Performance Evaluation of Single Stage and Multi Stage Grinder

THESIS

Submitted to the

Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur

In partial fulfillment of the requirements for

the Degree of

MASTER OF TECHNOLOGY

In

AGRICULTURAL ENGINEERING

(Processing & Food Engineering)

By

Swati Mahobiya

Department of Post Harvest Process & Food Engineering

College of Agricultural Engineering, Jabalpur 482004

Jawaharlal Nehru Krishi Vishwa Vidyalaya

Jabalpur, Madhya Pradesh

2014

CERTIFICATE – I

This is to certify that the thesis entitled **"Performance Evaluation of Single Stage and Multi Stage Grinder"** submitted in partial fulfillment of the requirement for the degree of **MASTER OF TECHNOLOGY in Agricultural Engineering** (**Processing and Food Engineering)** of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur is a record of the bonafide research work carried out by **Swati Mahobiya** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instruction.

All the assistance and helps received during the course of the investigation has been acknowledged by her.

Place: **Dr. A. K. Gupta**
Date: **Chairman of the Advisory Committee**

THESIS APPROVED BY THE STUDENT'S ADVISORY COMMITTEE

Committee	Name	Signature
Chairman	(Dr. A. K. Gupta)	--------------------------------
Member	(Dr. Mohan Singh)	--------------------------------
Member	(Dr. H. L. Sharma)	--------------------------------
Member	(Prof. C. M. Abrol)	--------------------------------

CERTIFICATE – II

This is to certify that the thesis entitled "**Performance Evaluation of Single Stage and Multi Stage Grinder**" submitted by Swati Mahobiya to Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur in partial fulfillment of the requirement for the degree of **MASTER OF TECHNOLOGY** in **Agricultural Engineering** in the Department of **Post Harvest Process and Food Engineering** has been, after evaluation, approved by the External Examiner and by the Student's Advisory Committee. after an oral examination on the same.

Place: Jabalpur **Dr. A. K. Gupta**
Date: **Chairman of the Advisory Committee**

MEMBER OF THE ADVISORY COMMITTEE

Committee	Name	Signature
Chairman	(Dr.A. K. Gupta)	---------------------------------
Member	(Dr. Mohan Singh)	---------------------------------
Member	(Dr. H. L. Sharma)	---------------------------------
Member	(Prof. C. M. Abrol)	---------------------------------

Head of the Department (PHP&FE) ---------------------------------

Director Instruction (JNKVV Jabalpur) ---------------------------------

ACKNOWLEDGEMENT

I**,** Swati Mahobiya, praise the Omniscient and Almighty God and express my deepest adorations for giving me this great opportunity to do M.Tech (Agril. Engg.) Post Harvest Process & Food Engineering.

Words fail when I express my deep sense of reverence and gratitude to Dr. A. K. Gupta, Assistant Professor, Dept. of Post Harvest Process & Food Engineering , College of Agricultural Engineering, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Chairman of my Advisory Committee, my venerable guide, the most efficient, eminent and sagacious personality. I am thankful to him for his most valuable and inspirational guidance, close supervision, constant encouragement and constructive criticism which kept my moral high throughout the some course of my study, especially the thesis period.

I am also thankful to the venerable member of my Advisory Committee Dr. Mohan Singh, faculty of Agricultural Engineering in College of Agricultural Engineering.

I also would like to thank the venerable member of my Advisory Committee Prof. C. M. Abrol, Assistant Professor Dept.of Post Harvest Process & Food Engineering.

I am also thankful to the venerable member of my Advisory Committee Prof. H. L. Sharma faculty of mathematics and statistics in College of Agril. Engg.for guiding and providing all the facility for completing project time to time, calculation and writing of thesis.

It gives me immense pleasure in expressing my humble gratitude to Mr. Suraj Patel, Librarian and staff of library of College of Agricultural Engineering, J.N.K.V.V., Jabalpur for providing necessary book facilities accordingly.

I find myself very lucky to have friends like Er. Tripti Sahu, Er. Sarita Dubey, Er. Swati Cyril, Er Ritesh Ranjan, Er. Arvind Yadav, Er. Aaradhana Patel, Er. Shradha Bhople and Shilpi Jain for getting all sorts of help from them.

I acknowledge my thanks to Mr. Lalit and Mr. Ramashish for their Cooperation from time to time.

Diction is not enough to express my gratitude from the deepest core of my soul to my respected father Shri Rajesh Kumar Mahobiya and mother Smt. Rohini Mahobiya, whose selfless love constant encouragement, obstinate sacrifices, sincere prayers, expectations and blessings have always been the most vital source of inspiration in my life.

