12	9.0	1.5	Not specified	60

Table 2.5. Specifications for turmeric rhizomes under FSSAI regulations

Sl.No.	Specification	Limits
1	Extraneous matter	Not more than 1.0 percent by weight
2	Defective rhizome	Not more than 12.0 percent by weight
3	Salmonella	Absent in 25g
4	Insect damaged matter	Not more than 1.0 percent by weight
5	Test for lead chromate	Negative (FSSAI, 2009)

Table 2.6. Specifications for turmeric powder under FSSAI regulations

Sl.No.	Specification	Limits
1	Moisture	Not more than 10.0 percent by weight
2	Total ash on dry basis	Not more than 9.0 percent by weight
3	Ash insoluble in dil HCL on dry basis	Not more than 1.5 percent by weight
4	Colouring powder expressed as curcuminoid content on dry basis	Not less than 2.0 percent by weight
5	Total starch	Not more than 60 percent by weight
6	Test for lead chromate	Negative (FSSAI, 2009)

Table 2.7. European Spice Association (ESA) quality and sanitation specifications

S.No.	Specification	Turmeric	
		Whole	Ground
1	Extraneous matter %	1	1
2	Foreign matter %	2	2
3	Ash % w/w max (ISO)	8 (BSI)	9 (ISO)
4	Acid insoluble ash % w/w , max	2 (BSI)	2.5 (ESA)
5	Maximum water % w/w max	12 (BSI)	10 (ISO)
6	Volatile oil %	2.5 (BSI)	1.5 (ESA)

S.No.	Specification	Turmeric	
		Whole	Ground
7	Microbe		
	Salmonella abs in 25 g,	105/g target, max 106/g absolute	
	yeast & molds		
	E. coli	102/g target, max 103/g absolute	

(ESA, 2011).

BSI : Bureau Standards Institute

ESA : European Spices Association

ISO: International Organization for Standardization

Table 2.8. Requirements of turmeric, whole and ground, under Indian Standards

Characteristic	Requirement	
	Turmeric, whole	Turmeric, ground
Curcumin content %(m/m) (min.)	2	2
Moisture content %, on d.b. (max)	11	11
Total ash % on d.b. (max)	8	8
Acid insoluble ash %, on d.b. (max)	-	1.5
Starch % on d.b. (max)	-	60
Lead (as Pb), mg/kg, max	10	10
Copper (as cu), mg/kg, max	5	5
Arsenic (as As), mg/kg, max	0.1	0.1
Zinc (as zn), mg/kg, max	25	25
Cadmium (as cd), mg/kg, max	0.1	0.1
Tin (as sn)	Nil	Nil

(BIS, 2010)

2.7. Near Infrared Spectroscopy

In the year 1800 William Herschel had discovered radiation beyond the visible red light; he separated the electromagnetic spectrum with a prism and found out that the temperature increased markedly towards and beyond the red light, i.e. in the near-infrared region. Karl Norris from the U.S. Department of Agriculture recognized the potential of this analytical technique and introduced "modern NIRS" into industrial practice (Aenugu *et al*., 2011).

Near Infrared Spectroscopy (NIRS) covers the transition from the visible spectral range to the mid-infrared region. In the area of NIR (800–2500 nm, respectively 12821–4000 cm^{-1}) mainly vibrations of –CH, –OH, –SH and –NH bonds of the organic molecules in a product are observed (Burns and Ciurczak, 2001). NIR spectroscopy was first used in agricultural applications by Karl Norris to measure moisture in grain. FT-NIR spectroscopy has proved to be a powerful analytical tool for analyzing a wide variety of samples used in the agricultural, nutritional, petrochemical, textile, and pharmaceutical industries, especially its use in the qualitative analysis of agricultural products and pharmaceutical samples has significantly increased during the last decade (Chen *et al*., 2008).

2.7.1. Theory and principles

NIR spectroscopy is based on the absorption of electromagnetic radiation at wavelengths in the range of 780– 2500 nm. NIR spectra of food products comprises of broad bands arising from overlapping absorptions corresponding mainly to overtones and combinations of vibrational modes involving C–H, O–H, and N–H chemical bonds (Osborne, 2000). The principle of NIR reflectance spectroscopy is that, light in the wavelength range of 1100 to 2500 nm contains compositional information which can be unraveled by sophisticated statistical techniques to report multiple analyses almost instantaneously (Nicolai *et al*., 2007).

For a given molecule, a normal mode of vibration corresponds to internal atomic motions in which all atoms move in phase with same frequency but with different amplitude. Additionally to these normal vibrations transitions corresponds to be called overtones. Transition from the ground state to the first excited state absorbs light strongly

in IR region and give rise to intense bands called the fundamental bands. Transition from the ground state to the second excited state with the absorption of NIR gives rise to weak bands called 1st overtone in NIR. Similarly 2nd, 3rd and 4th overtone bands will occur based on the transition to the third, fourth and fifth excited state with the absorption of NIR (Aenugu *et al.*, 2011).

Radiation interacting with a sample may be absorbed, transmitted or reflected. Thus, there are different NIR spectroscopy measurement modes fitting different applications. In practice, the common modes are transmittance, interactance, transflectance, diffuse transmittance, and diffuse reflectance, with the last two being most frequently used. In the wavelength range 1100–2500 nm, the amount of scattering makes the path length so high that transmittance through 1 cm thickness of most samples is negligible. This situation is called diffuse reflectance because most of the incident radiation is reflected. This measurement is suitable for thicker samples such as fruits and wheat powder. (Huang *et al*., 2008)

The appropriate NIR measuring mode will be dictated by the optical properties of the samples. Transparent materials are usually measured in transmittance. Turbid liquids or semi-solids and solids may be measured in diffuse transmittance, diffuse reflectance or transflectance depending on their absorption and scattering characteristics.

2.7.2. Construction

A NIR spectrometer is generally composed of a light source, a monochromator, a sample holder and a detector, allowing for transmittance or reflectance measurements. The light source is usually a tungsten halogen lamp, as it is small, rugged, cheap in cost and readily available. An optical layout of an FT NIR is shown in Fig 2.1.

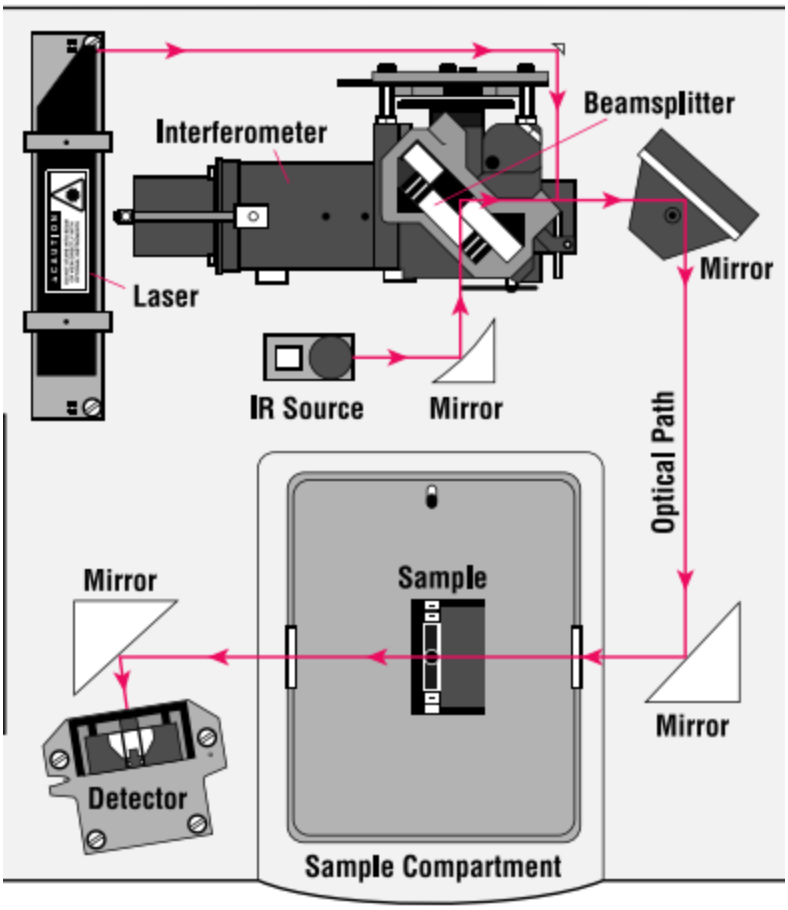

Fig. 2.1. Optical layout of an FT-NIR spectrometer (McCarthy and Kemeny, 2008)

Detector types include silicon, lead sulfide (PbS) and indium gallium arsenide (InGaAs). PbS detectors are slower, but very popular since they are sensitive from 1100 to 2500 nm and provide good signal-to-noise properties (Kawata, 2002). There are several types of sample cells, such as quartz cuvettes with defined optical path length for Liquids, specifically designed sample cells with quartz windows for semi-solids and powders, and adjusted sample holders for tablets and capsules have been developed (Kawano, 2002).

Diffraction grating, interferometer, diode-array or acousto-optic tunable filter (AOTF)-based instruments provide full spectral coverage. Selection of the appropriate technology is usually based upon the required analyte sensitivity, reliability, ease of use, calibration transferability and implementation needs (Reich, 2005). Presently, grating and interferometer-based instruments are mainly in use for the analysis. Fourier transform

spectrophotometer is based on Michelson interferometer. A Michelson interferometer is shown in Fig 2.2.

When the light beams strike the mirror it divides into various wavelengths by diffraction, which is directed into an interferometer. The interferometer consists of a beam splitter, two mirrors (stationary and a moving mirror) and a detector. The beam splitter takes the incoming infrared beam and divides it into two optical beams. One beam reflects to a flat mirror which is fixed in place. The other beam reflects to a flat mirror which is moving a very short distance (typically a few millimeters) away from the beamsplitter. The two beams reflect off of their respective mirrors and are recombined when they meet back at the beamsplitter. The recombined beam passes through the sample and is finally detected by the detector. Because the path that one beam travels is a fixed length and the other is constantly changing as its mirror moves, the signal which exits the interferometer is the result of these two beams "interfering" with each other.

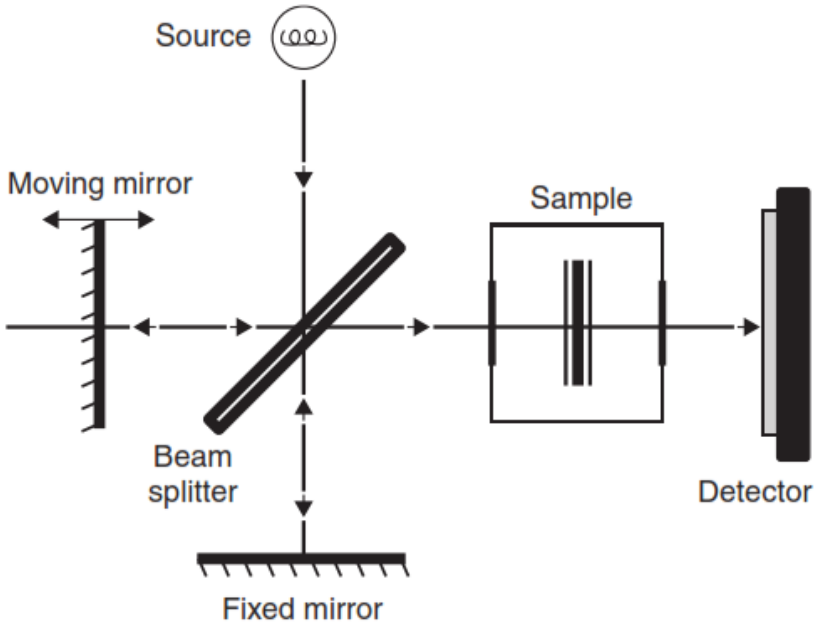

Fig.2.2. Michelson interferometer in FT NIR spectroscopy

The resulting signal is called an **interferogram** which has the unique property that every data point (a function of the moving mirror position) which makes up the signal has information about every infrared frequency which comes from the source (Subramanian and Rodriguez, 2009).

2.7.3. Fourier transformation

The measured interferogram signal is a plot between optical path difference or optical retardation and relative intensity. Optical path difference is the difference in distance travelled by two light beams due to the movement of mirror. The centre part of an interferogram is shown with maximum intensity called as centerburst. The centerburst provides information about the total amount of energy from the source and it does not contain any signal from the sample. The regions on either side of the centerburst are called the wings of the interferogram, where both constructive and destructive interference take place at varying levels and it contains the sample information (Subramanian and Rodriguez, 2009). The interferogram cannot be interpreted directly to make identification or extract useful information from it and has to be mathematically processed and fourier transformed to obtain the spectrum. This mathematical technique is called as **Fourier transformation**. This transformation is performed by the computer which then presents the user with the desired spectral information for analysis. This fast fourier transform reveals the information at each frequency obtained from the interferogram and displays a plot between wavenumber and absorbance (Mccarthy and Kemey, 2008).

2.7.4. Calibration

In order to estimate the quality parameters through NIR spectroscopy, the equipment should have a well defined, more precise calibration models to predict the exact parameter of interest in the food product. The values used for calibration are the values estimated by the conventional analytical methods (wet chemistry analysis). The calibration procedure involves recording the spectra for a number of samples, followed by calculations that allow the computer to determine the relationship between the spectra and their compositions. The process of establishing such a relationship by using a set of samples of known composition is called a calibration. If the number of samples is more for calibration, then the model can be developed more precisely. The calculations creates calibration model of the samples, so that future samples just need to have their spectra measured, while the computer can apply the model to those spectral measurements and estimate the composition of those unknown samples (Otles, 2009).

Before building a calibration model for a given analyte using NIR spectra or similar correlative techniques, a series of steps need to be considered such as sample selection, spectra pre-processing, algorithm selection, calibration and validation, and interpretation of the results obtained (Cozzolino *et al*., 2011). As a rule of thumb, samples used to build a calibration model should be selected from samples similar to those that will be analysed in the future. Knowledge of wet chemistry or reference data is very important to develop the calibration. It is important to remember that the wet chemistry or reference data with all their known inadequacies will be used to assess the performance of the NIRS calibrations. Before assessing the accuracy of a NIRS calibration, the error associated with the reference method (SEL=standard error of laboratory) should be known, but this is often ignored (Murray, 1993).

2.7.5. Pre processing methods

Interfering spectral parameters, such as light scattering, path length variations and random noise, resulting from variable physical sample properties or instrumental effects, call for mathematical corrections, so-called data pretreatments, which is done prior to multivariate modeling in order to reduce, eliminate or standardize their impact on the spectra. Since careful selection of data pretreatments can significantly improve the robustness of a calibration model.

The most widely used pre-processing techniques in NIR spectroscopy can be divided into two categories *viz*. scatter correction methods and spectral derivatives (Rinnan *et al*., 2009). Different spectral algorithms like vector normalization, multiplicative scattering correction (MSC), standard normal variate (SNV), min-max normalization, constant offset elimination, straight line subtraction, first derivative and second derivative were used for preprocessing of spectra for reproducibility of calibration model (Tripathi *et al*., 2010). Mathematical treatments used to compensate for scatter-induced baseline offsets include multiplicative scatter correction and standard normal variate. Both methods have originally been developed to process reflectance spectra, but they are also applied to transmittance spectra. Baseline shifts and intensity differences resulting from variable positioning or path length variations may be reduced or eliminated by normalization algorithms (Reich, 2005).

While most chemometrics software packages offer several normalisation methods, multiple scatter correction is the most popular normalisation technique (Naes *et al*., 2004). It is used to compensate for additive (baseline shift) and multiplicative (tilt) effects in the spectral data. Derivation is used often to remove baseline shifts and superposed peaks. Derivative spectra of order two are most popular as they can correct for both additive and multiplicative effects (Naes *et al*., 2004). Second derivative will enhance the resolution by removing the overlapping peaks and correcting the baseline. Mean centering removes any offset from the data (Onen *et al*., 2003). Out of a number of tested spectral preprocessing, the optimal preprocessing is characterized by the lowest statistical errors obtained in the data analysis. Optimal spectral preprocessing help to eliminate interferences and facilitate information extraction from NIR spectral data (Rinnan *et al*., 2009).

2.7.6. Chemometrics

Chemometrics is the science of relating measurements made on a chemical system or process to the state of the system via application of mathematical or statistical methods. Chemometrics has been used to extend and improve the potential application of NIRS technique in food industry. The multivariate-regression methods most frequently used in NIR spectroscopy are principal component regression (PCR) and Partial Least Square regression (PLS) (Martens and Naes, 1989). NIRS requires chemometrics to extract as much relevant information as possible from the analytical data (Blanco and Villarroya, 2002).

2.7.6.1. *Partial least square regression*

Among the various multivariate analysis techniques, the partial least-squares regression method is gaining importance in many fields of chemistry; analytical, physical, clinical chemistry and industrial process control can benefit from the use of the method (Geladi and Kowalski, 1986). Partial least square is a method for constructing predictive models when the factors are many and highly collinear. PLS models are slightly better than the PCR because they do not include latent variables that are less important to describe the variance of the quality parameter (Luinge et al., 1993).

Chemical analysis consists of two steps *viz*. calibration and validation. PLSR develops a model for sample's behavior. A model Y = f(X) is a relationship between two groups of variables, dependent Y and independent X. This is the calibration step, which establishes a linear relationship between the spectra and the reference values. Second is the prediction step where, independent variables are obtained from the dependent samples.

The quality of the calibration is evaluated by means of cross validation. Validation is performed by predicting a certain number of samples with known analyte concentration with the chemometric model. In cross validation one sample will be removed from the calibration set. Using the remaining samples, a chemometric model is developed and used to analyze the left out sample. Now the previous sample is replaced and second sample is removed. This procedure of removing samples, analyzing them, and returning them to the calibration data set is continued successively until all samples have been analyzed once. A comparison of the results with the actual concentration values shows how precisely the model predicts the samples.

The performance of the final PLS model was evaluated in terms of root mean square error of cross validation (RMSECV) and root mean square error of prediction (RMSEP) during test validation, and the coefficient of determination (R^2).

Sum of squared errors (SSE) is given by the quadratic sum of squares of residual values, where residual value is the difference between the true and fitted values.

$$SSE = \Sigma(Residual)^2 \qquad \textbf{….(2.1)}$$

The root mean square error of estimation (RMSEE) is calculated by the equation (2.2) where 'n' is the number of samples and 'r' is given as rank

$$\text{RMSEE} = \sqrt{\frac{1}{n-r-1}} \text{ X SSE} \qquad \textbf{….(2.2)}$$

The coefficient of determination (R^2) is the percentage of variance present in the true component values, which is developed in the regression. If R^2 value is equal to 1, then the fitted value will be same as the true value. The equation for finding coefficient of determination is given by the equation (2.3).

$$R^2 = \left(1 - \frac{SSE}{\Sigma (yi - ym)2}\right) \times 100 \quad \textbf{….(2.3)}$$

where,

y_m = mean of true values of all samples

y_i = true value of sample *i.*

The root mean square error of cross validation is calculated using the equation (2.4) given below:

$$\text{RMSECV} = \sqrt{\frac{\Sigma (\bar{y}_i - y_i)^2}{n}} \quad \textbf{….(2.4)}$$

where,

n = number of samples of training set (calibration)

$\bar{y}_i$ = reference measurement result for the sample *i*

y_i = the estimated result for sample *i* when model is developed.