Place : Jabalpur

Date: **(SWATI MAHOBIYA)**

Copyright Transfer Certificate

Title of the Thesis : **“**Performance Evaluation of Single Stage and Multi Stage Grinder"

Name of the candidate : Swati Mahobiya

Subject : Processing and Food Engineering

Department : Deptt. Of Post Harvest Processing and Food Engg

College : College of Agricultural Engg., JNKVV, Jabalpur

Year of thesis submission : 2014

Copyright Transfer

The undersigned Swati Mahobiya assigns to the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh, all rights under Copyright Act, that may exists in and for the thesis entitled, "Performance Evaluation of Single Stage and Multi Stage Grinder "submitted for the award of M.Tech. (Processing and Food Engineering) degree.

Date :
Place : Jabalpur

(Dr. A. K. Gupta)
Major Advisor

(Swati Mahobiya)
Student

DECLARATION AND UNDERTAKING BY THE CANDIDATE

I, Swati Mahobiya, D/o Rajesh Kumar Mahobiya, certify the work embodied in thesis entitled, “Performance Evaluation of Single Stage and Multi Stage Grinder” is my own first hand bonafide work carried out by me under the guidance of Dr. A. K. Gupta at Department of Post Harvest Processing and Food Engineering, College of Agricultural Engineering JNKVV, Jabalpur during 2014.

The matter embodied in the thesis has not been submitted for the award of any other degree / diploma. Due credit has been made to all the assistance and help.

I, undertake the complete responsibility that any act of misinterpretation, mistakes,errors of fact are entirely of my own.

I, also abide myself with the decision taken by my advisor for the publication of material extracted from the thesis work and subsequent improvement, on mutually beneficial basis, provided the due credit is given, thereof.

Place : Jabalpur **(Swati Mahobiya)**

Date :

List of Contents

List of Figure

List of Plates

List of Tables

List of Symbol

Symbol/Abrriviation	Meaning
AOAC	Association of official analytical chemist
ASTA	American Spice Trade Association
ANOVA	Analysis of Variance
CAE	College of Agricultural Engineering
d.b.	Dry Basis
J.N.K.V.V.	Jawaharlal Nehru Krishi Vishwa Vidyalaya
L C	Least Count
M.C.	Moisture content
SSG	Single stage hammer mill
DSG	Double stage hammer mill
Hr	Hour
Min	Minute
Sec	Second
=	Equals to
%	Percentage
°C	Degree Centigrade
x	Multiplication
hp	horse power
etc	et cetera
e.g.	Example
et al.	And others
MT	Million tonnes
g	Gram
kg	Kilogram
mg	Mili gram
ml	Mililitre
g/ml	Gram per litre
rpm	Revolution per minute

mm^2	Milimeter square
mm	Mili meter
Kg/m^3	kilogram per meter cube
g/cm^3	Gram per centi meter cube
m^2/g	Meter square per gram
µm	Micrometer
g/g	Gram/gram
temp	Temperature
Viz	Videlicet
a	Length
b	Width
c	Thickness
cm	Centi meter
W/m-k	Watt per meter Kelvin
KJ/Kg-k	Kilojoule per kilo gram Kelvin
m/s	Meter per second
D_P	Average particle size
F.M	Fineness modulus
Fig	Figure
i.e	That is
&	And
Θ	Theta
df	Degree of freedom
SS	Sum of squares
MS	Mean sum of squares

INTRODUCTION

Since time immemorial spices are used extensively for food preservation and to enhance the acceptability of the food. Spices are used in small amount but these are capable of adding health benefits in the food. In India different type of spices are grown and used for food preparation. The health benefits of spices were known to Indians for long time. It's use is not restricted to the food only but it can be used for the preparation of various cosmetic preparation and ointments for healing purpose.

Spices are commonly grown in India, Bangladesh, Turkey, China, Pakistan, Russia, Central Europe and Morocco (Bhuiyan*et al*., 2009). India is a leading producer of spices in the world (Table 1.1). In India, area under spices cultivation is 3075.90 thousand hectares with production of 5743.52 thousand MT (Indian Horticulture Database, 2013). Major spices producing states in India are Andhra Pradesh, Madhya Pradesh, Tamil Nadu, Orissa, Karnataka, Bihar, Uttar Pradesh and Haryana (Table 1.2).

Table 1.1 Major Spice producing countries

S. No.	Country	Production (million tones)
1	India	1,525,000MT
2	Bangladesh	139,775MT
3	Turkey	113,783MT
4	China	95,890MT
5	Pakistan	53,620MT

Reference: FAO& Agricultural Organization (2011).