For validating the test set, the root mean square error of prediction is given by the equation (2.5).

$$\text{RMSEP} = \sqrt{\frac{\Sigma (y_i - \hat{y}_i)^2}{n}} \quad \textbf{….(2.5)}$$

where,

n = number of samples in the test set,

y_i = the reference measurement result for the sample *i*

$\hat{y}_i$ = the estimated result of the model for the test sample *i*

The Residual Predictive Deviation (RPD), defined as the ratio between the standard deviation of the reference values and the standard error of performance (RMSECV or RMSEP) was used to verify the accuracy of the calibration models developed. If the SECV is large compared with the range of compositions (as S.D.), a relatively small RPD value results, and the NIR calibration model is considered not

robust. The higher the value of the RPD the greater the probability of the model to predict the chemical composition accurately in samples outside the calibration set. An RPD value greater than three (range 3.1–4.9) is considered fair and recommended for screening purposes, an RPD value greater than 5 (range 5–6.4) is considered good for quality control (Cozzolino *et al*., 2008).

2.7.7. Applications of FT-NIR spectroscopy

FT-NIR spectroscopy technique is a non-destructive analytical technique with the advantages of rapid sample analysis and simple operation. Compared to conventional analytical methods, FT-NIR spectroscopy is a fast, accurate, and nondestructive technique that can be used as a replacement of conventional sensory evaluation methods and time-consuming Chemical methods. Near infrared spectroscopy and chemometrics had proved their effectiveness for both qualitative and quantitative analyses in different fields as agriculture, food, chemical and oil industry.

2.7.7.1. *Cereals*

Hirano *et al*. (1998) studied a method to detect the internally moldy nuts by measuring the transmittance near infra red spectra of individual peanuts. The difference between normal and moldy nuts could be distinguished from each other by comparing the transmittance ratio of 700 nm to 1100 nm by NIR spectrometry. The fungal hydrolysis of the triglycerides that were contained in the nut seemed to account for these differences on the NIR spectra. NIR spectrometry were found to be more promising method than the Xray – CT and H-NMR-CT methods as they had low information and more time consuming.

Pettersson and Aberg (2003) reported a method to determine the mycotoxin deoxynivalenol (DON) in wheat kernel samples using near infrared transmittance. The best regression model was obtained for the wavelength range of 670–1100 nm with a slope of 0.949, a correlation coefficient of 0.984 and a standard error of 381 µg DON per kg. Thus it was concluded that it would be easier in future to screen the DON in wheat kernals at concentrations just above the proposed European limits for wheat flour.

Wang *et al*. (2004) studied the classification of healthy and fungal-damaged soybean seeds using PLS models with NIR spectroscopy. Classification accuracy was more than 99 per cent when the wavelength region of 490–1690 nm was used. The average of correct classification was 93.5 per cent for the calibration sample set and 94.6 per cent for the validation sample set. It was concluded that fungal- damaged soybean seeds could be easily classified using NIR spectroscopy.

Dale *et al*. (2010) conducted experiments to detect crude fat and crude fiber content of maize cobs and strains using Fourier transform- near infrared spectroscopy. The standard error prediction for crude fat and fiber was 0.71 per cent and 0.34 per cent respectively. Hence FT-NIR and partial least squares can be used to determine crude fat and crude fiber in ground maize with very good standard error of prediction.

Pojic *et al*. (2012) studied the protein content determination of wheat using near infrared spectroscopy. RMSEP values of 5, 7, and 10 subsamples were 0.2461, 0.2385 and 0.2474 respectively. The obtained results indicated that the NIR method for determination of protein content was robust for its application in wheat quality control regardless the deliberate changes in operational conditions.

2.7.7.2. *Meat products*

Bazar *et al*. (2007) developed a method to predict protein and fat content of rabbit hind leg meat using near infrared spectroscopy. Results indicated that the coefficients of determination (R^2) were 0.89 and 0.99 for fat, 0.85 and 0.96 for protein in fresh and freeze-dried samples respectively. Hence NIR spectroscopy is an applicable technique for quick analysis of raw rabbit hind leg meat.

Prieto *et al*. (2009) presented a review on the use of NIR spectroscopy to predict different meat properties. Properties include chemical composition (crude protein, intramuscular fat, moisture/dry matter, ash, gross energy, myoglobin and collagen), technological parameters (pH value; L*, a*, b* colour values; water holding capacity; Warner–Bratzler and slice shear force) and sensory attributes (colour, shape, marbling, odour, flavour, juiciness, tenderness or firmness). The usefulness of NIR for classification into meat quality grades and its potential application in the industry were also studied.

2.7.7.3. *Fruits*

Bureau *et al*. (2009) developed a method for the evaluation of apricot fruit quality using Fourier transform near infrared spectroscopy (FT-NIR). Measurements were performed individually on 877 apricot fruits from eight cultivars harvested at different ripening stages. Results showed that NIR could accurately predict the soluble solids and titratable acidity with correlation coefficients of 0.92 and 0.89 respectively. But, the prediction of the other quality such as firmness, ethylene production, individual sugars and organic acids were not sufficiently accurate due to high error of calibration and prediction.

Georgieva *et al*. (2013) studied the quality control of wild berry fruit extracts using NIR spectroscopy. In this study near infrared spectroscopy was used to detect differences between berry fruits (bilberry, cranberry, raspberry and strawberry) themselves, difference between the sample based on the preparation procedure and their quality decrease affected by the storage. The range of NIR used for this study was 904-1699 nm. PLS regression showed that the influence of the storage on the NIR spectra of samples was high (R^2=0.79). The results showed that NIRS can be used qualitatively to detect, to identify, and to qualify raw material.

2.7.7.4. Spices and Plantation crops

Chen *et al*. (2008) studied the identification of tea varieties using FT-NIR Spectroscopy with pattern recognition method. Seven varieties of Chinese tea were studied. Pattern recognition was done by Linear Discriminant Analysis (LDA) and Artificial Neural Network (ANN) models, where ANN model showed 100 per cent identification rate than LDA model. Hence results concluded that FT-NIR spectroscopy with ANN pattern recognition method can be successfully applied as a rapid method to identify tea varieties.

Chen *et al*. (2009) analysed the main catechin contents in green tea using near infrared spectroscopy. The catachin contents analysed were epigallocatechin gallate (EGCG), epigallocatechin(EGC), epicatechin gallate (ECG) and epicatechin (EC). Results showed that the correlations coefficients of the prediction set were R^2 = 0.9852, 0.9596 , 0.9760, 0.9763 for ECG, EC, EGCG and EGC respectively. Hence FT-NIR

spectroscopy together with PLS algorithm could be successfully applied to determine the main catechins contents in green tea.

Yao *et al*. (2010) measured the klason lignin, acid-soluble lignin and total lignin content in acacia spp using NIR spectroscopy. 78 samples of different families of Acacia spp. were used for this study. The RMSEP of calibration and prediction were generally lower than 0.5, indicating that klason lignin and total lignin content can be reliably predicted from spectra. Results concluded that NIR calibrations were successfully developed for predicting lignin content which showed reliable results.

Tripathi *et al*. (2010) developed a Nondestructive method of measuring curcuminoid content of turmeric powder by fourier transform near infrared (FT-NIR) spectrometer. Calibration was made from 24 samples which were analysed spectrophotometrically and cross validated with another 24 samples. The coefficient of determination (R^2) and root mean square error (RMSECV) values for cross validation were 0.97 and 0.104, which concluded FT-NIR could be used as an effective, non destructive tool for determining curcuminoid in turmeric.

Materials and Methods

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the materials used and the methods followed in the determination of the physical and frictional properties, biochemical analysis of polished turmeric rhizomes. Calibration, recording the spectra of turmeric and validation of Fourier Transform Near Infra-Red Spectroscopy (FT-NIR) are also presented.

3.1. Raw Materials

Polished turmeric rhizomes of both bulbs and fingers of Salem local and Erode local varieties were purchased from the 'Ulavan producer company Ltd' from Erode (Plate 3.1). Chemicals used for this study were of Analytical grade.

3.2. Physical Properties

The physical properties *viz.* size, volume, surface area, bulk density, true density and porosity of both turmeric varieties were determined in the present study and compared. The methods followed to determine these properties are detailed below.

3.2.1. Size

Size, generally refers to the characteristic of an object which determines space requirement within the limit and is described in terms of length, width and thickness. Four samples (Erode fingers, Erode bulbs, Salem fingers and Salem bulbs) each weighing 1 kg was randomly drawn from the bulk. Each sample was mixed thoroughly and finally 30 rhizomes from each sample were randomly selected. The dimensions along three mutually perpendicular axes, namely major (length, a), intermediate (width, b) and minor (thickness, c) of each rhizome were measured using a digital vernier calliper having an accuracy of 0.02 mm. Using the dimensions measured geometric mean diameter (GMD), sphericity, arithmetic mean diameter (AMD), square mean diameter (SMD), equivalent diameter (EQD) and aspect ratio (AR) were determined by the following equations (Mohesenin, 1986)

3.1.a. Salem bulb

3.1.b. Salem finger

3.1.c.Erode bulb

3.1.d. Erode finger

Plate 3.1. Polished turmeric rhizomes of Erode local and Salem local variety

Geometric mean diameter = $\sqrt[3]{abc}$ **..... (3.1)**

Sphericity = $\frac{\sqrt[3]{abc}}{a}$ **.....(3.2)**

Arithmetic mean diameter = $\frac{a+b+c}{3}$ **.....(3.3)**

Square mean diameter = $\sqrt{ab+bc+ca}$ **.....(3.4)**

Equivalent diameter = $\frac{AMD+GMD+SMD}{3}$ **.....(3.5)**

Aspect ratio = $\frac{b}{a}$ **.....(3.6)**

The unit volume (V) and surface area (S) were determined as per the following equations (Jain and Bal, 1997).

Surface area = $\frac{\pi Ba2}{2a-B}$ **.....(3.7)**

Volume = $\frac{\pi Ba2}{6(2a-B)}$ **.....(3.8)**

Where, B = $\sqrt{bc}$

3.2.2. Bulk density

Bulk density was calculated as the ratio between mass and bulk volume of turmeric rhizomes. Turmeric samples were filled randomly in a cylinder with height and radius of 20 cm and 4.95 cm. The mass of the filled cylinder was weighed and the volume of the cylinder was calculated. The bulk density of the turmeric rhizomes was determined by taking ten replications of all the four samples.

3.2.3 True density

The true density of turmeric rhizomes was determined by the platform scale method (Mohsenin, 1986). The turmeric samples were first weighed on a precision electronic balance having a least count of 0.01 g and then immersed in water in a container placed above the electronic balance. The mass of displaced water was recorded and used in the following expression to determine the true volume. True density of the turmeric rhizomes was determined by taking ten replications of all the four samples.

$$\text{True volume},(m^3) = \frac{\text{Mass of displaced water},(kg)}{\text{Density of water},\ (kg\,m^{-3})} \qquad \textbf{.....(3.9)}$$

By knowing the mass of the turmeric rhizomes in the air and the true volume, the true density was obtained as the ratio between the mass to its true volume.

$$\rho_t = \frac{W_a}{V_t} \qquad \textbf{.....(3.10)}$$

Where,

ρ_t is the true density of turmeric rhizomes, kg m^{-3}

W_a is the mass of turmeric rhizomes in air, kg

V_t is the true volume of turmeric rhizomes, m^3

3.2.4. Porosity

The porosity of the turmeric rhizomes was computed using the following formula (Kaleemullah and Kailappan, 2003).

$$\varepsilon = 1 - \left(\frac{\rho_b}{\rho_t}\right) \times 100 \qquad \textbf{.....(3.11)}$$

where,

ε is the porosity, %

ρ_b is the bulk density, kg m^{-3}

ρ_t is the true density, kg m^{-3}

3.3 Frictional Properties

Frictional properties such as angle of repose and coefficient of friction of turmeric rhizomes on selected surfaces were studied to understand the ease with which the rhizomes move over selected surfaces during transportation.

3.3.1. Angle of repose

The angle of repose is the angle made by the material with the horizontal surface when piled from a known height. Ten kg of turmeric rhizomes were piled over a horizontal surface. The radius of the pile was calculated from the circumference of the pile and the slant height of the pile was determined by measuring the actual slope of the pile. Angle of repose was determined by taking ten replications of all the four samples. The angle of repose was calculated using the following formula.

$$\theta = \tan^{-1}\left(\frac{h}{r}\right) \qquad \textbf{.....(3.12)}$$

Where,

θ is the angle of repose, degrees

r is the radius of the pile, cm

h is the slant height of the pile, cm

3.3.2. Coefficient of friction

The apparatus consists of a frictionless pulley fitted on a frame, a bottomless cylindrical container (94 mm diameter and 98 mm height), loading pan and test surfaces. The bottomless container was placed first on the test surface and filled with a known quantity of rhizomes and weights were added to the loading pan until the container began to slide. The mass of rhizomes and the added weights represent the normal force and frictional force, respectively. The test surfaces used in the experiment were galvanized iron, mild steel, aluminium and stainless steel. Experiments were replicated 5 times by emptying and refilling the container with different samples every time and the average value was determined and recorded as the average static coefficient of friction. The co-efficient of static friction was calculated as the ratio of the frictional force to the normal force as, (Sahay and Singh, 1994)

$$\mu = \frac{F}{N} \qquad \textbf{.....(3.13)}$$

Where, μ is the co-efficient of friction

F is the frictional force, kg

N is the normal force, kg

3.4. Quality Analysis of Turmeric Rhizomes

Quality analysis of turmeric rhizomes is very important in case of grading. In this study three parameters have been selected for quality analysis in turmeric, they are curcumin, starch and moisture content.

3.4.1. Sample preparation

Samples were prepared every day before the biochemical analysis. 50 grams of Turmeric rhizomes were powdered in a dhall mill and sieved to pass through 1 mm screen for biochemical analysis. Samples were packed in zip lock covers within the aluminum foil package to avoid the loss of volatile compounds till the analysis.

3.4.2. Curcumin content

Curcumin content was determined as per the procedure followed by BIS – 10925: 1984 (Plate 3.2). The standard curcumin solution was first prepared by taking 25 mg of standard curcumin into a 100 ml volumetric flask and diluted to mark with alcohol. 1 ml of the solution was transferred to 100 ml volumetric flask and diluted to mark with alcohol; this standard solution contains 2.5 mg (0.0025 g/ litre) curcumin.

50 mg of the prepared sample were taken with 50 ml of alcohol in a round bottom flask. The mixture was refluxed for two and a half an hour in an air condenser. The extract was cooled and filtered into a 50 ml volumetric flask. 1 ml of the extract was diluted to 9 ml of alcohol. The absorbance of the extract and the standard solution was measured at 425 nm against alcoholic blank in a spectrophotometer (Make: Systronics, Ahmedabad) (plate 3.3). Curcumin content was estimated by the following formula.

$$\textbf{Curcumin content (\%)} = \frac{\textbf{0.0025 X } A_{425} \textbf{ X volume made up X dilution factor X 100}}{\textbf{0.42 X weight of the sample X 1000}} \quad \textbf{.....(3.14)}$$

$\mathbf{A_{425}}$ **=** absorbance at 425 nm. (BIS – 10925: 1984)

3.4.3. Moisture content estimation

The moisture content was determined by the dean and stark distillation method according to the Indian Standard Specification- IS: 1797-1985 (Plate 3.4). The principle of this method is to determine the amount of water by distilling the material with an organic liquid which is not miscible with water and collecting the distillate in a graduated tube.