Table 1.2 Major Spice producing states in India

S.No.	Spices	State
1.	Fenugreek	Rajasthan, Uttar Pradesh, Gujarat.
2.	Ginger	Andhra Pradesh, Karnataka, Kerala, Madhya Pradesh, Meghalaya, Orissa, Arunachal Pradesh, West Bengal, Mizoram, Sikkim, Himachal Pradesh, Tamil Nadu, Uttaranchal, Chattisgarh, Jharkhand.

3.	Red Chilli	Andhra Pradesh, Gujarat, Karnataka, Maharashtra, Orissa, Rajasthan, Tamil Nadu, Uttar Pradesh, West Bengal, Madhya Pradesh, Uttaranchal.
4.	Turmeric	Andhra Pradesh, Karnataka, Orissa, Tamil Nadu, West Bengal,Maharashtra, Kerala, Assam, Bihar, Meghalaya, Tripura, Uttar Pradesh,Arunachal Pradesh,
5.	Cumin	Rajasthan, Gujarat, Uttar Pradesh
6.	Fennel	Gujarat, Rajasthan, Uttar Pradesh
7.	Garlic	Haryana, Madhya Pradesh, Maharashtra, Orissa, Uttar Pradesh, Gujarat, Karnataka, Rajasthan, Chattisgarh, Bihar.
8.	Coriander	Rajasthan, Uttar Pradesh, Uttaranchal.

Reference: Spices board India (2013).

India is a leading exporter of spices. Annually it export about 1.9 lakh tone of different spices and spice products earning a foreign exchange of about 700 crores. Major spices exported from India are coriander, pepper, turmeric, chilies, ginger, fenugreek seed and cumin.

Red chilli (*Capsicum annum*) also known as chilli pepper, paprika and laal mirch belongs to Solanaceae family. Chilli peppers have high levels of vitamins and minerals. Red chilies contain large amounts of vitamin C and small amounts of carotene (Provitamin A). They are very high in potassium, magnesium and iron. Their very high vitamin C content can also substantially increase the uptake of non-heme iron from other ingredients in a meal, such as beans and grains. India is one of the largest producer and exporter of red chilli with an annual export of nearly 1304.38 MT (Indian Horticulture Database, 2013).

Ginger (Zingiber officinale) also known as adrak belongs to fabaceae family. Dried and fresh ginger which is used for industrial purpose due to extraction of oleoresin. It is an important crop which plays an important role in ayurvedic medicine as a folk remedy to promote cleaning of the body through perspiration, to calm nausea, and to stimulate the appetite. India is one of the largest producer and exporter of ginger with an annual export of nearly 682.23 MT (Indian Horticulture Database, 2013).

Fenugreek (*Trigonella foenum graecum*) also known as methi belongs to fabaceae family. Fenugreek seed are strongly aromatic and flavourful seed are bitter in taste but loss their bitterness, if roasted slightly. They are rich in vitamins such as thiamin, folic acid, riboflavin, niacin, vitamins A, B_6 and C. India is one of the major producer and exporter of fenugreek with an annual export of nearly 112.87MT(Indian Horticulture Database, 2013).

The spices, either in whole form, or in the powder form, possess a mild, sweet, and slight pungent odour and are extensively used as condiments. The spices are also used as a flavoring agent in different foods namely pastries, cookies, buns, cakes and breads (Akgul, 1993). In addition to the traditional food uses, these have been widely used in the medicine. Chemically, spice comprises of two important constituents viz. the essential oil and the fatty acids.

Spices are commonly used in powdered form. The size reduction of spices is done by mechanical means without changing chemical properties of the ground products. Grinding is basically a size reduction process. Enormous quantity of heat energy is generated during grinding which rises temperature of ground spices, the grinding mill and the ambient air. A part of the heat energy is utilized in vaporizing the moisture contained in the spices. On an average, the temperature of the product being grounded usually rise above 40^0C (Perry and Hall, 1965).The rise in temperature of spices subjected to grinding is mainly responsible for vaporization of volatile oil of spices, resulting in degradation in aromatic quality of spices and economic losses to the producer.

In India, grinding of red chilli, ginger, fenugreek seed etc. is usually done at small scale. All size reduction machines such as in attrition and hammer mills, involve shearing and impact action. Due to high temperature generated during grinding process the temperature of the ground spices rises quickly above the temperature of vaporization of volatile oils. Due to the vaporization of oil there is a reduction in the quality of the ground product.To minimize the quality loss spice milling is normally carried out under conditions which minimize both air flow rate and elevated temperature (McCabe *et al* 1985).The critical deterioration temperature at which undesirable changes occur in the spices (i.e. volatile oil loss, oxidation, discoloration or physical transformation) is only about 36°C and in some spices such as nutmeg and mace, it may be as low as 32°C (King and Judson,1974).