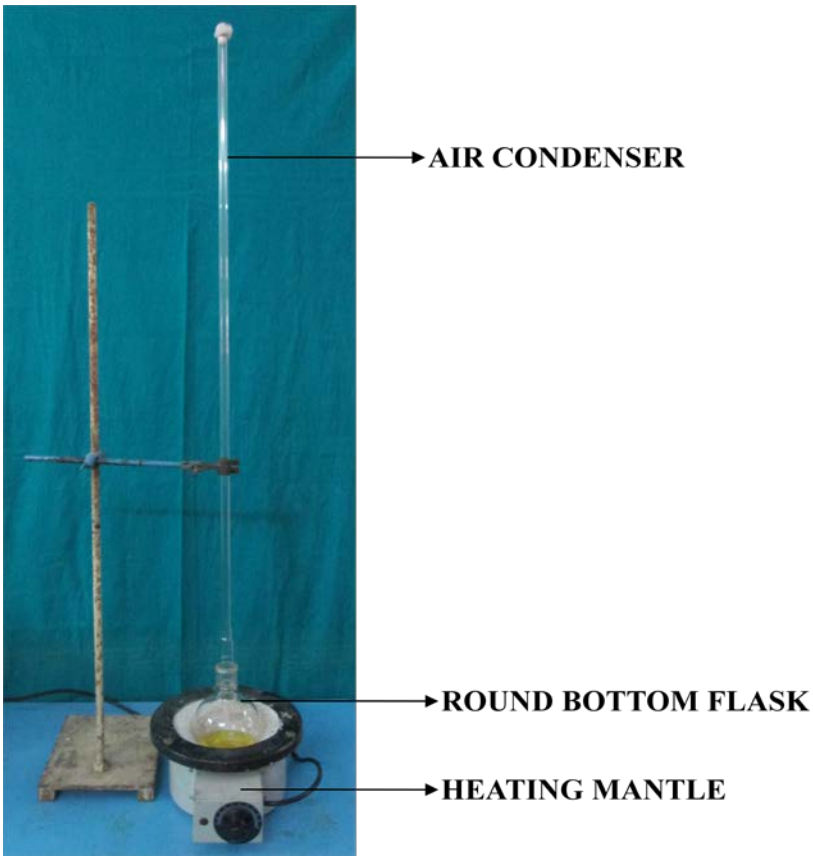

Plate 3.2. Solvent reflux method of curcumin estimation

Plate 3.3. Spectrophotometer

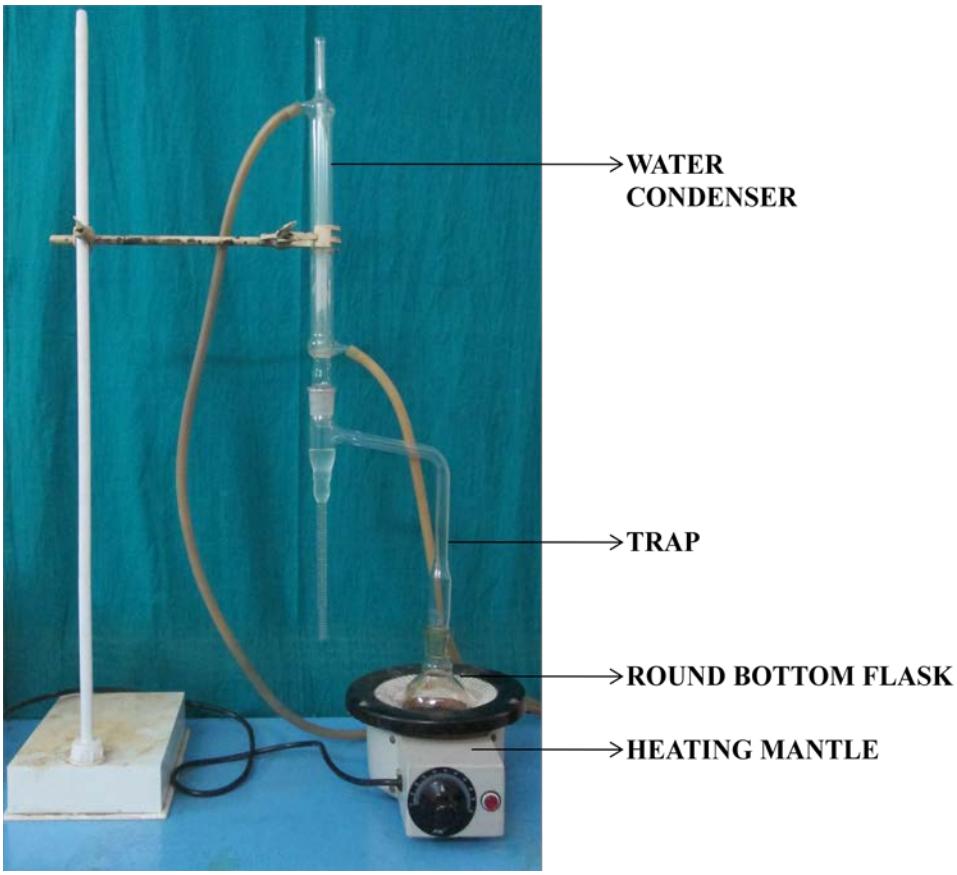

Plate 3.4. Dean and stark apparatus for moisture content estimation

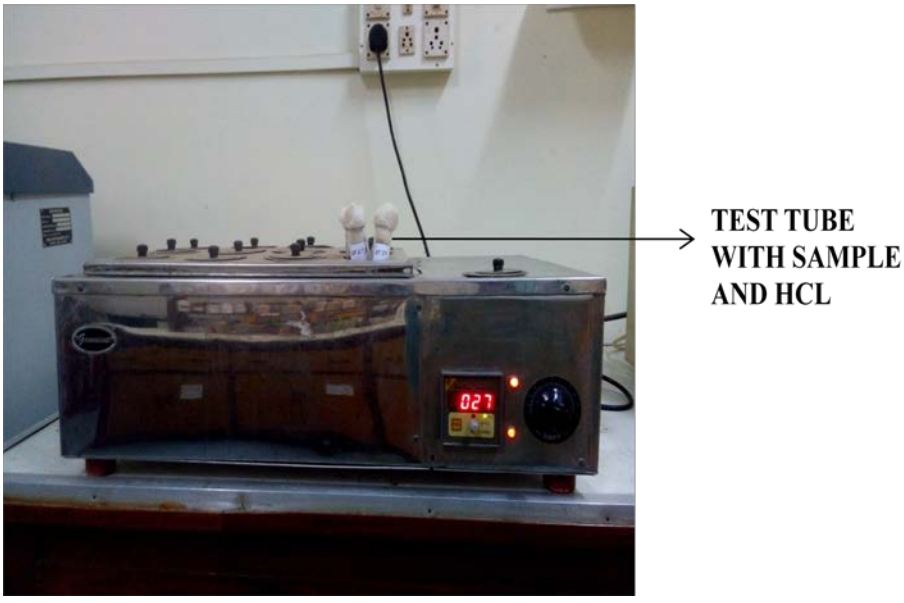

Plate 3.5. Water bath for acid hydrolysis method in starch estimation

The apparatus consists of a round bottomed flask provided with a reflux condenser discharging into a trap connected to the flask. The trap consists of a graduated tube which has a capacity of 5 ml. The trap serves to collect and measure the condensed water and to return the condensed solvent to the flask. 20 g of the prepared sample was taken in a round bottom flask. 75 ml of toluene was added to it. The apparatus was assembled and the flask was heated in such a way that the distillation rate was about 2 drops per second until most of water distills over, then the rate of distillation was increased to 4 drops per second. Glass beads were added to avoid bumping. Reflux was continued until the water level in the receiver remains unchanged for 30 minutes and then the source of heat was switched off. Water if any held up in the condenser were dislodged with a wire loop. The receiver was cooled, the volume of the water was read and the percentage moisture content was calculated by the following formula.

$$\textbf{Moisture\%} = \frac{\textbf{volume in ml of water collected X 100}}{\textbf{mass in gm of the test portion}} \qquad \textbf{.....(3.15)}$$

3.4.4. Starch estimation

Starch was estimated according to the Indian standard specification – IS: 3576 – 1994 (plate 3.5). Generally starch consists of 20% water soluble amylase and 80% water insoluble amylopectin. Hence the acid hydrolysis method is adopted which hydrolyses the entire sample to sugars in 3 hours. The standard stock solution was prepared by weighing 0.5 g of dextrose in a 100 ml graduated flask and diluted to mark with water. The solution was titrated against 10 ml Fehling's solution. Amount of dextrose consumed by the Fehling's solution was noted.

0.1 g of the prepared sample were first defatted by washing with petroleum ether till the washings are free from yellow color. The ether free residue was washed with 10 ml of 10% alcohol and then with 20 ml of cold water. The residue was then hydrolyzed with 10 ml of 2.5% dilute Hydrochloric acid (HCl) for 3 hours. After cooling the excess of HCl was neutralized using sodium carbonate till the effervescence stops. The contents were transferred to a 50 ml volumetric flask and were diluted up to mark with water. The solution was filtered and the filtrate was titrated against 10 ml Fehling's solution.

In the boiling fehling solution, filtrate was added drop by drop till brick red color appears. A few drops of methyl blue indicator were added and titration continued until the brick red color reappears. Percentage of starch was calculated by the following formula.

$$\text{Starch \%} = \frac{a \times 50 \times 100 \times 0.9}{200 \times b \times c} \quad \text{.....(3.16)}$$

a = amount (ml) of standard 0.5% dextrose solution consumed by Fehling's Solution

b = amount (ml) of starch solution of sample consumed by the Fehling's solution.

c = weight (g) of the sample taken.

3.5. Fourier Transform Near Infra-Red Spectroscopy

3.5.1. Instrument

The experiment was carried out in Fourier Transform Near Infra-Red Spectrometer (FT-NIR) (Make: Bruker optics, MATRIX-I, Germany) which measures the spectrum in diffuse reflectance mode using integrating sphere (Plate 3.6). The system was operated by Spectral Acquisition and Processing Software (OPUS software, version 7.2, Bruker optics, Germany). The spectra were obtained at a resolution of 8 cm^{-1} over a wavelength range of 12500-3600 cm^{-1} with 64 scans per spectrum. Tungsten halogen lamp was used as the light source; Michelson interferometer equipped with beam splitter with lead sulphide (PbS) detector was capable of detecting the interference of the light beam passing through the sample. The interferogram collected by the detector was converted into a spectrum by fourier transforming the interferogram. The multivariate analysis was carried out using QUANT software (version 7.2, Bruker optics, Germany), which performs partial least square regression (PLSR) technique for developing models.

3.5.3 Spectra recording

The spectra of the samples were recorded daily before the conventional biochemical analysis. The spectra for each sample were replicated thrice. Each replication is the average of 3 spectra recorded by shuffling the orientation in the sample cup, so as to standardize the orientation of particles. Totally 360 spectra of 120 samples of turmeric rhizomes were recorded.

Plate 3.6. Fourier Transform Near Infrared Spectroscopy

3.5.2. Preprocessing methods

There are 11 important spectral preprocessing methods available in the software which includes no spectral preprocessing, constant offset elimination (COE), straight line subtraction (SLS), Vector Normalization (VN), Min max normalization (MMN), Multiplicative scatter correction (MSC), first derivative, second derivative, first derivative+S LS, first derivative+VN and first derivative+MSC. Though each preprocessing has its own function on the spectra, the choice of best spectral preprocessing is purely based on trial and error. In the present study, spectral preprocessing such as vector normalization, first derivative and vector normalization + first derivative are used, since they are used in most of the diffuse reflectance equipments and recommended by the equipment manufacturers.

3.5.3. Calibration and validation

QUANT 7.2 software was used for multivariate analysis using partial least square regression. The calibration model was developed using the PLS algorithm. In this study sample used for calibration and validation were same. The PLS model was validated by leave-one-out cross validation method, one sample will be removed and the model is made with the remaining data. The value for the left out sample is predicted based on the model developed and prediction residual is computed. This process is repeated until every data is left out once, then all the prediction residuals are combined to compute the validation results. The suitability of the developed model was based on higher coefficient of determination value (R^2) and lowest standard error of cross validation (RMSECV) (Xue *et al*., 2011).

3.6. Statistical Design

For the present study, 30 samples from each variety (Erode local and Salem local) of the fingers and bulbs with the total of 120 samples were taken. For all the 120 samples curcumin, moisture and starch content were estimated by the conventional wet chemistry method. The mean and standard deviation of the physical and chemical properties were calculated using MS-Excel package. The Partial Least Square regression was carried out using QUANT software (version 7.2). The design layout of the experiment is shown in Table 3.1.

Table 3.1. Design layout of the experiment

Independent variables	Polished turmeric samples a) Erode local (fingers and bulbs) b) Salem local (fingers and bulbs)
Dependent variables	a) Curcumin content
	b) Moisture content
	c) Starch content

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

This chapter deals with the results obtained from various experiments conducted on physical and frictional properties of turmeric rhizomes. The quality parameters such as curcumin, starch and moisture content were analysed using conventional method, whose results are discussed for all the samples of bulbs and fingers of Erode and Salem local varieties of turmeric. Validated models for all the three quality parameters using Fourier Transform Near Infrared spectroscopy are presented and discussed. The results of the present investigations were compared with the results of the previous researchers work on similar agricultural produces and discussed.

4.1. Physical and Frictional Properties

The results of physical properties *viz.* size, bulk density, true density and porosity; frictional properties *viz.* angle of repose and coefficient of friction of turmeric rhizomes are presented and discussed in this section. These properties were found for all four samples of turmeric rhizomes viz. Erode bulb, Erode fingers, Salem bulb and Salem fingers.

4.1.1. Physical properties

The results of different physical properties of turmeric rhizomes are presented and discussed below.

4.1.1.1. Size

Measurements of the three major perpendicular dimensions, length, breadth and thickness of all four turmeric samples are presented in Table 4.1. The observed values of length, breadth and thickness of the rhizomes are presented in Annexure A1 to A3. From the table it was observed that the highest length of 64.33 mm was recorded by Salem finger samples. Highest breadth of 27.19 mm and thickness of 24.68 mm was recorded by Salem bulb samples. Geometric mean diameter, arithmetic mean diameter, square mean diameter and equivalent diameter of 5.59 mm, 32.56 mm, 55.16 mm and 35.11 mm respectively were found to be higher for Salem bulb samples, as the dimensions were higher for this sample. Highest unit volume of 0.33 mm^3 and surface area of 9.36 mm^2

were observed for Erode bulb samples. Observed values are presented in Annexure A3 to A10. Balasubramanian *et al*. (2012) studied the physical properties of turmeric rhizomes and reported an increase in the arithmetic mean diameter, geometric mean diameter, square mean diameter and equivalent diameter with the increase in dimensions of turmeric rhizomes.

Sinker *et al*. (2005) conducted the preliminary evaluation of 21 varieties of turmeric rhizomes. Longest mother rhizome was recorded by Rajapuri (9.23 cm), maximum weight of mother rhizome (90.35 g) and primary rhizomes (208.92 g) were recorded by Salem variety.

Table 4.1. Dimensions of turmeric rhizomes

Dimensions	Turmeric rhizomes			
	Erode finger	**Erode bulb**	**Salem finger**	**Salem bulb**
Length(mm)	53.68 ± 15.28	33.60 ± 18.26	64.33 ± 8.64	45.82 ± 4.71
Breadth(mm)	10.45 ±0.07	23.23 ± 4.53	15.84 ±1.65	27.19 ± 0.54
Thickness(mm)	9.32 ± 0.04	21.41 ± 4.38	14.24 ± 1.29	24.68 ± 0.96
Geometric mean diameter(mm)	4.15±0.18	5.04±0.34	4.93± 0.2	5.59±0.18
Arithmetic mean diameter(mm)	24.49±2.75	26.08±3.74	31.47±2.72	32.56±2.16
Square mean diameter(mm)	33.9±3.03	44.6±6.18	46.41±3.81	55.16±3.5
Equivalent diameter(mm)	20.85± 1.92	25.24±3.42	27.6±2.21	31.11±1.94
Aspect ratio	0.2±0.04	0.71±0.13	0.25±0.03	0.59±0.05
Surface area(mm^2)	2.36±0.39	9.36±1.71	3.34±0.38	8.45±0.88
Unit volume(mm^3)	0.12±0.01	0.33±0.05	0.14±0.01	0.27±0.02

(Values are Mean±SD)

(n=30)

4.1.1.2. Bulk density, true density and porosity

The bulk density, true density and porosity of bulbs and fingers of the turmeric were measured and are presented in Table 4.2. Observed values are presented in Annexure A11 to A13. From the table it was evident that the Salem bulb sample had the highest bulk density of 647.79 kg m^{-3} and true density of 1266.4 kg m^{-3} and the lowest bulk density of 384.66 kg $m^{-3}$and true density of 1225.5 kg m^{-3} were observed for Erode finger samples. Porosity is inversely proportional to true density hence, maximum porosity of 68.6 percent was recorded by Erode finger samples and minimum porosity of 48.84 percent was recorded by Salem bulb samples.

Table 4.2. Bulk density, true density and porosity of turmeric rhizomes

Samples	Bulk density, kg m^{-3}	True density, kg m^{-3}	Porosity, %
Erode finger	384.66 ± 4.96	1225.2±.30.36	68.6 ± 3.93
Erode bulb	632.46 ± 6.2	1241.6±74.57	49.29 ± 1.38
Salem finger	511.92 ± 9.2	1237.7 ± 63.65	58.29 ± 2.36
Salem bulb	647.79 ±15.48	1266.4 ± 70.38	48.72 ± 2.87

(Values are Mean±SD)
(n=10)

Athmaselvi and Varadharaju (2002) reported the bulk density and true density values of Erode variety as 416.16 kg m^{-3} and 948.67 kg m^{-3} respectively. Porosity was reported as 56.13 percent. Balasubramanian *et al*. (2012) reported the bulk density, true density and porosity of IISR allepey supreme variety for three grades (I 25–35 mm, II: 35–45 mm, III: 45–55 mm) of turmeric rhizomes as 348 – 260 kg m^{-3}, 1354- 1341 kg m^{-3} and 74.53–80.93 per cent respectively.

The variation of these values with the present study could have been due to the soil type, agronomical practices followed *etc*.

4.1.2. Frictional properties

The results of frictional properties *viz.* angle of repose and coefficient of friction of turmeric rhizomes on selected surfaces are presented and discussed below.

4.1.2.1. Angle of repose

The angle of repose of the bulbs and fingers of the turmeric rhizome are presented in Table 4.3. The observed values are presented in Annexure A14. From the table it was observed that the maximum angle of repose of 49.35 degrees was recorded by Salem finger samples and minimum angle of repose of 40.56 degrees was recorded by Salem bulb samples.

Table 4.3. Angle of repose of turmeric rhizomes

Samples	Angle of repose, degrees
Erode fingers	48.59 ± 1.79
Erode bulb	45.59 ± 0.68
Salem finger	49.35 ± 0.88
Salem bulb	40.56 ± 1.9

(Values are Mean±SD)
(n=10)

Balasubramanian *et al*. (2012) reported the angle of repose of IISR allepey supreme variety turmeric rhizomes (grades I, II and III) as 37.57 degrees, 38.44 degrees and 38.90 degrees respectively.

4.1.2.2. Coefficient of friction

The coefficient of friction of bulbs and fingers of the turmeric rhizomes are presented in Table 4.4. Observed values for coefficient of friction are presented in Annexure A15 to A18. Different surfaces used were stainless steel, aluminium, galvanised iron and mild steel. From the table it was clear that, stainless steel recorded minimum coefficient of friction and mild steel recorded maximum coefficient of friction in bulbs and fingers of both the variety. The coefficient of friction recorded with mild steel surface were 0.514, 0.516, 0.521 and 0.532 for Erode finger, Erode bulb, Salem finger and Salem bulb samples respectively. Arora *et al*. (2007) reported the coefficient of friction of polished turmeric rhizomes on galvanized iron sheet as 0.436. In the present study Erode fingers and bulbs had a coefficient of friction of 0.445 and 0.497 respectively with galvanised iron surface.

Athmaselvi and Varadharaju (2002) reported the static coefficient of friction of turmeric rhizomes of BSR I, BSR II and Erode variety. Coefficient of friction was maximum in mild steel surfaces and minimum in stainless steel surfaces of all three varieties.

Balasubramanian *et al*. (2012) also reported that the static coefficient of friction of IISR allepey supreme variety of turmeric rhizomes was maximum in mild steel among plywood, mild steel and aluminium surfaces. This indicates that the results of the present study are in line with the previous researchers.

Table 4.4. Coefficient of friction of turmeric rhizomes

Metal surfaces	Coefficient of friction (Mean±SD), n=10			
	Erode finger	Erode bulb	Salem finger	Salem bulb
Stainless steel	0.226 ± 0.02	0.231 ± 0.01	0.384 ± 0.04	0.313 ± 0.01
Aluminium	0.382 ± 0.01	0.391 ± 0.02	0.473 ± 0.03	0.479 ± 0.03
Galvanized iron	0.445 ± 0.02	0.497 ± 0.03	0.508 ± 0.03	0.513 ± 0.03
Mild steel	0.514 ± 0.01	0.516 ± 0.02	0.521 ± 0.01	0.532 ± 0.05

4.2. Quality Analysis of Turmeric Rhizomes

Three major parameters *viz.* moisture, starch and curcumin content were selected for the quality analysis of turmeric rhizomes. All the three parameters were determined for 30 samples each of Erode bulb, Erode finger, Salem bulb and Salem fingers. Totally 120 samples were analysed for moisture, starch and curcumin contents. Mean values of moisture, starch and curcumin content of all four samples are presented in Table 4.5. Observed values of curcumin, moisture and starch content of the 30 samples are presented in Annexure A19 to A21. From the table it was observed that the maximum curcumin content of 4.52 percent was recorded by Salem fingers and minimum of 2.95 percent was recorded by Erode bulb samples.

Sinker *et al*. (2005) studied the curcumin content of 21 varieties of turmeric rhizome and reported that the highest curcumin content of 4.44 and 4.36 per cent was recorded by salem bulbs and fingers respectively. Pathak *et al*. (2010) reported the

variation in physico-chemical characteristics in *Cucuma longa* procured from different zones of India. Curcumin content was higher (3.24 per cent) in south zone among north, east, west and central zones.

From the table it was clear that the highest moisture content of 8.98 percent was recorded by Erode bulb samples and lowest of 7.05 percent was recorded by Erode finger samples. Lokhande *et al.* (2013) studied the effect of curing and drying methods on recovery, curcumin and essential oil content of different cultivars of turmeric and reported that the Curcumin and moisture content of Salem variety were 4.98 per cent and 9.08 per cent respectively.

In the present study, maximum starch content of 57.79 percent was recorded by Erode finger samples and minimum of 56.68 percent was recorded by Salem bulb samples. Leonel *et al.* (2003) have recorded 47 percent of starch content in *C. longa* and 57.7 percent in *C. zedoaria.* Kuttigounder *et al*. (2011) reported the starch yield as 56 percent.

Table 4.5.Quality analysis of turmeric rhizomes

Samples	Curcumin content, %	Moisture content, %	Starch, %
Erode finger	3.18 ±0.18	7.05±0.38	57.79±0.06
Erode bulb	2.95± 0.11	8.98±0.55	56.87±0.07
Salem finger	4.51±0.28	7.88±0.74	57.13±0.05
Salem bulb	3.17±0.19	7.98±0.74	56.68±0.001

(Values are Mean±SD)
(n=30)

4.3. Fourier Transform Near Infrared Spectroscopy

Fourier transform near infrared spectroscopy (FT-NIR) was used for the quality analysis of turmeric rhizomes, through which grading of the rhizomes can be done according to the quality parameters. In the present study the quality parameters assessed were curcumin content, starch and moisture content. Samples were prepared everyday and the spectra was recorded for each sample before the quality analysis. Quality analysis of all 120 samples was done by conventional method and these values were used to build up the calibration model. The partial least square regression technique and cross validation method was used to develop and validate the model.

4.3.1. Spectra recording

The light beams from interferometer passes through the sample and is detected by lead sulphide detector. The detected signals are fourier transformed to obtain the spectrum. The spectra has a wavenumber range of 12500 to 3600 cm^{-1}. The spectra recorded for all 120 samples are shown in Fig.4.1 to 4.4

Selection of the spectral range and the choice of data preprocessing methods are of central importance.

4.3.2. Selection of spectral range

The wavelength region selection is important in developing a robust calibration model. Spectral range selection is based on the peaks formed in the spectra, as these peaks has the maximum absorbtion of the compounds. Other baseline shifts, spectral noise have been eliminated. Hence in the present study, the regions of 8662.3 - 7927.3 cm^{-1}, 7238.2 - 6411.3 cm^{-1}, 5431.2 - 4941.2 cm^{-1}, 4971.8 - 4497.1 cm^{-1}, 4497.1 - 4190.8 cm^{-1} were selected for the calibration development.

4.3.3 Preprocessing methods

Apart from choosing the right frequency, the data preprocessing method is the second important model parameter. Preprocessing methods help PLS algorithm to establish a good correlation between the spectral data and the concentration data. In the present study the spectra were preprocessed by vector normalization, first derivative and vector normalization + first derivative methods. The preprocessed spectra for estimation of curcumin, starch and moisture content are shown in Fig. 4.5 to 4.8.

4.3.4. Quality evaluation of turmeric rhizomes using FT-NIR

Fourier transform near infrared spectroscopy is used for the development of non destructive quality evaluation of turmeric rhizomes. The results obtained from the conventional analysis for curcumin, starch and moisture content were used for this model development. The values obtained in conventional analysis were fed in the system to the respective spectra, which were recorded prior to conventional analysis.

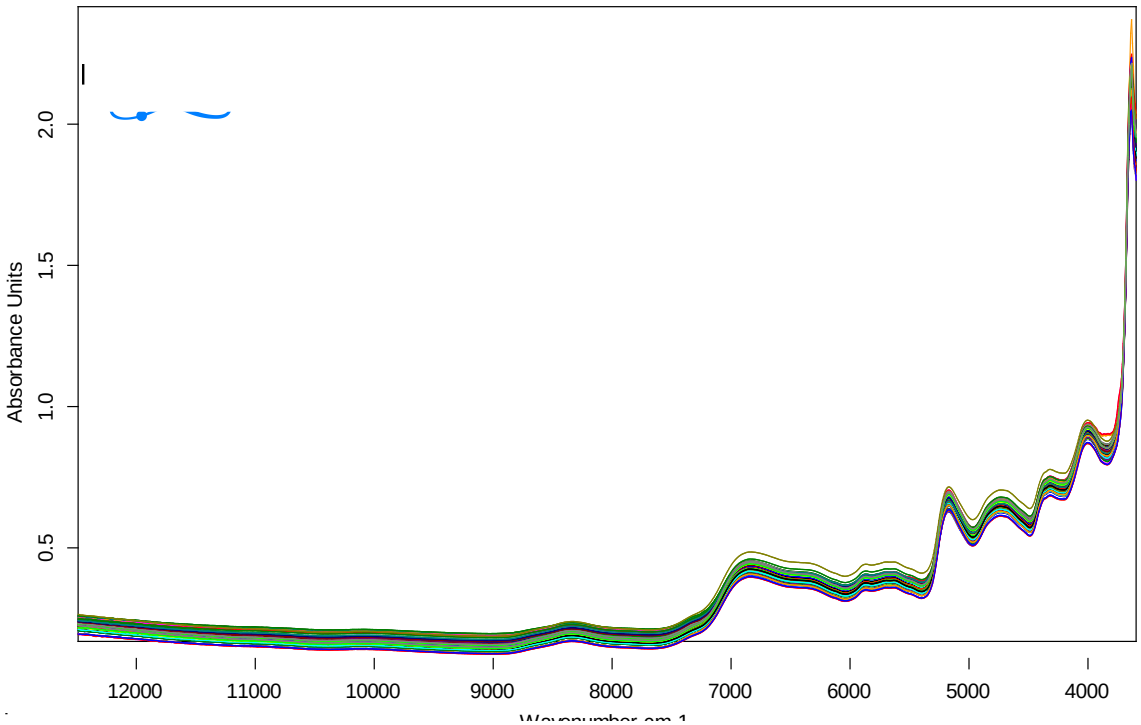

Fig.4.1 Spectra obtained for Erode bulb samples

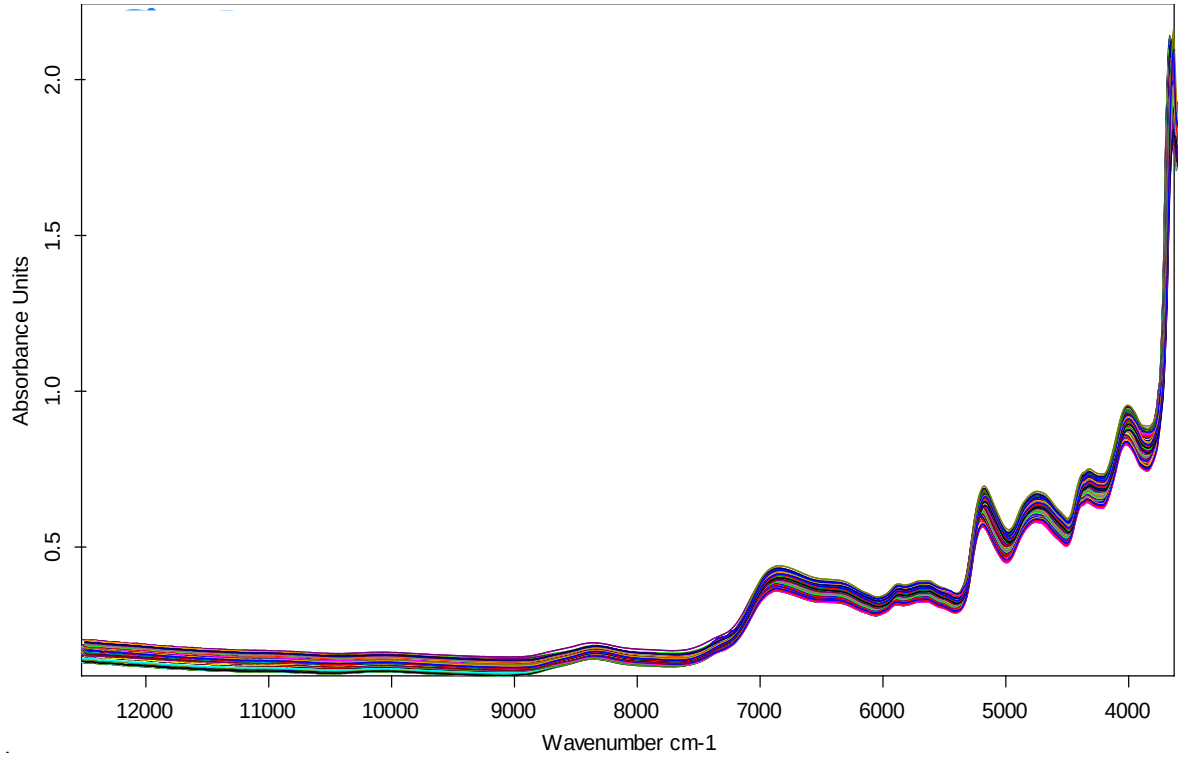

Fig.4.2 Spectra obtained for Salem bulb samples

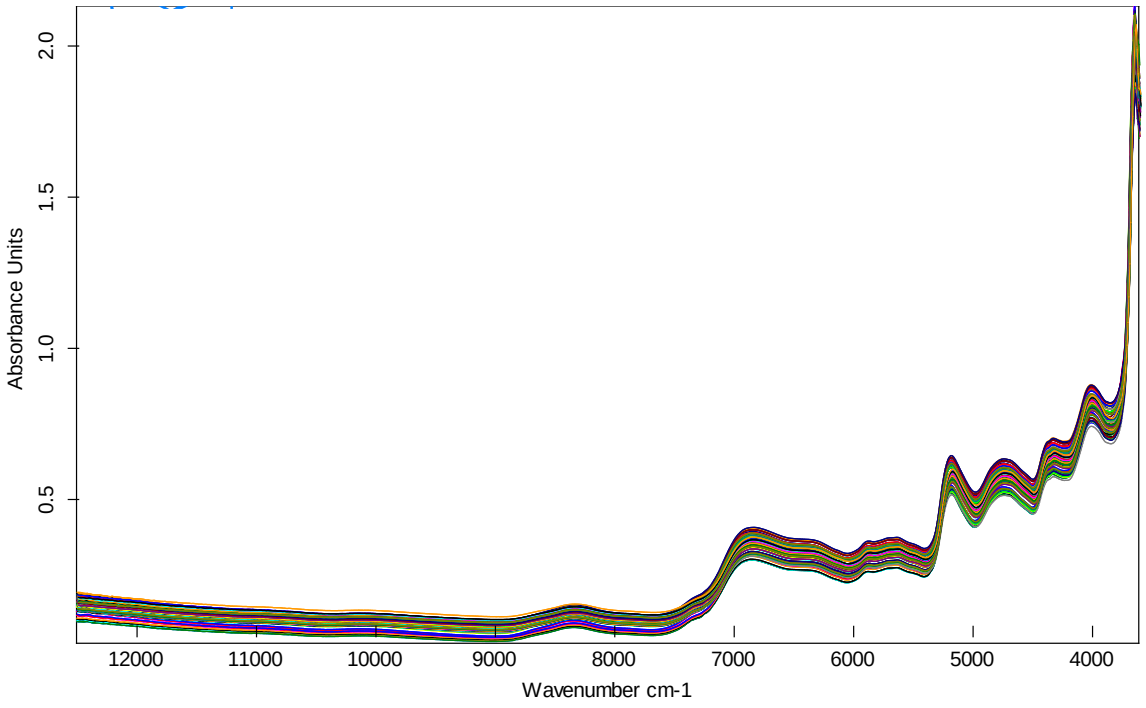

Fig.4.3 Spectra obtained for Erode finger samples

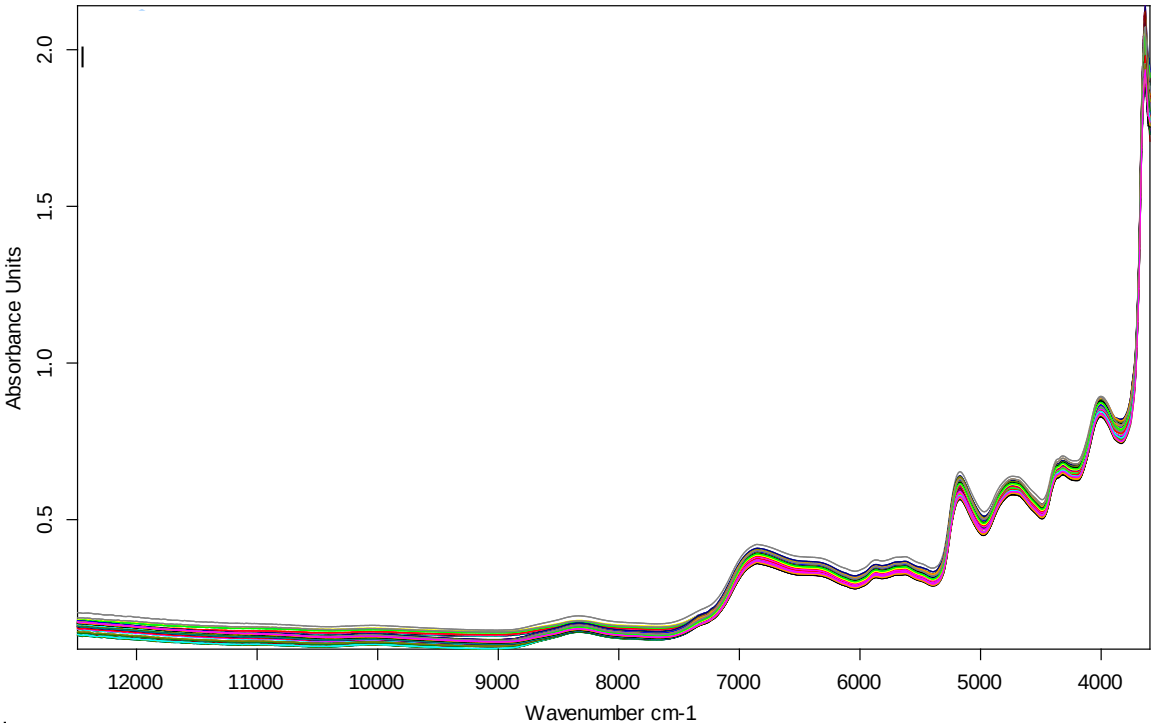

Fig.4.4 Spectra obtained for Salem finger samples

4.3.4.1. Estimation of curcumin content in turmeric rhizomes using FT-NIR Spectroscopy

Curcumin content for 30 samples of fingers and bulbs of Erode local and Salem local were analysed conventionally by spectrophotometric method. The values were incorporated and the spectra recorded were preprocessed with vector normalization, first derivative and vector normalization+first derivative methods. Observed values and NIR predicted values are shown in Annexure A19 and A22 respectively. The values obtained from conventional analysis ranged from 2.82 per cent to 4.91 per cent and the values obtained through cross validation in FT-NIR spectroscopy ranged from 2.78 percent to 4.81 percent. After the calibration and validation of these values, model was developed. A robust calibrated model was selected on the basis of high R^2 value and low RMSECV values. The results using various preprocessing method including R^2 value and RMSECV values are given in Table 4.6.

From the table it is apparent that among the three preprocessing methods First derivative + vector normalisation showed maximum R^2 value of 0.919 and minimum RMSECV value of 0.178. The linear regression plot between the true values obtained from conventional analysis and predicted values by FT-NIR spectroscopy using the calibrated model is given in Fig.4.9.

The straight line equation is represented as

$$y = 0.927x + 0.250 \qquad \textbf{……(4.1)}$$

The Residual Predictive Deviation value for the present model was 3.52, which is considered to be desirable for prediction purposes.

Tripathi *et al*. (2010) estimated the curcuminoid content of turmeric powder by fourier transform near infrared (FT-NIR) spectroscopy. Calibration was made from 24 samples which were analysed spectrophotometrically and cross validated with another 24 samples. The values of coefficient of determination (R^2) and root mean square error of cross validation (RMSECV) were 0.97 and 0.104, which showed a best fit model.

Table 4.6. PLS model for determination of curcumin using FT-NIR spectroscopy

Pre-processing methods	R^2	RMSECV%
No spectral pre-processing	0.899	0.199
Vector normalisation	0.909	0.186
First derivative	0.913	0.189
First derivative + vector normalisation	**0.919**	**0.178**

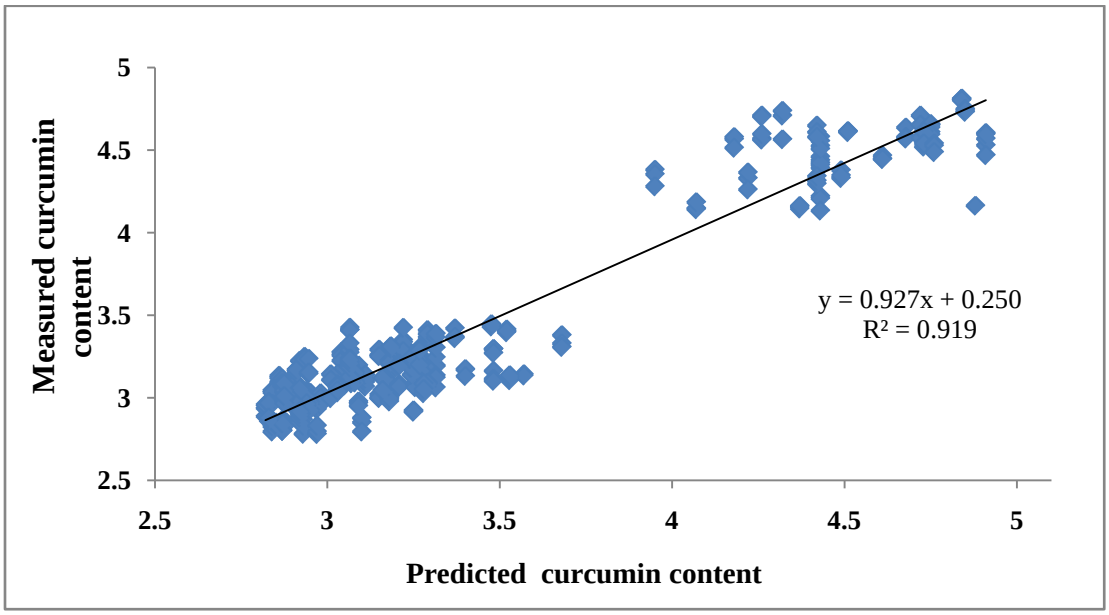

Fig.4.9.Linear plot between measured and predicted values of curcumin content

4.3.4.2. Estimation of moisture content in turmeric rhizomes using FT-NIR Spectroscopy

Moisture content for all 120 samples were analysed conventionally by Dean and Stark distillation method. The values are incorporated and the spectra recorded are preprocessed with vector normalization, first derivative and vector normalization+first derivative methods. Observed values and NIR predicted values are shown in Annexure A20 and A23 respectively. The values obtained from conventional analysis ranged from 7 per cent to 9.5 per cent. While, the values obtained through cross validation in FT-NIR spectroscopy ranged from 6.7 per cent to 9.7 per cent.