The manually operated traditional grinding mills are of low capacity and are less efficient. The products obtained from traditional grinding mills are generally of poor quality and involves lots of labour. To reduce labour and to assure better quality products and economic returns use of powder operated high capacity grinding mills are gaining popularity in urban as well as in rural areas. Modern methods of grinding such as cryogenic grinding and low temperature grinding are capital intensive and involve highly skilled workers. Keeping the above discussion in consideration present study was planned with following objectives:

1. To evaluate the performance of single stage and double stage hammer mill on grinding, biochemical and sensory characteristics of selected spices.
2. To work out economics of production of spice powder from selected methods of grinding.

REVIEW OF LITERATURE

Spices constitute an important group of agricultural commodities which are virtually indispensable in the culinary art. The term 'spices' applies to such natural plant or vegetable products or mixtures thereof, in whole or ground form, as are used for imparting flavour, aroma and piquancy to and for seasoning of foods. Spices are well-known as appetisers and are considered volatile in the culinary art all over the world. They add a tang and flavour to otherwise insipid or bland foods. Some of them also possess antioxidant properties, while others are used as preservatives in some foods like pickles and chutneys. Some spices also possess strong anti-microbial activities. Many of them possess medicinal properties and have a profound effect on human health. Spices increase the secretion of saliva rich in ptyalin which facilitates digestion of starch in the stomach, rendering the meals which are rich in carbohydrates, easily digestible.

Spices are usually consumed in ground form. Grinding of spices is an age old practice. Main aim of grinding is to obtain good quality powder of small size particles having pleasing colour & aroma. The past work done is reviewed in the following sections.

2.1 Engineering Properties of Spices

Engineering properties of foods are important for scale-up, product process design and optimization for storage of foods. Though, engineering properties can vary widely, they may be roughly categorized as physical properties (related to size, shape etc.), mechanical properties, thermal properties, rheological properties and aerodynamic properties. The subsequent sections will discuss these properties related to grinding of spices.

2.1.1 Physical Properties of spices

Altuntas *et al* (2004) established that the some physical properties of fenugreek are a function of moisture content. The average length, width, thickness, geometric mean diameter and unit mass of the fenugreek seed ranged from 4.01 to 4.19 mm, 2.35 to 2.61 mm, 1.49 to 1.74 mm, 2.40 to 2.66 mm and 0.0157 to 0.0164 g respectively as the moisture content increased from 8.9 to 20.1% d.b. In the moisture content range, studies on rewetted fenugreek seed showed that the sphericity increased from 60.79 to 64.06%, the seed volume from 12.58 to 13.83 mm^3, 1000 seed mass from 15.48 to 16.39 g and surface area from 18.09 to 22.18 mm^2. As the moisture content increased from 8.9 to 20.1% (d.b.), the bulk density, kernel density were found to decrease from 701.16 to 645.81 kg/m^3 and 1240.36 to 1165.25 kg/m^3, whereas angle of repose and porosity were found to increase from 14.34° to 16.88° and 43.47 to 44.58%, respectively. The static and dynamic coefficients of friction on various surfaces, namely, plywood, mild steel and galvanized metal also increased linearly with increase in moisture content. The plywood surface offered the maximum friction followed by mild metal and galvanized metal.

Yalc *et al* (2006) established that the physical properties of kernels, grains, and seeds are necessary for the design of equipment to handle, transport, process and store the crop. The physical properties of coriander seeds have been evaluated as a function of seed moisture content, varying from 7.10% to 18.94% (d.b.). In the moisture range, seed length decreased linearly from 4.74 to 4.61 mm and width, thickness, arithmetic mean diameter and geometric mean diameter increased linearly from 3.67 to 3.93 mm, 3.39 to 3.54 mm, 3.93 to 4.03 mm and 3.88 to 3.99 mm respectively with increase in moisture content. The sphericity, seed volume and seed surface area increased nonlinearly from 0.820 to 0.867%, 24.97 to 28.52 mm^3, and 42.09 to 45.62 mm^2, respectively. One thousand seed weight increased linearly from 8.72 to 9.71 g. The true density increased nonlinearly with increase or decrease in moisture content from 332 to 349 kg/m^3 while bulk density decreased linearly 234.1 to 220.2 kg/m^3 in the range of moisture content between 7.10% and 18.94%, d.b. Also, porosity values of coriander seeds increased nonlinearly from 33.03% to 35.79%. The highest static coefficient of friction was found on the plywood surface. The static coefficient of friction increased nonlinearly from 0.435 to 0.877, 0.425 to 0.775, 0.379 to 0.839, 0.364 to 0.781, 0.344 to 0.650, and 0.325 to 0.694 for plywood, polypropylene knitted bag, polyvinyl chloride, galvanized iron, cast polypropylene and stainless steel surfaces, respectively. The angle of repose increased linearly from 24.9º to 30.7º with the increase of moisture content.