After the calibration and validation of these values, model was developed. A robust calibrated model was selected on the basis of high R^2 value and low RMSECV values. The results using various preprocessing method including R^2 value and RMSECV values are given in Table 4.7.

From the table it was observed that among the three preprocessing methods vector normalisation showed maximum R^2 value of 0.811 and minimum RMSECV value of 0.328. The linear regression plot between the true values obtained from conventional analysis and predicted values by FT-NIR spectroscopy using the calibrated model is given in Fig.4.10.

The straight line equation is represented as

$$y = 0.840x + 1.274 \qquad \textbf{.....(4.2)}$$

The RPD value for the present model is 3.5, which is considered to be desirable for prediction purposes. Sinija and Mishra (2009) developed a method for determination of moisture content in green tea granules using FT-NIR spectroscopy. The PLS regression method gave R^2 values of 0.9975 and RMSECV value of 0.83. The straight line equation was represented as

$$y = 0.9796x + 0.2739 \qquad \textbf{.....(4.3)}$$

Table 4.7. PLS model for determination of moisture content using FT-NIR spectroscopy

Preprocessing methods	**R^2**	**RMSECV%**
No spectral preprocessing	0.798	0.339
Vector normalisation	**0.811**	**0.328**
First derivative	0.783	0.352
First derivative + vector normalisation	0.783	0.352

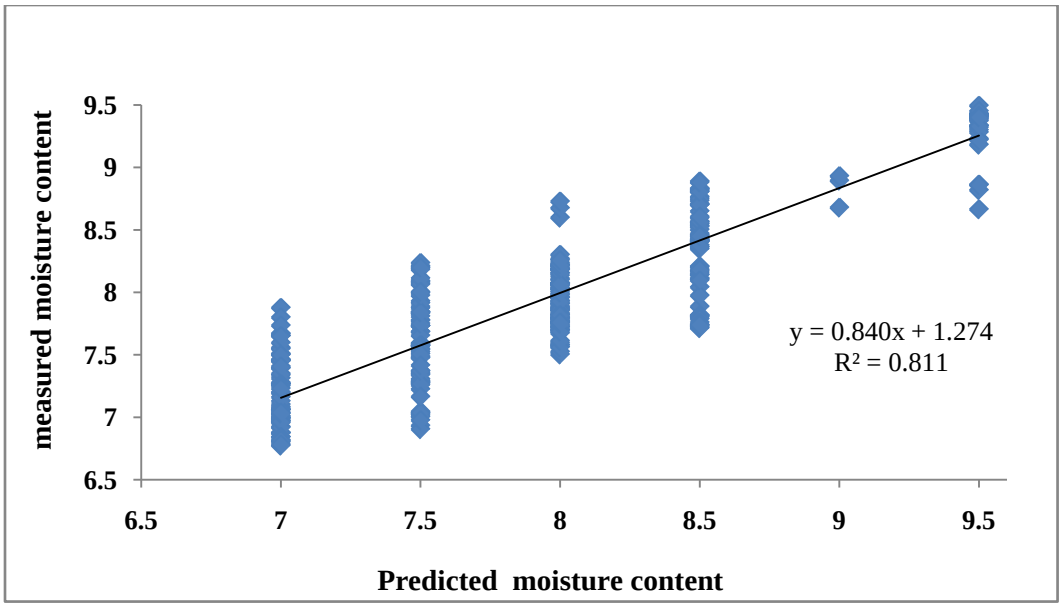

Fig.4.10.Linear plot between measured and predicted values of moisture content

4.3.4.3. Estimation of starch content in turmeric rhizomes using FT-NIR Spectroscopy

Starch content for all 120 samples were analysed conventionally by acid hydrolysis method. The values are incorporated and the spectra recorded are preprocessed with vector normalization, first derivative and vector normalization+first derivative methods. The observed values and NIR predicted values are shown in Annexure A21 and A24 respectively. The values obtained from conventional analysis ranged from 56.68 per cent to 57.81 per cent, while, the values obtained through cross validation in FT-NIR spectroscopy ranged from 56.57 percent to 57.94 percent.

After the calibration and validation of these values, model was developed. A robust calibrated model was selected on the basis of high R^2 value and low RMSECV values. The results using various preprocessing method including R^2 value and RMSECV values are given in Table 4.8.

From the table it is evident that among the three preprocessing methods vector normalisation showed maximum R^2 value of 0.968 and minimum RMSECV value of 0.077. The linear regression plot between the true values obtained from conventional analysis and predicted values by FT-NIR spectroscopy using the calibrated model is given in Fig.4.10.

The straight line equation is represented as

$$y = 0.971x + 1.614 \quad \textbf{.....(4.4)}$$

The RPD value for the present model is 5.59, which is considered to be desirable for prediction purposes. An RPD value greater than 5 (range 5 – 6.4) is considered good for quality control (Cozzolino *et al*., 2008).

Table 4.8. PLS model for determination of starch using FT-NIR spectroscopy

Preprocessing methods	**R^2**	**RMSECV%**
No spectral preprocessing	0.967	0.077
Vector normalisation	**0.968**	**0.0765**
First derivative	0.962	0.0837
First derivative + vector normalisation	0.962	0.083

Lohumi *et al*. (2014) studied the corn starch adulteration in onion powder using FT-NIR spectroscopy. The PLSR model predicted adulteration with an R^2 value of 0.98 and a standard error of prediction of 1.18 per cent.

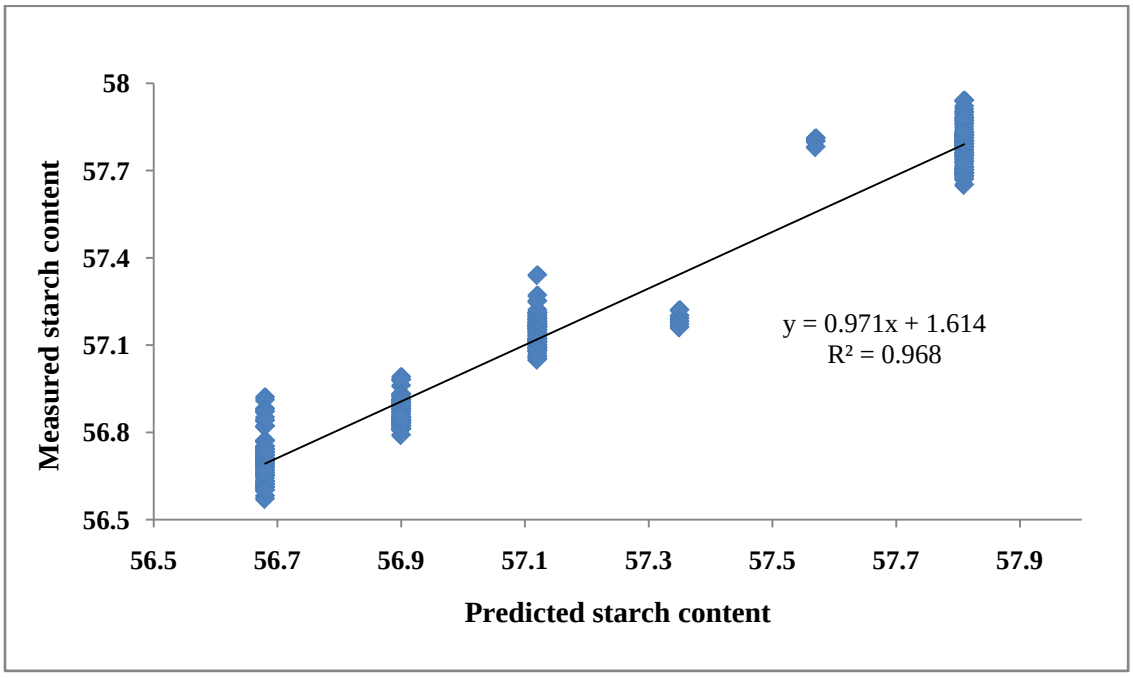

Fig.4.11.Linear plot between measured and predicted values of starch content

4.5. Grading of Turmeric Rhizomes

Using the developed model, turmeric rhizomes can be graded based on their quality parameters. FT-NIR spectroscopy can analyse the unknown samples in 22 seconds and estimates the values of curcumin, starch and moisture content of the samples. Based on these values, samples can be graded into standard and special grades. This rapid analysis of quality parameters helps to check the specifications and requirements of large volumes of turmeric samples intended for export. This developed method by FT-NIR spectroscopy will be more useful for the export agencies and industries.

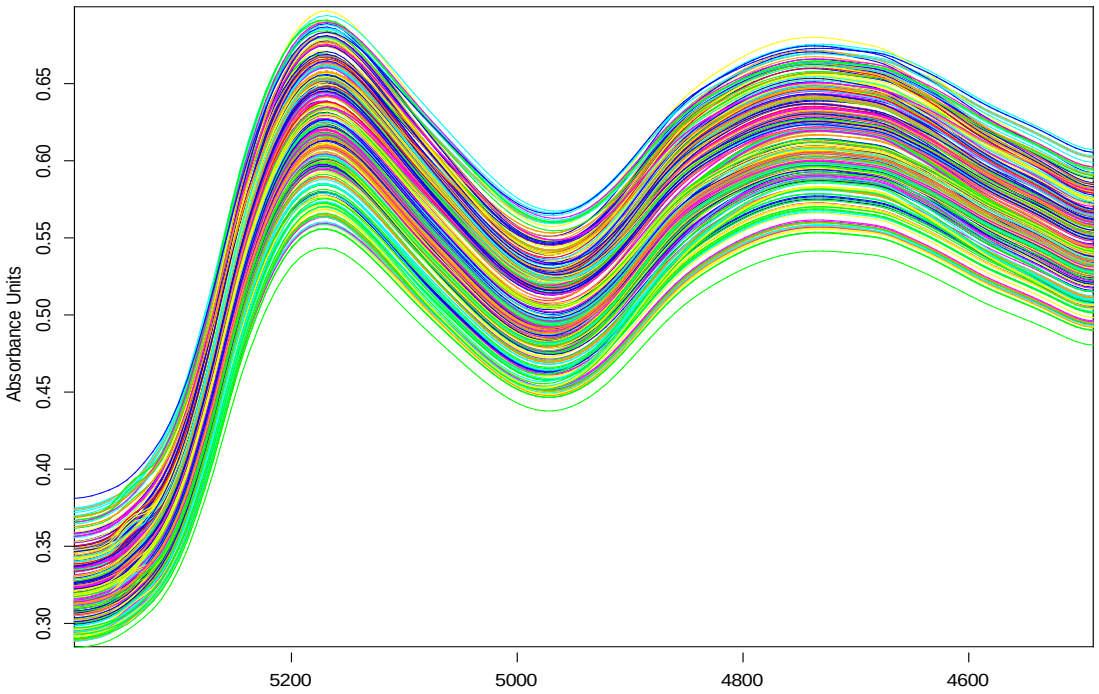

Fig.4.5. Spectra of Turmeric samples with no spectral Preprocessing method

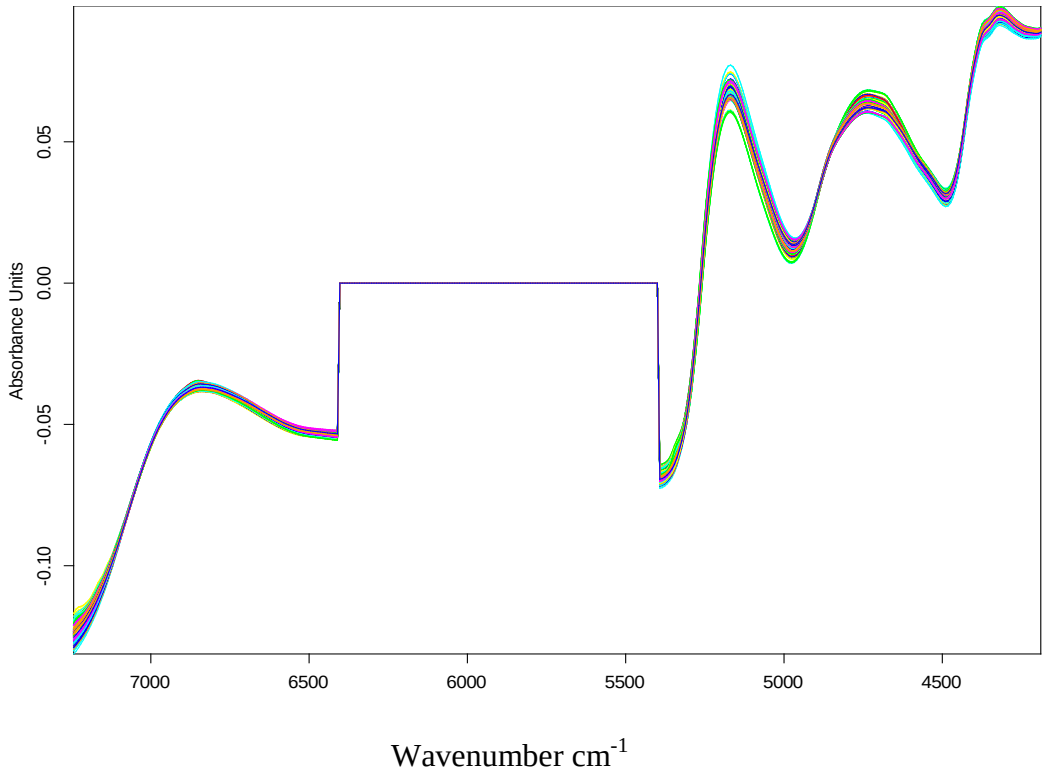

Fig.4.6. Spectra of Turmeric samples Preprocessed by vector normalisation method

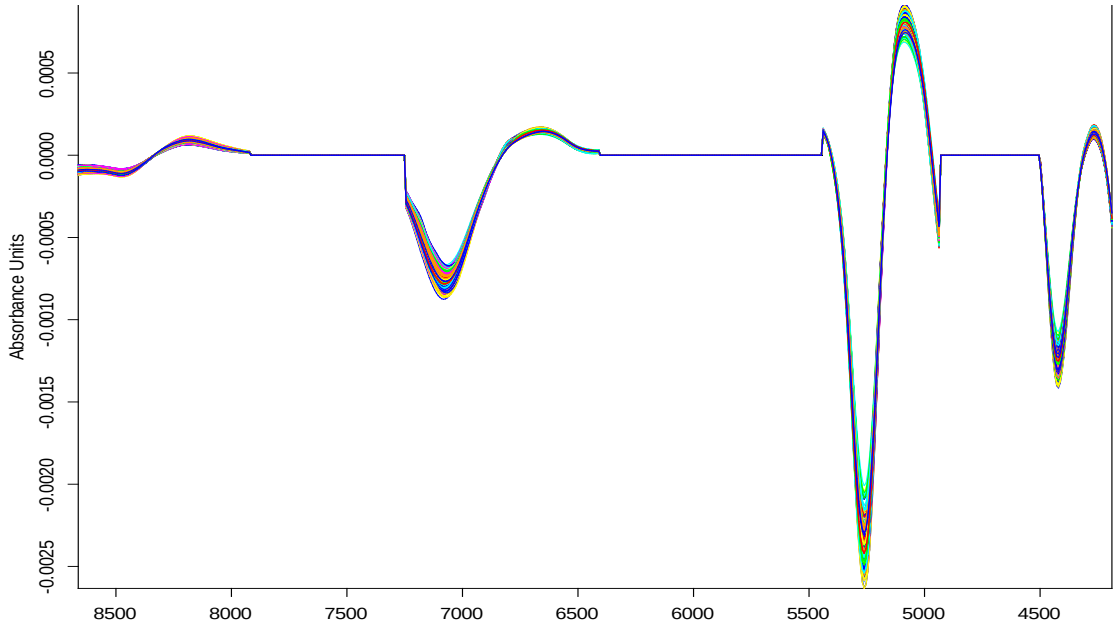

Fig.4.7. Spectra of Turmeric samples Preprocessed by First derivative method.

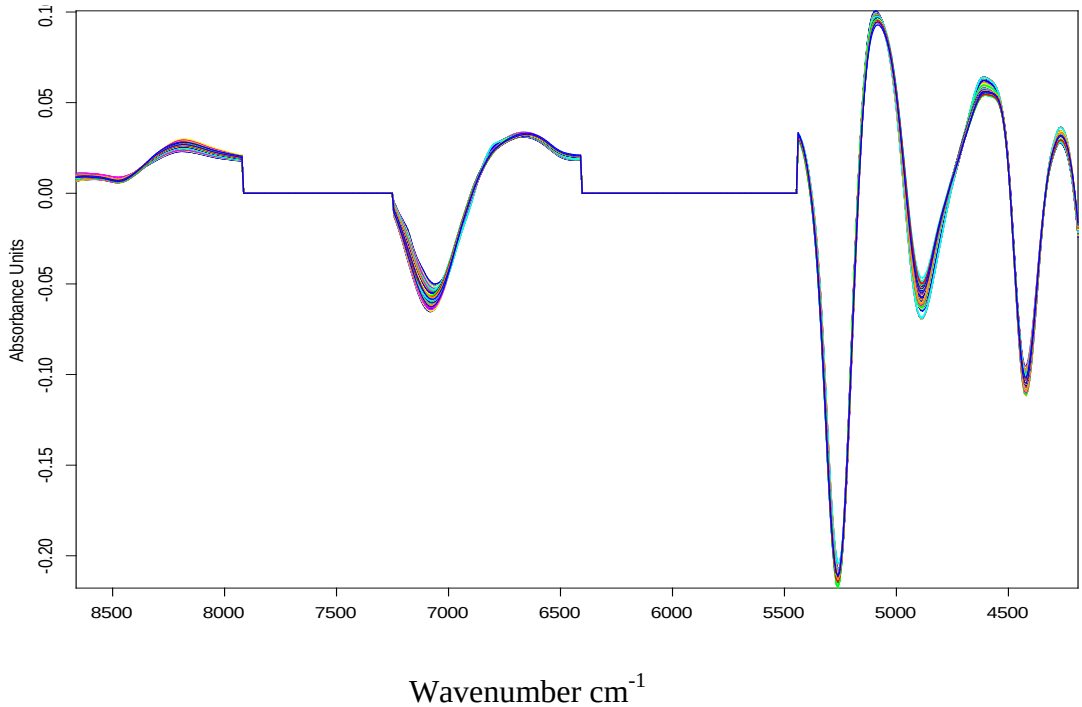

Fig.4.8. Spectra of Turmeric samples Preprocessed by Vector normalization and First derivative method.

Summary and Conclusion

CHAPTER V

SUMMARY AND CONCLUSION

Turmeric has been unique for its medicinal uses and socio-religious practices since ancient times. India is the largest producer and exporter of turmeric and it ranks fourth in production among the spices. In India, Andhra Pradesh holds a major share in turmeric production and in Tamilnadu, Erode takes the first place in production. Popular cultivars of Tamil Nadu are Erode local and Salem local.Turmeric is a rich source of phenolic compounds where, curcuminoids, is widely used as a dietary spice and colouring agent in food and herbal medicine. It is valuable for its pharmacological activities, such as anti-inflammatory, anti-microbial, anti-oxidant, anti-parasitic, anti-mutagenic and anti-cancer affects.It has been valued worldwide as a functional food, due to its health promoting properties.

Rhizomes of *C. longa* consists of protein, fat, minerals, carbohydrates, moisture content, essential oil, curcumin and oleoresins. Major quality parameters in turmeric are curcumin, oleoresin and essential oil contents.The post-harvest operations have much significance for achieving high export quality. After harvesting, processing of turmeric involves three steps *viz.* curing, drying and polishing.These polished rhizomes are separated as fingers, bulbs and brokens. Commercially polished rhizomes are graded manually or using machines based on their dimensions, whereas the Spices Grading and Marking Rules are based on the quality parameters.Most instrumental techniques measuring these properties are destructive, slow and involves a considerable amount of manual work. Therefore, there is a demand for new and rapid analytical techniques for quality assessment.

Keeping the above points in view, the present study was carried out to develop a rapid, non-destructive grading method based on the quality parameters of turmeric.The important physical properties namely size, bulk density, true density, porosity and frictional properties such as angle of repose and coefficient of friction on selected surfaces were studied for four turmeric samples namely Erode fingers, Erode bulbs, Salem fingers and Salem bulbs.

Three important quality parameters *viz.* curcumin, starch and moisture content were analysed in turmeric rhizomes. Each 30 of all four turmeric samples (totally 120 samples) were analysed for curcumin, starch and moisture content by using conventional analytical methods (wet chemistry). The curcumin content of 120 samples was in the range of 2.82 to 4.91 per cent, moisture content ranged from 7 to 9.5 per cent and starch content varied from 56.68 to 57.81 per cent.

A non destructive method of quality evaluation was developed using FT-NIR Spectroscopy. Powdered samples were prepared and their spectra were recorded before chemical analysis. The results obtained from the conventional analysis for curcumin, starch and moisture content were used for calibrating the instrument and model development. The spectral pre processing methods such as vector normalization, first derivative and first derivative + vector normalization were used to eliminate interferences and facilitate information extraction from spectral data. The performance of the final model was evaluated in terms of root mean square error of cross validation (RMSECV) and coefficient of determination (R^2).

The evaluation of curcumin content by FT-NIR spectroscopy was in the range of 2.78 to 4.81 per cent, moisture content ranged from 6.77 to 9.73 per cent and starch varied from 56.57 to 57.94 per cent. The results of the study are summarized and presented below.

- Among the four samples, maximum length of 64.33 mm was recorded in Salem finger samples and minimum (33.6 mm) in Erode bulb samples. Maximum breadth and thickness of 27.19 and 24.68 mm respectively was recorded by Salem bulb samples and minimum (10.45 and 9.32 mm) by Erode finger samples.
- Bulk density of 647.79 kg m^{-3} and true density of 1266.4 kg m^{-3} was higher for Salem bulb samples and lower (384.66 kg $m^{-3}$and 1225.5 kg m^{-3}) for Erode finger samples.
- Highest porosity of 68.6 per cent was observed in Erode finger samples and lowest (48.84 per cent) in Salem bulb samples.
- Unit volume of 0.33 mm^3 and surface area of 9.36 mm^2 were higher for Erode bulb samples and lower (0.12 mm^3 and 2.36 mm^2) for Erode finger samples.

- Maximum angle of repose of 49.35º was recorded by Salem finger samples and minimum of 40.56º by Salem bulb samples.
- Among the different surfaces studied, mild steel recorded maximum coefficient of friction and stainless steel recorded minimum coefficient of friction in bulbs and fingers of both the turmeric varieties.
- Using conventional analysis, Salem fingers had the maximum curcumin content of 4.91 per cent and minimum of 2.82 per cent was recorded by Erode bulb samples.
- Highest moisture content of 9.5 per cent was recorded by Erode bulb samples and lowest of 7.05 per cent was recorded by Erode finger samples by conventional analysis.
- Erode finger had the maximum starch content of 57.81 per cent and minimum of 56.68 per cent was recorded by Salem bulb samples by conventional analysis.
- The curcumin content by FT- NIR Spectroscopy was in the range of 2.78 to 4.81 per cent. First derivative + vector normalisation showed maximum R^2 value of 0.919 and minimum RMSECV value of 0.178.
- The moisture content by FT- NIR Spectroscopy was in the range of 6.77 to 9.73 per cent. Vector normalisation showed maximum R^2 value of 0.811 and minimum RMSECV value of 0.328.
- The starch content by FT- NIR Spectroscopy was in the range of 56.57 to 57.94 per cent. Vector normalisation showed maximum R^2 value of 0.968 and minimum RMSECV value of 0.076.
- Linear regression equations were developed using the robust calibrated models which could be used as a non destructive method of quality evaluation using FT-NIR Spectroscopy. Higher R^2 value of more than 0.80 for all quality parameters showed that, FT-NIR Spectroscopy could be used as a reliable non destructive method to determine the quality parameters of turmeric rhizomes.

Future works

The results could be improved and made robust by adding more number of samples with data set in a narrow range.

References

REFERENCES

Aenugu, H.P.R., D.S. Kumar and Srisudharson. 2011. Near Infra Red Spectroscopy – An Overview. ***International Journal Of Chemtech Research***. 3(2): 825-836.

Agricultural statistics at a glance. 2012. Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India. pp. 173-176.

Alander, J.T., V. Bochko, B. Martinkauppi, S. Saranwong, and T. Mantere. 2013. A review of optical nondestructive visual and near-infrared methods for food quality and safety. ***International Journal of Spectroscopy***. 1-36.

Anandaraj, M., S. Devasahayam, T.J. Zachariah, S.J. Eapen, B. Sasikumar and C.K. Thankamani. 2001. Turmeric (Extension Pamphlet). Indian Institute of Spices Research, Calicut, Kerala, India.

Arora, M., V.K. Sehgal and S.R. Sharma. 2007. Quality evaluation of mechanically washed and polished turmeric rhizomes. ***Journal of Agricultural Engineering***. 44(2): 39-43.

Athmaselvi, K.A and N. Varadharaju. 2002. Physical and thermal properties of turmeric rhizomes. ***Madras Agricultural Journal***. 89: 666-671.

Balakrishnan, K.V. 2007. Postharvest Technology and processing of turmeric. *In*: Ravindran, P. N., K. Nirmal babu and K. Sivaraman. Turmeric the genus curcuma. Taylor and Francis group publishing. London. New York. pp.193-296.

Balashanmugan, P.V. 1991. Processing and curing of turmeric. ***South Indian Horticulture.*** 39(4): 214-216.

Balasubramanian, S., A.M. Mohite, K.K. Singh, T.J Zachariah and T. Anand. 2012. Physical properties of turmeric (*curcuma longa L.*). ***Journal of Spices and Aromatic Crops.*** 21(2): 178-181.

Bazar, G., Z. Princz, G. Jekkel, L. Locsmandi, G. Andrassy-baka, G. Kover, Z. Szendro and R.Romvari. 2007. NIRS prediction for protein and intramuscular fat content of rabbit hind leg meat. 1:1-5.

Benzie, I.F and S. Wachtel-Galor. 2011. Turmeric, the golden spice. *In*: Herbal medicine: biomolecular and clinical aspects. Prasad, S and B. B. Aggarwal. (Eds.) CRC Press. Taylor & Francis group. USA

Bertouche, S., V. Tomao, K. Ruiz, A. Hellal and C. Boutekedjiret. 2012. First approach on moisture determination in food products using alpha-pinene as an alternative solvent for Dean–Stark distillation. ***Food Chemistry***. 134: 602-605.

Blanco, M and I. Villarroya. 2002. NIR spectroscopy: A rapid-response analytical tool. Trends in analytical Chemistry. 21(4): 240-250.

Bureau of Indian Standards. 1984. IS-10925- Specification for turmeric oleoresin.

Bureau of Indian Standards. 2010. Indian standard spices and condiments- turmeric, whole and ground – specification.

Bureau, S., D. Ruiz, M. Reich, B. Gouble, D. Bertrand, J.M. Audergon and M.G.C.R. Catherine. 2009. Rapid and non-destructive analysis of apricot fruit quality using FT-near-infrared spectroscopy. ***Food Chemistry***. 113: 1323-1328.

Burns, D.A., and E.W. Ciurczak. 2001. Handbook of Near- Infrared Analysis, CRC press. Taylor & Francis group. USA.

Chandrasekar, V. 2007. Design and development of a rotary drier for coleus tuber. Unpublished M.Tech. Thesis, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, India.

Chakraverty, A. 1995. Post Harvest Technology of Cereals, Pulses and Oilseeds. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi.

Chattopadhyay, I., K. Biswas, U. Bandyopadhyay and R.K. Banerjee. 2004. Turmeric and curcumin: Biological actions and medicinal applications. ***Current Science***. 87: 44-53.

Chaudhary, A.S., S.K. Sachan and R.L. Singh. 2006. Studies on varietal performance of turmeric *(Curcuma longa L.)*. ***Indian Journal of Crop Science***. 1: 189-190.

Chen, Q., J. Zhao, M. Liu and J. Cai. 2008. Nondestructive Identification of Tea (*Camellia sinensis L.*) varieties using FT-NIR spectroscopy and pattern recognition. ***Czech Journal of Food Sciences.*** 26(5): 360-367.

Chen, Q., J. Zhao, S. Chaitep and Z. Guo. 2009. Simultaneous analysis of main catechins contents in green tea (*Camellia sinensis L.*) by Fourier transform near infrared reflectance (FT-NIR) spectroscopy. ***Food Chemistry***. 113(4): 1272-1277.

Cheng A.L., C.H. Hsu and J.K. Lin. 2001. Phase I clinical trial of curcumin, a chemopreventive agent, in patients with high-risk or pre-malignant lesions. ***Anticancer Research***. 21: 2895-2900.

Coskuner, Y and E. Karababa. 2006. Physical properties of coriander seeds. ***Journal of food engineering***. 80: 408-416

Cozzolino, D., M.J. Kwiatkowski, R.G. Dambergs, W.U. Cynkar, L.J. Janik, G. Skouroumounis and M. Gishen. 2008. Analysis of elements in wine using near infrared spectroscopy and partial least squares regression. ***Talenta***. 74(4): 711-716.

Cozzolino, D., W.U. Cynkar, N.Shah and P. Smith. 2011. Multivariate data analysis applied to spectroscopy: Potential application to juice and fruit quality. *Food Research International*. 44: 1888-1896.

Dale, L.M., I. Rotar, R. Vidican, A. Bogdan and G. Budurea. 2010. Research on crude fat and crude fiber content on maize cob and strains by FT-NIR Spectrum. ***UASVM Agriculture***. 67(1): 2010.

Dean, E.W. and D.D. Stark. 1920. A convenient method for the determination of water in petroleum and other organic emulsions. ***The journal of industrial and engineering chemistry***. 12(5): 486-490.

Directorate of Marketing and Inspection. 2012. Turmeric Grading and Marking Rules, 1964. Ministry of Agriculture, Government of India.

European Spice Association. 2011. European Spice Association quality minima document for herbs and spices.

FSSAI. 2009. Food Safety and Standards Act, 2006. Ministry of Health and Family Welfare, Government of India.

Forgacs, E and T. Cserhati. 2002. Thin-layer chromatography of natural pigments: new advances. ***Journal of Liquid Chromatography and Related Technologies***. 25: 1521 – 1541.

Gantait, A., T. Barman and P.K. Mukherjee. 2011. Validated method for estimation of curcumin in turmeric powder. ***Indian Journal of Traditional Knowledge***. 10(2): 247-250.

Geladi, P and B.R. Kowalski. 1986. Partial least-squares regression: A tutorial. ***Analytica Chimica Acta***. 185: 1–17.

Georgieva. M., I. Nebojan, K. Mihalev, N. Yoncheva, J.G. Kljusuric and Z. Kurtanjek. 2013. Application of NIR spectroscopy and chemometrics in quality control of wild berry fruit extracts during storage. ***Croatian Journal of Food Technology***. 8: 67-73.

Govindrajan, V.A. 1980. Turmeric chemistry, Technology and quality. ***CRC Critical Review in Food Science and Nutrition.*** 12(3): 199-301.

Himesh, S., P.S. Sharan, K. Mishra, N. Govind and A.K. Singhai. 2011. Qualitative and quantitative profile of curcumin from ethanolic etxtract of *Curcuma longa*. ***International Research Journal of Pharmacy***. 2(4): 180-184.

Hirano, S., N. Okawara and S. Narazaki. 1998. Near infrared detection of internally mouldy nut. ***Bioscience Biotechnology and Biochemistry***. 62(1): 102–107.

Huang, H., H. Yu, H. Xu and Y. Ying. 2008. Near infrared spectroscopy for on/in-line monitoring of quality in foods and beverages: A review. ***Journal of Food Engineering***. 87(3): 303-313.

Indian Standard Specification No IS: 1797-1985, Methods of test for spices and condiments.

Indian Standard Specification No IS: 3576 – 1994, Specifications for turmeric whole and ground.

Jain, R.K and S. Bal. 1997. Properties of pearl millet. ***Journal of Agricultural Engineering Research***. 66: 85–91.

Jayaprakasha, G.K., L.J.M Rao and K.K. Sakariah. 2002. Improved HPLC method for the determination of Curcumin, Demethoxycurcumin, and bisdemethoxycurcumin. ***Journal of Agricultural and Food Chemistry***. 50: 3668–3672.

Jayashree, E. 2009. Studies on mechanization of field level post harvest operations in ginger (*Zingiber officinale*) with reference to washing, peeling and drying. Ph.D. Thesis, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, India.

Jiang, A., A. Somogyi, N.E. Jacobsen, B.N.Timmermann and D.R. Gang. 2009. Analysis of curcuminoids by positive and negative electrospray ionization and tandem mass spectrometry. ***Rapid Communication in Mass Spectrometry.*** 20: 1001–1012

Jilani, M.S., K. Waseem, Rehman, M. Kiran, Ghazanfarullah and J. Ahmed. 2012. Performance of different turmeric cultivars in dera ismail khan. ***Pakistan Journal of Agricultural Sciences.*** 49(1): 47-51.

Jose, K.P. and C.M. Joy. 2009. Solar tunnel drying of turmeric (*Curcuma longa* Linn. Syn. C. Domestica val.) for quality improvement. ***Journal of Food Processing and Preservation***. 33: 121–135.

Kaleemullah, S and R. Kailappan. 2003. Geometric and morphometric properties of chillies. ***International Journal of Food Properties***. 6(3): 481-498.

Kamble, K. J., V.M. Ingale and D.P. Kaledhonkar. 2011. Comparative study of curcumin extraction from turmeric varieties grown in Maharashtra. ***African Journal of Food Science***. 5(14): 780-789.

Kamble, K.J and S.B. Soni. 2009. A study of improving turmeric processing. *Karnataka Journal of Agricultural Science.* 22(1): 137-139.

Kawano, S. 2002. Sampling and sample presentation. *In*: Near Infrared Spectroscopy: Principles, Instruments, Applications. Siesler, H.W., Y. Ozaki, S. Kawata, H.M. Heise (Eds.) Wiley-VCH Verlag GmbH, Weinheim. pp. 115–124.

Kawata, S. 2002. New techniques in near-infrared spectroscopy. *In*: Near Infrared Spectroscopy: Principles, Instruments, Applications. Siesler, H.W., Y. Ozaki, S. Kawata, H.M. Heise (Eds.) Wiley-VCH Verlag GmbH, Weinheim. pp. 75–84.

Kibar, H and T. Özturk. 2008. Physical and mechanical properties of soybean. ***International agrophysics***. 22: 239-244.

Krishnamoorthy, N., A.G. Mathew, E.S. Nambudiri, S. Shivasankar, Y.S. Lewis and C.P. Natarajan. 1976. Oil and oleoresin of turmeric. ***Tropical Science*** 18(1): 37–45.

Kuttigounder, D., J.R. Lingamallu and S. Bhattacharya. 2011. Turmeric Powder and Starch: Selected Physical, Physicochemical, and Microstructural Properties. ***Journal of food science.*** 76: 1284-1291.

Lampe, V., J. Milobdeska and V. Kostanecki. 1910. Synthese von p, p-dioxy- and p-oxy dicinnamoylmethane. Berichte der Deustschen Chemischen Gesellschaft. 43: 2163.

Leonel, M., S.B.S. Sarmento and M.P. Cereda. 2003. New starches for the food industry: Curcuma longa and Curcuma zedoaria. ***Carbohydrate polymers***. 54: 385-388.

Lohumi, S., S. Lee, W. Lee, M.S. Kim, C. Mo, H. Bae and B. Cho. 2014. Detection of starch adulteration in onion powder by FT-NIR and FT-IR spectroscopy. ***Journal of Agricultural and Food Chemistry***. 1-28.

Lokhande, S.M., R.V. Kale, A.K Sahoo and R.C. Ranveer. 2013. Effect of curing and drying methods on recovery, curcumin and essential oil content of different cultivars of turmeric *(Curcuma longa L).* ***International Food Research Journal***. 20(2): 745-749.

Luinge, H.J., E. Hop, E.T.G. Lutz, J.A. van Hemert and E.A.M. De Jong. 1993. Determination of the fat, protein and lactose content of milk using Fourier transform infrared spectrometry. ***Analytica Chimica Acta..*** 284: 419–433.

Madan, M.S. 2007. Turmeric- production, marketing and economics. *In*: Ravindran, P. N., K. Nirmal babu and K. Sivaraman. Turmeric the genus curcuma. Taylor & Francis group publishing. London. New York. pp. 369-408.

Martens, H and T. Naes. 1989. Multivariate Calibration, John Wiley & Sons, New york. pp. 205-234.