Mishra and Kulkarni (2009) stated that the engineering properties of turmeric rhizomes depends upon the moisture content. The average length, width and thickness of turmeric were 42.77, 10.85 and 9.51 mm respectively at 12.4% moisture content (db). The volume, surface area and angle of repose were observed as 2.76 cm^3, 7925.33 mm^2 and 33º, respectively. The bulk density, true density, porosity and terminal velocity of turmeric rhizome were observed as 622.33 kg/m^3, 1253.93 kg/m^3, 50.37 % and 7.22 m/s respectively.

2.1.2 Mechanical Properties of spices

Mohsenin (1980) has defined the mechanical properties "as those having to do with the behaviour of the material under applied forces." Rheology has been defined as "a science devoted to the study of deformation and flow," and more recently as "the study of those properties of materials that govern the relationship between stress and strain" (Dealy, 1982). Stress is defined as the intensity of force components acting on a body and is expressed in units of force per unit area. Strain is the change in size or shape of a body in response to the applied force. Strain is a non-dimensional parameter (reported as a ratio or percentage) and is expressed as change in relation to the original size or shape.

Szczesniak (1983) Mechanical properties of spices have received the greatest attention lately. The reason for this activity is the fact that, in addition to affecting the mechanical behaviour of the product during transport, handling and processing, the mechanical properties form the basis for the sensory property or texture. During mastication and industrial size reduction processes (e.g., slicing, grinding, pureeing) it is desirable to have a 'weak' product that will disintegrate in the proper manner when forces are applied. On the other hand, during transport and industrial handling, it is desirable to have a 'strong' product one which will not suffer any substantial damage when impact or static compressive forces are applied.

2.2 Grinding characteristic

2.2.1 Grinding Methods

The hand operated processes were used in India for household processing. In such method generally deshi grinder and khalbattas (hand P) were used. The first roller mills appeared in Russia as early as 1882 and were improved in later year to make it in the present from.

In 2005 crushing & grinding conference conducted by IIR discusses the challenges associated with the process design of single stage mills, the design flexibility required to ensure a robust circuit and the operating techniques adopted at successful installations. The discussion culminates with selection criteria and generic operating philosophy for single stage autogenous and semi autogenous grinding mills.

Yusof *et al* (2012) studied the size reduction of three spices, namely cinnamon, coriander and star anise as influenced by loading weight and grinding time. Grinding was conducted in a knife mill. The dependent variables used for assessing performance were grinding efficiency, size reduction ratio and grinding rate. Simple experimental model was built using Microsoft Excel for showing the relationship between cumulative size reduction function (B_{ij}) and selectivity function (S_i) with the physical properties like density, moisture content and hardness of spices used. It was observed that there was a gradual decrease in size of spices up to grinding of 1 min and then it became constant. Among the three spices, cinnamon achieved the highest size reduction as evaluated by efficiency, size reduction rate and size reduction ratio. The optimum loading weight for grinding was found 30 g irrespective of the type of spices. The data of cumulative size reduction function, selectivity and particle size fitted to second-order polynomial equation with the highest goodness of fit. This study indicated that the size reduction/grinding using knife mill was greatly influenced by physical properties of spices among the factors studied.

Zeng *et al* (2013) compared the effects of cryogenic grinding and hammer milling on the flavour attributes of black, white and green pepper. The flavour attributes were analysed using headspace solid-phase microextraction (HS-SPME) and gas chromatography-mass spectrometry (GC/MS), sensory evaluation and electronic nose (e-nose) analysis. Cryogenic grinding resulted in minimal damage to the colour, flavor and sensory attributes of the spices. Cryogenic grinding was also better than hammer milling at preserving the main potent aroma constituents, but the concentrations of the main aroma constituents were dramatically reduced after storing the samples at 4 ºC for 6 months. Pattern matching performed by thee-nose further supported sensory and instrumental findings. Overall, cryogenic grinding was superiorto hammer milling for preserving the sensory properties and flavour attributes of pepper without significantly affecting its quality

Gajabe (2013) studied the effect of single stage and multi stage grinding on the quality attributes (fineness modulus, particle size, volatile oil and colour) of the coriander. It was observed that double stage grinding is superior than single stage grinding.