McCarthy, W.J and G.J. Kemeny. 2008. Fourier transform spectrophotometers in the near infrared. *In*: handbook of near infrared analysis, 3rd Ed. CRC Press. pp. 79-93.

Mehta, K.G., D.V. Raghava Rao and S.H. Patel. 1980. Relative curcumin content during various growth stages in the leaves and rhizomes of three cultivars of Curcuma longa and C. amada. *In*: Nair, M.K., T. Premkumar, P.N. Ravindran and Y.R. Sarma. (Eds.) Proc. National Seminar on Ginger and Turmeric, Central Plantation Crops Research Institute, Kasaragod. pp.76-78.

Mohsenin, N.N. 1986. Physical Properties of Plant and Animal Materials. 2nd Ed. (revised). Gordon and Breach Science Publishers, New York.

Murray, I. 1993. Forage analysis by near infrared spectroscopy. In: Davies, A., R.D. Baker, S.A. Grant and A.S. Laidlaw (Eds.) Sward Management Handbook. UK: British Grassland Society. pp. 285−312

Naes, T., T. Isaksson, T. Fearn and T. Davies. 2004. A user friendly guide to multivariate calibration and classification. NIR Publications, Charlton, Chichester, UK.

Nair, M.K., M.C. Nambiar and M.J. Ratnambal. 1980. Cytogenetics and crop improvement of ginger and turmeric. In: Nair M.K., T. Premkumar, P.N. Ravindran and Y.R. Sarma (Eds.) Proc. National Seminar on Ginger and Turmeric, Central Plantation Crops Research Institute, Kasaragod. pp.15-23.

Nicolai, B.M., K. Beullens, E. Bobelyn, A. Peirs, W. Saeys, K.I. Theron and J. Lammertyn. 2007. Nondestructive measurement of fruit and vegetable quality by means of NIR spectroscopy: A review. ***Post harvest biology and technology***. 46(2): 99-118.

Onen, M.L., T.H. Pulkkinen, C.S. Imard, M. Rasanen and H. Vuorela. 2003. Development and validation of a near-infrared method for the quantitation of caffeine in intact single tablets. ***Analytical chemistry***. 75(4): 754-760.

Onu, L.T. and G.I. Okafor. 2002. Effect of physical and chemical factor variations on the efficiency of mechanical slicing of Nigerian ginger (Zingiber Officinale Rosc.). ***Journal of Food Engineering***. 56: 43–47.

Osborne, B.G. 2000. Near infrared spectroscopy in food analysis. BRI Australia Ltd, North Ryde, Australia. Wiley publications, New York, pp. 1–14.

Otles, S. 2009. Handbook of Food Analysis Instruments. Food Analysis Equipment and Supplies. CRC Press. Taylor & Francis group. pp.247-280.

Pathak, N., V. Naithani, J. Singh, P. Bhole and M. Chaudhary. 2010. An Assessment of Variation in Active Ingredients of Ampucare from Different Zones of India. ***International Journal of Pharmaceutical Sciences and Drug Research***. 2(2): 123-126.

Patil, M.B., S.V. Taralkar, V.S. Sakpal, S.P. Shewale and R.S. Sakpa. 2011. Extraction, isolation and evaluation of anti inflammatory activity of curcuminoids from *curcuma longa*. ***International Journal of Chemical Sciences and Applications.*** 2(3): 172-174.

Petterson, H and L. Aberg. 2003. Near infrared spectroscopy for determination of mycotoxins in cereals. ***Food Control***. 14(4): 229-232.

Pirt, S.J and W.J. Whelan. 1951. The determination of starch by acid hydrolysis. ***Journal of the Science of Food and Agriculture*** . 224-228.

Pojic, M., J. Mastilovic and N. Majcen. 2012. The Application of Near Infrared Spectroscopy in Wheat Quality Control. ***Infrared Spectroscopy - Life and Biomedical Sciences***. 1: 167-184.

Prieto, N., R. Roehe, P. Lavín, G. Batten and S. Andrés. 2009. Application of near infrared reflectance spectroscopy to predict meat and meat products quality: A review. ***Meat Science.*** 83(2): 175-186.

Pruthi, J.S. 1980. Quality Control, Packaging and Storage of Turmeric. In: Turmeric - Status papers and Abstracts, National Seminar on Ginger and Turmeric, Central Plantation Crops Research Institute,Calicut, India. pp. 128-139.

Rao, M.R., K.R.C. Reddy and M. Subbarayudu. 1975. Promising turmeric types of Andhra Pradesh. Arecanut & spices bulletin. pp 56-92.

Ravindran, P. N., K. Nirmal babu and K. Sivaraman. 2007. Turmeric the genus curcuma. Taylor & Francis group publishing. London. New York.

Reich, G. 2005. Near-infrared spectroscopy and imaging: Basic principles and pharmaceutical applications. ***Advanced Drug Delivery Reviews***. 57(8): 1109-1143.

Rinnan, A., F. Berg and S.B. Engelsen. 2009. Review of the most common pre-processing techniques for near-infrared spectra. ***Trends in Analytical Chemistry***. 28(10): 1201-1222.

Rohman, A. 2012. Analysis of curcuminoids in food and pharmaceutical products. ***International Food Research Journal.*** 19(1): 19-27.

Sahay, K.M. and K.K. Singh. 1994. Unit Operations of Agricultural Processing. Vikas Publishing House Pvt. Ltd., New Delhi.

Sankaracharya, N.B and C.P. Natarajan. 1975. Technology of spices. ***Arecanut and Spices Bull***. 7(2): 27-43.

Sinjia, V and H. Mishra. 2009. FT-NIR spectroscopy for caffeine estimation in instant green tea powder and granules. ***LWT - Food Science and Technology***. 42(5): 998-1002.

Sinker, P., P. Haldankar, R.G. Khandekar, S.A.Ranpise, G.D.Joshi and B.B.Mahale. 2005. Preliminary evaluation of turmeric (curcuma longa L.) varieties at konkan region of Maharashtra. ***Journal of spices and aromatic crops***. 14(1): 28-33.

Sivaraman, K. 2007. Agronomy of turmeric. *In*: Ravindran, P. N., K. Nirmal babu and K. Sivaraman. Turmeric the genus curcuma. Taylor & Francis group publishing. London. New York. pp 129-154.

Spices Board. 1995. Quality Improvement of turmeric. ***Spices Board of India***. 12: 2-5.

Spices Board. 2008. Turmeric. Spice Board of India. Ministry of Commerce and Industry, Government of India. Cochin.

Srinivasan, K.R. 1952.The coloring matter in turmeric. ***Current Science***. 21: 311-313.

Subramanian, A and L. Rodriguez-soana. 2009. Fouier Transform Infrared Spectroscopy. In: Infrared Spectroscopy for Food Quality Analysis and Control. Sun, D., A. Subramanian and L. Rodriguez-soana. **A**cademic press. pp.145-178.

Tanaka, K., Y. Kuba, T. Sasaki, F. Hiwatashi and K. Komatsu. 2008. Quantitation of Curcuminoids in Curcuma Rhizome by Near-infrared Spectroscopic Analysis. **Journal of Agricultural and Food Chemistry**. 56: 8787-8792.

Tripathi, S., K.G. Patel and A.M. Bafna. 2010. Non destructive determination of curcuminoids from turmeric powder using FT-NIR. ***Journal of Food Science and Technology***. 47(6): 678-681.

Veillet, S., V. Tomao, F. Visinoni and F.Chemat. 2010. Green procedure using limonene in the Dean-Stark apparatus for moisture determination in food products. ***Analytica Chimica Acta***. 674: 49-52.

Veillet, S., V. Tomao, F. Visinoni and F.Chemat. 2009. New and rapid analytical procedure for water content determination:Microwave accelerated Dean-Stark. ***Analytica Chimica Acta***. 632: 203-207.

Vogel, H.A and J. Pelletier. 1815. Curcumin-biological and medicinal properties. ***Journal of pharmaceutical sciences***. 2:50.

Wang, D., F.E. Dowell, M.S. Ram and W.T. Schapaugh. 2004. Classification of Fungal-Damaged Soybean Seeds Using Near-Infrared Spectroscopy. ***International Journal of Food Properties.*** 7(1): 75-82.

Weiss, E.A. 2002. Spice Crops. CAB International Publishing, Oxon, UK.

Xue, J., C. Wu, L. Wang, S. Jiang, G. Huang, J. Zhang, S. Wen and L. Ye. 2011. Dynamic prediction models for alkaloid content using NIR technology for the study and online analysis of parching in areca seed. ***Food Chemistry.*** 126(2): 725-730.

Yao, S., G. Wu, M. Xiang, S. Zhou and J. Pu. 2010. Determination of lignin content in Acacia spp. Using near-infrared reflectance spectroscopy. ***BioResources***. 5(2): 556-562.

Annexure

ANNEXURE

Table A1. Length (mm) of 30 rhizomes for both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	55.9	45.17	62.96	48.55
2	51.48	30.24	57.18	38.16
3	41.85	31.12	68.79	41.77
4	56.36	46.47	56.46	42.75
5	53.14	37.02	63.97	51.32
6	53.77	49.78	67.93	48.24
7	64.51	37.91	58.73	51.75
8	51.97	40.34	73.82	43.57
9	57.5	29.82	66.44	43.45
10	52.2	41.01	66.36	51.26
11	48.94	39.57	63.81	41.73
12	51.24	34.93	64.4	45.65
13	54.05	40.04	79.14	44.27
14	58.11	35.62	66.26	50.13
15	48.62	32.54	68.8	49.84
16	59.9	33.17	61.44	35.88
17	68.6	34.85	69.04	47.04
18	45.75	27.48	57.15	46.58
19	57.52	31.43	55.16	43.71
20	55.97	34.55	67.54	50.28
21	69.3	29.29	62.72	49.9
22	49.87	29.04	51.1	45.84
23	62.61	31.88	64.16	41.58
24	65.32	26.21	59.35	49.02
25	59.45	23.4	61.36	42.8
26	47.83	27.48	72.96	45.29
27	39.28	34.92	52.5	57.1
28	49.07	30.82	62.27	45.47
29	46.12	22.67	73.12	39.69
30	34.28	19.35	75.18	41.89
MEAN±S.D	**53.68±15.28**	**33.6±18.26**	**64.33 ± 8.64**	**45.82 ± 4.71**

Table A2.Breadth (mm) of 30 rhizomes for both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	10.2	23.67	15.53	28.59
2	11.29	21.32	12.39	27.28
3	10.84	19.33	17.11	25.85
4	11.59	25.72	15.46	27.46
5	11.66	21.37	12.98	27.53
6	9.87	28.51	14.63	26.9
7	10.65	25.58	12.99	24.7
8	10.69	24.61	15.3	25.31
9	10.12	23	18.34	28.86
10	9.95	22.38	14.8	24.86
11	9.84	21.73	15.2	26.44
12	8.56	26.35	16.9	26.67
13	10.01	25.87	18.38	27.36
14	9.85	23.3	18.29	27.57
15	8.66	22.29	14.8	27.67
16	10.71	22.16	15.52	22.08
17	10.74	22.86	15.31	23.89
18	12.32	23.8	15.57	30.53
19	10.52	26.87	15.08	27.73
20	11.67	21.19	17.1	30.08
21	8.32	22.65	17.91	29.92
22	8.36	21.78	15.68	27.51
23	12.3	18.68	16.13	24.97
24	8.83	18.53	14.09	29.16
25	11.54	20.82	19.34	27.45
26	11	24.42	15.24	28.57
27	11.54	35.79	16.47	28.17
28	9.76	23.35	13.84	28.02
29	12.16	21.78	16.85	26.83
30	10.1	17.27	17.86	27.82
MEAN±S.D	**10.45 ±0.07**	**23.23 ± 4.53**	**15.84 ±1.65**	**27.19 ± 0.54**

Table A3.Thickness (mm) of 30 rhizomes for both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	9.74	22.53	14.28	26.35
2	11.3	20.52	12.26	26.94
3	7.78	17.54	13.11	23.25
4	10.72	23.73	13.03	24.07
5	8.45	20.51	12.26	25.07
6	8.48	26.57	16.71	22.87
7	9.77	24.7	12.89	23.48
8	8.84	22.23	14.43	23.38
9	10	22.19	16.66	26
10	8.83	21.89	14.37	22.85
11	6.19	20.52	12.33	24.87
12	7.86	22.54	15.3	23.95
13	9.82	24.7	14.93	24.09
14	9.08	21.45	15.89	25.19
15	8.51	20.98	12.95	26.47
16	10.29	21.97	13.33	20.33
17	7.75	22.09	14.15	23.99
18	11.17	21.66	14.93	28.25
19	8.28	25.33	14.36	26.52
20	10.15	20.36	14.56	25.16
21	8.46	20.67	13.97	24.13
22	8.03	20.9	14.78	22.28
23	11.49	18.41	14.41	22.21
24	8.7	16.99	13.29	26.15
25	10.57	19.22	17.57	23.87
26	9.84	22.63	12.73	25.94
27	10.16	23.32	14.12	26.11
28	8.13	21.62	11.62	26.73
29	11.43	18.3	15.78	24.96
30	9.67	16.33	16.11	24.99
MEAN±S.D	**9.32 ± 0.04**	**21.41 ± 4.38**	**14.24 ± 1.29**	**24.68 ± 0.96**

Table A4. Geometric mean diameter (mm) of 30 rhizomes for both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	4.21	5.37	4.91	5.76
2	4.33	4.86	4.53	5.51
3	3.90	4.68	4.98	5.41
4	4.37	5.52	4.74	5.52
5	4.16	5.03	4.65	5.73
6	4.06	5.79	5.05	5.56
7	4.34	5.36	4.63	5.57
8	4.12	5.29	5.04	5.44
9	4.24	4.98	5.23	5.65
10	4.08	5.21	4.92	5.55
11	3.79	5.10	4.78	5.49
12	3.89	5.24	5.05	5.55
13	4.18	5.43	5.28	5.55
14	4.16	5.11	5.17	5.71
15	3.91	4.97	4.86	5.76
16	4.33	5.03	4.83	5.03
17	4.23	5.10	4.96	5.48
18	4.29	4.92	4.87	5.86
19	4.14	5.27	4.78	5.64
20	4.33	4.96	5.06	5.79
21	4.12	4.89	5.01	5.75
22	3.87	4.86	4.77	5.52
23	4.55	4.71	4.96	5.34
24	4.14	4.49	4.73	5.78
25	4.39	4.59	5.25	5.52
26	4.16	4.97	4.92	5.68
27	4.08	5.55	4.79	5.89
28	3.96	4.99	4.65	5.69
29	4.31	4.56	5.19	5.46
30	3.87	4.19	5.28	5.55
MEAN±S.D	**4.15±0.18**	**5.04±0.34**	**4.93± 0.2**	**5.59±0.18**

Table A5. Arithmetic mean diameter (mm) of 30 rhizomes for both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	25.28	30.46	30.92	34.49
2	24.69	24.027	27.28	30.79
3	20.16	22.66	33.01	30.29
4	26.23	31.97	28.32	31.43
5	24.42	26.3	29.74	34.64
6	24.04	34.95	33.09	32.67
7	28.31	29.39	28.20	33.31
8	23.83	29.06	34.52	30.75
9	25.87	25.01	33.81	32.77
10	23.66	28.43	31.84	32.99
11	21.66	27.27	30.45	31.01
12	22.55	27.94	32.2	32.09
13	24.63	30.20	37.48	31.91
14	25.68	26.79	33.48	34.29
15	21.93	25.27	32.18	34.66
16	26.97	25.77	30.09	26.09
17	29.03	26.6	32.83	31.64
18	23.08	24.31	29.22	35.12
19	25.44	27.88	28.2	32.65
20	25.93	25.37	33.1	35.17
21	28.69	24.20	31.53	34.65
22	22.087	23.91	27.19	31.88
23	28.8	22.99	31.57	29.59
24	27.62	20.58	28.91	34.78
25	27.187	21.15	32.76	31.37
26	22.89	24.84	33.64	33.27
27	20.33	31.34	27.69	37.13
28	22.32	25.26	29.24	33.41
29	23.24	20.92	35.25	30.49
30	18.02	17.65	36.38	31.57
MEAN±S.D	**24.49±2.75**	**26.08±3.74**	**31.47±2.72**	**32.56±2.16**

Table A6. Square mean diameter (mm) of 30 rhizomes for both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	34.84	51.19	45.81	58.49
2	35.92	41.26	39.51	52.95
3	29.39	38.55	47.99	51.49
4	37.17	53.93	42.54	53.52
5	34.16	44.59	42.12	58.22
6	32.72	59.15	48.72	54.92
7	37.70	50.38	41.08	55.44
8	33.31	49.36	49.15	52.08
9	35.47	43.10	51.29	55.98
10	32.69	48.01	46.35	54.89
11	29.08	46.02	44.09	52.90
12	30.14	47.98	48.29	54.31
13	34.21	51.61	53.95	54.19
14	34.49	45.76	50.55	57.79
15	30.14	43.31	45.84	58.57
16	36.99	44.17	44.49	44.39
17	36.76	45.51	47.44	53.15
18	34.82	42.01	44.45	60.01
19	34.19	48.18	42.92	55.74
20	36.60	43.21	48.86	59.45
21	35.12	41.68	47.43	58.47
22	29.74	41.17	42.29	53.81
23	40.38	39.07	46.82	50.16
24	34.96	35.29	42.57	58.94
25	37.90	36.57	51.04	53.40
26	33.24	42.96	47.27	56.66
27	31.14	53.84	42.88	61.93
28	30.94	43.48	41.79	56.91
29	35.03	36.16	51.49	52.20
30	27.85	30.53	53.31	53.92
MEAN±S.D	**33.9±3.03**	**44.6±6.18**	**46.41±3.81**	**55.16±3.5**

Table A7. Equivalent diameter (mm) of 30 rhizomes for both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	21.44	29.00	27.21	32.91
2	21.65	23.38	23.78	29.75
3	17.82	21.96	28.66	29.06
4	22.59	30.47	25.21	30.15
5	20.92	25.31	25.50	32.86
6	20.27	33.29	28.95	31.05
7	23.45	28.38	24.64	31.44
8	20.42	27.91	29.56	29.43
9	21.86	24.36	30.11	31.47
10	20.14	27.22	27.70	31.14
11	18.17	26.13	26.44	29.80
12	18.86	27.05	28.52	30.65
13	21.00	29.08	32.24	30.54
14	21.44	25.89	29.74	32.59
15	18.66	24.52	27.63	32.99
16	22.76	24.99	26.47	25.17
17	23.34	25.74	28.41	30.09
18	20.73	23.75	26.18	33.65
19	21.25	27.11	25.29	31.34
20	22.28	24.51	28.99	33.47
21	22.64	23.59	27.99	32.95
22	18.56	23.31	24.75	30.39
23	24.57	22.26	27.79	28.36
24	22.24	20.12	25.41	33.16
25	23.17	20.77	29.67	30.09
26	20.09	24.26	28.61	31.86
27	18.52	30.24	25.12	34.98
28	19.08	24.58	25.22	32.00
29	20.86	20.55	30.64	29.39
30	16.58	17.46	31.66	30.34
MEAN±S.D	**20.85± 1.92**	**25.24±3.42**	**27.6±2.21**	**31.11±1.94**