2.2.2 Temperature rise during grinding.

Goswami *et al* (2002) observed that with an increment in feed rate of cumin in attrition mill. There was a gradual rise in temperature and decrease in size of the ground cumin, but the specific energy consumption and work index were decreased first and then increased. The effect of feed temperature of cumin at 100 ºC gave quite low values of rise in temperature, specific energy consumption, work index and high value of reduction ratio compared to feed temperatures of cumin at 30 and 40 ºC.

Meghwal *et al* (2010) conducted studies on ambient and cryogenic grinding to test the novelty of cryogenic grinding and pointed the drawbacks of ambient grinding. Comparative study had shown that ambient grinding need more power (8.92%) and specific energy (14.5%) than cryogenic grinding. Particle size analysis had shown that cryogenic grinding produced coarser particles. Comparative study of energy law constant shows that ambient is more power consumptive. The higher amount of volatile oil (2.15 ml/100 g) content was found in cryogenic grinding and also powder of freshness and lower whiteness (40%) and higher yellowness (14%) indices found for cryogenic grinding.

2.2.3 Fineness modulus and particle size.

Singh and Sahay (1996) Fineness modulus indicates the uniformity of grinding each in resultant product. It is determined by adding the weight fractions retained above sieve and dividing the sum of 100. The average particle in mm is represented in terms of fineness modulus and can be estimated by standard following equation

$$D_P = 0.135 \square (1.366)^{Fm}$$

Where, D_P = average particle size diameter, mm

Fm= fineness modulus

Yang *et al* (2008) determined that the superfine grinding could produce a narrow and uniform particle size distribution in dry ginger. The physico–chemical properties of five types of ginger powders with particles size of 300, 149, 74, 37 and 8.34 µm were investigated. The size was smaller for ginger powders, greater for the surface area (from 0.331to 1.320 m^2/g) and bulk density (from 0.3069 to 0.3426 g/ml) and smaller for the angle of repose (from 51.50^0 to 46.33^0) and slide (from 45.80^0 to 39.50^0). The values of water absorption index (WAI), water solubility index (WSI) and protein content significantly increased with decreasing the size of ginger particles ($p < 0.05$). Interestingly, the values of WAI, WSI and protein content of ginger powder with a particle size of 8.34 µm during soaking reached 0.52 g/g, 33.70% and 84.93% for 60 min, respectively.

Barnwal *et al* (2013) Experiments on grinding of fenugreek seed were conducted in a pin mill type spice grinder to investigate the effect of moisture content, feed rate and grinder speed on some dependent variables such as average particle size of the ground fenugreek powder, colour values (L, a and b), colour parameters i.e hue, chroma and browning index, thermal properties such as specific heat, thermal conductivity and thermal diffusivity. The particle size, colour parameters i.e L, a, b, hue, chroma and browning index of fenugreek powder varied from 0.345±0.001 to 0.390±0.002 mm, 71.13±0.51 to 83.03±1.41, 1.11±0.13 to 4.43±0.18, 27.45±1.51 to 32.36±2.14, 80.03±0.43 to 87.82±1.01°, 28.72 ± 1.17 to 32.36±1.70 and 41.22±3.11 to 66.85±4.34, respectively in moisture range of 6.4-13.6% db, screw speed (3-4 rpm) and grinder speed (8000 to 11000 rpm). The values of thermal conductivity, specific heat and thermal diffusivity of fenugreek powder, at 30 °C within moisture range (6.4-13.6% db), varied significantly from 0.063 ± 0.003 to 0.077 ±0.002 W/m-K, 10.74 ± 0.098 to 16.64 ±1.24 kJ/kg-K and 7.12× 10^{-9} - 10.70× 10^{-9} m^2–1s, respectively.

2.3 Volatile oil.

Hydro distillation using the Clevenger apparatus is the official AOAC method for the analysis of volatile oils by the spices as reported by **Ertl,** (1997).

Manzan *et al* (2003) reported three types of hydro distillation; with water immersion, and vapor injection, and with direct vapor injection. It is versatile process that can be employed for small or large industries.

Silva *et al.* (2005) investigated that the influence of different hydro distillation procedures on the deodorization of turmeric. Among the methods tested, distillation under high vaccum, using a Kjedahl apparatus and using a rotary evaporator where not viable or efficient. Distillation of medium size grated turmeric using a Clevenger apparatus for 4 hr provided a powder with less residual turmeric flavor. The deodorization of turmeric using the Clevenger method would allows widespread use in the food industry.