Table A8. Aspect ratio of 30 rhizomes for both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	0.18	0.52	0.25	0.59
2	0.22	0.70	0.22	0.71
3	0.26	0.62	0.25	0.62
4	0.21	0.55	0.27	0.64
5	0.22	0.57	0.20	0.54
6	0.18	0.57	0.21	0.56
7	0.17	0.67	0.22	0.48
8	0.21	0.61	0.21	0.58
9	0.17	0.77	0.27	0.66
10	0.19	0.54	0.22	0.48
11	0.20	0.55	0.24	0.63
12	0.16	0.75	0.26	0.58
13	0.19	0.65	0.23	0.62
14	0.17	0.65	0.27	0.55
15	0.18	0.68	0.21	0.55
16	0.18	0.67	0.25	0.62
17	0.16	0.66	0.22	0.51
18	0.27	0.87	0.27	0.65
19	0.18	0.85	0.27	0.63
20	0.21	0.61	0.25	0.59
21	0.12	0.77	0.28	0.59
22	0.17	0.75	0.31	0.60
23	0.19	0.58	0.25	0.60
24	0.13	0.71	0.24	0.59
25	0.19	0.89	0.31	0.64
26	0.23	0.89	0.21	0.63
27	0.29	1.02	0.31	0.49
28	0.2	0.76	0.22	0.62
29	0.26	0.96	0.23	0.67
30	0.29	0.89	0.24	0.66
MEAN±S.D	**0.2±0.04**	**0.71±0.13**	**0.25±0.03**	**0.59±0.05**

Table A9. Unit volume (mm^2) of 30 rhizomes for both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	55.9	45.17	62.96	48.55
2	51.48	30.24	57.18	38.16
3	41.85	31.12	68.79	41.77
4	56.36	46.47	56.46	42.75
5	53.14	37.02	63.97	51.32
6	53.77	49.78	67.93	48.24
7	64.51	37.91	58.73	51.75
8	51.97	40.34	73.82	43.57
9	57.5	29.82	66.44	43.45
10	52.2	41.01	66.36	51.26
11	48.94	39.57	63.81	41.73
12	51.24	34.93	64.4	45.65
13	54.05	40.04	79.14	44.27
14	58.11	35.62	66.26	50.13
15	48.62	32.54	68.8	49.84
16	59.9	33.17	61.44	35.88
17	68.6	34.85	69.04	47.04
18	45.75	27.48	57.15	46.58
19	57.52	31.43	55.16	43.71
20	55.97	34.55	67.54	50.28
21	69.3	29.29	62.72	49.9
22	49.87	29.04	51.1	45.84
23	62.61	31.88	64.16	41.58
24	65.32	26.21	59.35	49.02
25	59.45	23.4	61.36	42.8
26	47.83	27.48	72.96	45.29
27	39.28	34.92	52.5	57.1
28	49.07	30.82	62.27	45.47
29	46.12	22.67	73.12	39.69
30	34.28	19.35	75.18	41.89
MEAN±S.D	**0.12±0.01**	**0.33±0.05**	**0.14±0.01**	**0.27±0.02**

Table A10. Surface area (mm^3) of 30 rhizomes for both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	55.9	45.17	62.96	48.55
2	51.48	30.24	57.18	38.16
3	41.85	31.12	68.79	41.77
4	56.36	46.47	56.46	42.75
5	53.14	37.02	63.97	51.32
6	53.77	49.78	67.93	48.24
7	64.51	37.91	58.73	51.75
8	51.97	40.34	73.82	43.57
9	57.5	29.82	66.44	43.45
10	52.2	41.01	66.36	51.26
11	48.94	39.57	63.81	41.73
12	51.24	34.93	64.4	45.65
13	54.05	40.04	79.14	44.27
14	58.11	35.62	66.26	50.13
15	48.62	32.54	68.8	49.84
16	59.9	33.17	61.44	35.88
17	68.6	34.85	69.04	47.04
18	45.75	27.48	57.15	46.58
19	57.52	31.43	55.16	43.71
20	55.97	34.55	67.54	50.28
21	69.3	29.29	62.72	49.9
22	49.87	29.04	51.1	45.84
23	62.61	31.88	64.16	41.58
24	65.32	26.21	59.35	49.02
25	59.45	23.4	61.36	42.8
26	47.83	27.48	72.96	45.29
27	39.28	34.92	52.5	57.1
28	49.07	30.82	62.27	45.47
29	46.12	22.67	73.12	39.69
30	34.28	19.35	75.18	41.89
MEAN±S.D	**2.36±0.39**	**9.36±1.71**	**3.34±0.38**	**8.45±0.88**

Table A11. Bulk density (kg m^{-3}) of both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	383.33	622.66	500	650
2	378	636.66	528	640
3	386.66	632.66	496.6	652
4	382.66	627.33	517.3	669.33
5	376	624.66	514.66	646
6	389.33	641.33	506.66	656
7	386	630.66	510.66	651.33
8	385.33	634	518	654.66
9	392.66	634.66	510.66	609.33
10	386.66	640	516.66	649.33
MEAN±S.D	**384.66±4.96**	**632.46±6.2**	**511.92±9.2**	**647.79±15.48**

Table A12. True density (kg m^{-3}) of both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	1052.6	1272.7	1369.23	1225
2	1250	1230.76	1109	1147.05
3	1400	1187.5	1340	1346.15
4	1142.85	1250.03	1058.8	1291.66
5	1052	1250	1179.4	1214.28
6	1344	1222.2	1215.3	1194.44
7	1538.46	1250	1326.92	1363.63
8	1250	1250	1220.5	1318.18
9	1086	1266.66	1363.63	1258.06
10	1136.3	1300	1194.44	1305.55
MEAN±S.D	**1225.22±30.36**	**1241.6±74.57**	**1237.7±63.65**	**1266.4±70.38**

Table A13. Porosity (%) of both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	63.58	51.08	63.48	46.94
2	69.76	48.27	52.39	44.20
3	72.38	46.72	62.94	51.57
4	66.52	49.81	51.14	48.18
5	64.26	50.03	56.36	46.79
6	71.03	47.53	58.31	45.08
7	74.91	49.55	61.52	52.24
8	69.17	49.28	57.56	50.34
9	63.84	49.89	62.55	51.57
10	65.97	50.77	56.75	50.26
MEAN±S.D	**68.6±3.93**	**49.293±1.38**	**58.29±2.36**	**48.72±2.87**

Table A14. Angle of repose (º) of both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	49.08	48.12	48.12	38.92
2	48.12	45	49.08	40.23
3	49.08	46.08	48.12	37.56
4	49.08	45	50.013	38.92
5	49.08	43.87	50.9	41.49
6	48.12	46.08	49.08	42.7
7	49.08	49.08	50.01	42.7
8	47.12	43.87	49.08	41.49
9	48.12	43.87	49.08	42.7
10	49.08	45	50.01	38.92
MEAN±S.D	**48.59±1.79**	**45.59±0.68**	**49.35±0.88**	**40.56±1.9**

Table A15. Coefficient of friction of salem bulb variety

Sl.no	Stainless steel	aluminium	Galvanized iron	Mild steel
1	0.315	0.434	0.542	0.499
2	0.325	0.505	0.489	0.492
3	0.303	0.472	0.54	0.597
4	0.308	0.479	0.48	0.498
5	0.305	0.507	0.517	0.598
6	0.315	0.506	0.44	0.492
7	0.303	0.479	0.64	0.519
8	0.308	0.475	0.52	0.577
9	0.315	0.44	0.41	0.588
10	0.320	0.507	0.58	0.509
MEAN±S.D	**0.313±0.01**	**0.479±0.03**	**0.514±0.03**	**0.532±0.05**

Table A16. Coefficient of friction of salem finger variety

Sl.no	Stainless steel	aluminium	Galvanized iron	Mild steel
1	0.373	0.439	0.473	0.5
2	0.442	0.5	0.527	0.545
3	0.333	0.464	0.48	0.52
4	0.409	0.452	0.542	0.51
5	0.364	0.51	0.52	0.53
6	0.344	0.488	0.537	0.51
7	0.393	0.459	0.49	0.525
8	0.422	0.454	0.522	0.53
9	0.353	0.478	0.483	0.52
10	0.344	0.449	0.481	0.541
MEAN±S.D	**0.384±0.04**	**0.473±0.03**	**0.508±0.03**	**0.521±0.01**

Table A17. Coefficient of friction of Erode bulb variety

Sl.no	Stainless steel	Aluminium	Galvanized iron	Mild steel
1	0.255	0.42	0.465	0.487
2	0.22	0.380	0.512	0.527
3	0.23	0.36	0.45	0.513
4	0.213	0.4	0.48	0.457
5	0.237	0.395	0.427	0.543
6	0.24	0.325	0.5	0.49
7	0.227	0.37	0.476	0.517
8	0.233	0.346	0.435	0.477
9	0.22	0.384	0.505	0.523
10	0.24	0.36	0.48	0.519
MEAN±S.D	**0.231±0.009**	**0.391±0.02**	**0.497±0.03**	**0.516±0.02**

Table A18. Coefficient of friction of Erode finger variety

Sl.no	Stainless steel	aluminium	Galvanized iron	Mild steel
1	0.192	0.45	0.554	0.635
2	0.242	0.462	0.581	0.607
3	0.212	0.431	0.538	0.612
4	0.258	0.419	0.577	0.538
5	0.227	0.465	0.569	0.546
6	0.232	0.452	0.561	0.627
7	0.238	0.442	0.597	0.592
8	0.214	0.421	0.54	0.558
9	0.247	0.44	0.583	0.615
10	0.238	0.432	0.574	0.607
MEAN±S.D	**0.226±0.02**	**0.382±0.01**	**0.445±0.02**	**0.514±0.01**

Table A19. Curcumin content (%) of 30 samples for both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	3.208	3.09	4.678	3.05
2	3.255	3.08	4.72	3.11
3	2.869	2.97	4.75	3.11
4	2.875	3.1	4.43	3.04
5	2.934	3.09	4.91	3.15
6	3.315	2.94	4.75	3.27
7	3.529	2.89	4.18	3.21
8	3.244	2.86	4.61	3.29
9	2.946	2.95	3.99	3.68
10	3.232	2.98	4.32	3.37
11	3.476	2.93	4.73	3.52
12	3.22	2.95	4.91	3.29
13	3.22	2.88	4.26	3.05
14	3.24	2.84	4.07	3.06
15	3.267	3.15	4.43	3.57
16	3.184	3.18	4.22	2.92
17	2.875	2.91	4.88	3.03
18	3.065	2.94	4.37	3.08
19	3.482	2.87	3.95	3.29
20	3.315	2.97	4.43	3.18
21	3.065	2.84	4.88	3.4
22	3.208	2.85	4.42	3.065
23	3.482	2.87	4.49	3.17
24	3.065	3.25	4.26	3.18
25	3.029	2.82	4.51	2.92
26	3.315	2.91	4.43	3.16
27	3.065	2.83	4.76	3.03
28	3.291	2.83	4.42	3.01
29	3.279	2.92	4.84	2.91
30	3.065	2.92	4.85	3.07
MEAN±S.D	**3.187±0.184**	**2.953±0.114**	**4.515±0.283**	**3.17±0.189**

Table A20. Moisture content (% w.b.) of 30 samples for both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	7.5	9.5	6	7.5
2	7.5	9.5	6	8
3	7.5	9.5	8.5	8.5
4	7	10	7	7.5
5	7	9.5	8	8.5
6	7	9.5	8	8.5
7	7	9.5	8.5	7.5
8	7.5	9.5	7	8
9	7.5	9.5	8	7.5
10	7	9.5	8	8
11	7.5	9.5	8	7.5
12	7	9.5	8	7.5
13	7.5	9.5	8.5	8
14	7.5	8.5	7.5	8
15	7.5	8.5	8.5	7.5
16	7	8.5	8	8
17	7	8.5	9	7.5
18	6.5	8.5	8	8
19	7	8.5	7.5	8
20	7	8.5	7.5	8.5
21	6.5	8.5	7.5	8
22	7	8.5	8	8
23	6.5	8.5	7.5	7.5
24	7	8.5	9	7.5
25	6.5	8.5	7.5	7.5
26	7	8	8	8
27	6	9	9	9.5
28	7	8.5	8.5	9
29	7	8.5	7.5	8
30	7	9.5	8.5	8.5
MEAN±S.D	**7.05±0.38**	**8.98±0.55**	**7.88±0.74**	**7.98±0.74**

Table A21. Starch content (%) of 30 samples for both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	57.57	56.9	57.12	56.68
2	57.81	56.9	57.35	56.68
3	57.57	56.9	57.12	56.68
4	57.81	56.9	57.12	56.68
5	57.81	56.9	57.12	56.68
6	57.81	56.9	57.12	56.68
7	57.81	56.9	57.12	56.68
8	57.81	56.68	57.12	56.68
9	57.81	56.9	57.12	56.68
10	57.81	56.9	57.12	56.68
11	57.81	56.68	57.12	56.68
12	57.81	56.9	57.12	56.68
13	57.81	56.9	57.12	56.68
14	57.81	56.9	57.12	56.68
15	57.81	56.9	57.12	56.68
16	57.81	56.9	57.12	56.68
17	57.81	56.9	57.12	56.68
18	57.81	56.9	57.12	56.68
19	57.81	56.68	57.12	56.68
20	57.81	56.9	57.35	56.68
21	57.81	56.9	57.12	56.68
22	57.81	56.68	57.12	56.68
23	57.81	56.9	57.12	56.68
24	57.81	56.9	57.12	56.68
25	57.81	56.9	57.12	56.68
26	57.81	56.9	57.12	56.68
27	57.81	56.9	57.12	56.68
28	57.81	56.9	57.12	56.68
29	57.81	56.9	57.12	56.68
30	57.81	56.9	57.12	56.68
MEAN±S.D	**57.79±0.06**	**56.87±0.07**	**57.13±0.05**	**56.68±0.001**

Table A22. Predicted Curcumin content (%) using FT-NIR for both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	3.08	3.08	4.47	3.19
2	3.07	3.02	4.62	3.29
3	3.08	2.96	4.52	3.37
4	3.07	2.91	4.66	3.30
5	3.36	2.99	4.53	3.28
6	3.23	3.03	4.65	3.30
7	3.27	3.13	4.59	3.37
8	3.24	3.10	4.55	3.38
9	3.33	3.05	4.54	3.07
10	3.35	3.06	4.53	3.16
11	3.46	2.83	4.52	3.22
12	3.36	2.89	4.54	3.11
13	3.20	2.99	4.71	3.11
14	3.09	2.99	4.23	3.17
15	3.16	3.03	4.33	3.21
16	3.25	2.95	4.43	3.18
17	3.08	2.78	4.28	3.25
18	3.44	2.70	4.27	3.19
19	3.31	2.82	4.31	3.24
20	3.26	2.8	4.42	3.14
21	3.25	2.78	4.25	3.25
22	3.19	2.99	4.29	3.26
23	3.17	2.93	4.37	3.07
24	3.16	2.97	4.65	3.11
25	3.15	2.94	4.72	3.16
26	3.14	2.87	4.6	3.09
27	3.19	2.94	4.59	3.28
28	3.15	2.91	4.75	3.18
29	3.07	3.05	4.69	3.07
30	3.17	3.08	4.73	3.14
MEAN±S.D	**3.211±0.111**	**2.952±0.107**	**4.511±0.159**	**3.204±0.091**

Table A23. Predicted Moisture content (% w.b.) using FT-NIR for both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	7.59	9.11	7.89	8.64
2	7.54	8.91	7.81	8.13
3	7.59	9.38	8.15	8.14
4	7.11	9.34	8.00	8.12
5	7.27	9.58	7.99	7.84
6	7.05	9.27	8.10	8.08
7	7.24	9.41	8.14	8.01
8	7.18	9.7	8.04	7.96
9	7.16	9.39	8.18	8.06
10	7.44	9.44	8.27	8.10
11	7.67	9.44	8.29	7.59
12	6.81	9.5	8.19	7.78
13	6.97	9.38	7.72	8.02
14	7.02	9.48	7.68	7.94
15	6.93	8.68	7.5	7.58
16	6.84	8.76	7.6	7.67
17	6.83	8.55	7.82	7.92
18	7.23	8.66	7.57	8.22
19	7.23	8.48	7.75	8.15
20	7.31	8.41	7.76	7.67
21	7.16	8.35	7.7	7.69
22	7.24	8.38	7.75	7.76
23	7.21	8.49	7.98	7.83
24	6.77	8.48	7.93	7.69
25	6.90	8.48	6.98	7.53
26	6.95	8.65	6.97	7.59
27	6.79	8.59	6.94	7.41
28	6.97	8.76	6.87	7.95
29	6.97	8.88	7.40	7.74
30	6.76	9.14	7.2	7.88
MEAN±S.D	**7.12±0.26**	**8.97±0.438**	**7.74±0.409**	**7.88±0.258**

Table A24. Predicted Starch content (%) using FT-NIR for both the varieties

Sl.no	Erode finger	Erode bulb	Salem finger	Salem bulb
1	57.8	56.9	57.31	56.74
2	57.74	56.89	57.17	56.7
3	57.8	56.83	57.2	56.7
4	57.75	56.83	57.15	56.73
5	57.7	56.82	57.18	56.72
6	57.7	56.85	57.11	56.74
7	57.71	56.85	57.16	56.73
8	57.65	56.85	57.1	56.64
9	57.68	56.86	57.1	56.62
10	57.75	56.87	57.11	56.68
11	57.75	56.84	57.09	56.6
12	57.73	56.86	57.1	56.67
13	57.8	56.85	57.12	56.69
14	57.79	56.93	57.21	56.71
15	57.83	56.89	57.17	56.73
16	57.77	56.97	57.16	56.59
17	57.75	56.92	57.2	56.65
18	57.7	56.91	57.17	56.61
19	57.82	56.88	57.16	56.62
20	57.68	56.84	57.2	56.64
21	57.91	56.84	57.18	56.77
22	57.88	56.86	57.16	56.71
23	57.94	56.84	57.2	56.77
24	57.88	56.89	57.15	56.73
25	57.84	56.87	57.11	56.73
26	57.87	56.87	57.15	56.7
27	57.82	56.83	57.11	56.68
28	57.82	56.81	57.08	56.73
29	57.81	56.81	57.05	56.71
30	57.83	56.8	57.04	56.72
MEAN±S.D	**57.78±0.073**	**56.86±0.038**	**57.15±0.054**	**56.69±0.049**