Anwar *et al* (2011) described the physio-chemical composition of the essential oil derived from the seeds of coriander (*Coriandrum sativum*). Hydro distilled essential oil content from coriander seeds was found to be 0.15%. The physicochemical properties namely density (25 °C), refractive index (25 °C), acid value, ester value, and optical rotation (25 °C) determined for the essential oil were found to be 0.8310, 1.4592, 4.0, 23.7, and 11.5 g/cm^3 respectively. A total of 48 chemical constituents representing 90% of the essential oil tested were identified using Gas chromatography flame ionization detector (GC-FID) and Gas chromatography-mass spectroscopy (GC-MS). Linalool with contribution of 69.60% was found to be the principal constituent. Other important components identified were: geranyl acetate (4.99%), γ-terpinene (4.17%), α-pinene (1.63%), anethol (1.15%) and *p*cymene (1.12%). The analyzed essential oil mainly comprised of oxygenated monoterpene hydrocarbons (80.83%), followed by monoterpene hydrocarbons (8.00%), sesquiterpene hydrocarbons (0.47%) and oxygenated sesquiterpene hydrocarbons (0.35%). Overall, the physicochemical attributes and chemical profile of the tested essential oil from Pakistan were reasonably comparable with those investigated for coriander seed essential oils from other regions of the world suggesting its potential for functional foods and cosmetics applications.

2.4 Sensory characteristics of spices

Narasimhan et al (1990) suggested the sensory assessment of foods for colour, odour, and pungency of taste by 15 trained judges (both male and female) between 25 and 35 years old. Approximately 2.0 g of each sample were placed in a disposable petri dish and given to each panellist. The single-blind study was performed by labeling each sample with a unique three-digit number. The panellists were instructed to record their ratings using a 10-point hedonic scaleThe mean quality ratings were designated as follows: 2 was considered‘‘not usable’’, 3–4 was ‘‘poor’’, 5 was ‘‘average’’, 6 was ‘‘fair’’,7–8 was ‘‘good’’, and 9–10 was ‘‘very good’’

Waje *et al* **(**2008) Odour and pungency of taste were evaluated using a pepper powder fusion, which was prepared by dissolving 1.0 g of powder in 100 ml of 60 ºC water

2.5 Colour analysis

Topuz *et al (2009)* Discoloration and microbial proliferation are two major problems associated with production of paprika (Capsicum annuum L.) with traditional drying methods. In the present study, the Refractance Window Drying (RWD) method was employed to dry paprika in comparison with freeze drying, hot-air oven drying, and natural convective drying methods. In order to evaluate the color quality of paprika, the reflected color parameters, extractable color, red/yellow pigment ratio, and browning index were measured immediately after drying and during three-month storage. The freeze-dried and RWD-dried paprika showed better reflected color characteristics. The highest extractable color and browning index values were recorded in naturally convective dried paprika. There was no significant difference in browning index between freeze-died and RWD-died samples.

The reflected color degradation of the paprika was highly associated with brown reaction. A gradual discoloration was observed in all paprika samples during storage.

MATERIAL AND METHODS

To study the effect of single stage and double stage grinding on the quality attributes of selected spices, experiments were carried out at Department of Post Harvest Process and Food Engineering, College of Agricultural Engineering, Jabalpur. The spice chosen for the present study were red chilli, dry ginger and fenugreek seed. A brief description of materials used and the methodology adopted for the present study is presented in following sections.

3.1 Material

3.1.1 Spices

Red chilli, dry ginger and fenugreek were procured from the local market of Jabalpur. After cleaning, spices were stored at room temperature (25 ºC) for one month for moisture equilibration. The moisture content of the spices, after equilibration, as determined by the ASTA (1985) method, was observed to be 12% (dry basis).

3.1.2 Packaging material

Low density polyethelyene bags were used for packaging of ground spices.

3.1.3 Chemicals

All the chemicals viz sodium sulphate (Na_2SO_4), Benzyl benzoate, diethyl ether, alcohal and toluene required for present study were available in laboratory of college.

3.2 Method

3.2.1 Experimental plan

The grinding behavior of spices (red chilli, dry ginger, fenugreek seed) was studied in both single stage and double stage hammer mill under different operational conditions described below under experimental plan. In both grinding mills variable of operational speed is fixed at 4540 rpm. The independent variable such as feed rate of sample were three level for(red chilli - 6, 12,18 kg/hr),(dry ginger - 5, 10 ,15 kg/hr) and (fenugreek seed- 12, 15, 18 kg/hr) and moisture content also have three levels for(red chilli - 7, 9, 11 d.b%), (dry ginger - 7, 8, 9 d.b%) and (fenugreek seed- 7, 9, 11 d.b%). The observed dependent variables for the experiments were increases in temperature, volatile oil, fineness modulus, particle size and colour analysis based on the results of the experimental observations during grinding process was done. An experimental plan is presented in Table 3.1.

Table 3.1 Experimental Plan

<table>
<tr><th>S.N.</th><th>Independent variable</th><th>Level</th><th>Dependent variable</th></tr>
<tr><td>1.</td><td>Spices
a) Dry red chilli.
b) Dry Ginger.
c) Fenugreek.</td><td>3</td><td rowspan="4">I) Grinding characteristics
a. Temperature of powder during grinding (°C)
b. Fineness modulus
c. Particle size analysis

II) Biochemical properties of spice powder
a. Volatile oil
b. Specific gravity of oil
c. Refractive index of oil

III) Sensory properties
a. Colour
b. Flavour
c. Texture
d. Overall acceptability</td></tr>
<tr><td>2.</td><td>Grinding method
a) Single stage Grinding
b) Double stage Grinding</td><td>2</td></tr>
<tr><td>3.</td><td>Feed rate, (kg/hr)
a) Dry red chilli (6,12,18)
b) Ginger (5,10,15)
c) Fenugreek (12,15,18)</td><td>3</td></tr>
<tr><td>4.</td><td>Moisture content (db, %)
a) Dry red chilli (7,9,11)
b) Ginger (7, 8, 9)
c) Fenugreek(7,9,11)</td><td>3</td></tr>
</table>

In all the experiments the speed of the hammer will be kept constant at 4540 rpm (784.05 m/s)

3.2.2 Experimental design

The symmetrical factorial completely randomized design was used for both single and double stage grinding. In both grinding study, an experiment plan comprising of independent variable. A full design matrix is single stage hammer mill and similarly for double stage hammer mill presented in Table

3.2, Table 3.3, Table 3.4, Table 3.5 and Table 3.6 there are nine experiments in each grinding mill. The level and variables decided on the basis of previous work and preliminary experiments are as follows:

3.2.3 Data analysis

The full factorial experimental design was adopted for experiment as it provided sufficient information for statistically acceptable results (Steel and Tories, 1980). Statistically analysis of data in terms of ANOVA and correlation analysis between independent variables and dependent variables was conducted using Design expert 6.08 statistical software package.

Table 3.2 Design details of process/independent variable parameters

S No	Independent variable				
	A. single stage hammer mill				
1.	Feed rate (kg/hr) Red Chilli Ginger Fenugreek	F_R F_G F_F	9	X_{R1}	6
				X_{R2}	12
				X_{R3}	18
				X_{G1}	5
				X_{G2}	10
				X_{G3}	15
				X_{F1}	12
				X_{F2}	15
				X_{F3}	18
2.	Moisture content (db)	M_R M_G M_F	9	Y_{R1}	7
				Y_{R2}	9
				Y_{R3}	11
				Y_{G1}	7
				Y_{G2}	8
				Y_{G3}	9
				Y_{F1}	7
				Y_{F2}	9
				Y_{F3}	11

Table 3.3 Design details of process/independent variable parameters

S.No	Independent variable				
	B. Double stage hammer mill				
1.	Feed rate (kg/hr) Red Chilli Ginger Fenugreek	F_R F_G F_F	9	X_{R1}	6
				X_{R2}	12
				X_{R3}	18
				X_{G1}	5
				X_{G2}	10
				X_{G3}	15
				X_{F1}	12
				X_{F2}	15
				X_{F3}	18
2.	Moisture content (db)	M_R M_G M_F	9	Y_{R1}	7
				Y_{R2}	9
				Y_{R3}	11
				Y_{G1}	7
				Y_{G2}	8
				Y_{G3}	9
				Y_{F1}	7
				Y_{F2}	9
				Y_{F3}	11

Table 3.4 Experimental design matrix for single and double stage grinding method for red chilli

S.No	Coded value		Actual value	
1	X_{R1}	Y_{R1}	6	7
2	X_{R1}	Y_{R2}	6	9
3	X_{R1}	Y_{R3}	6	11
4	X_{R2}	Y_{R1}	12	7
5	X_{R2}	Y_{R2}	12	9
6	X_{R2}	Y_{R3}	12	11
7	X_{R3}	Y_{R1}	18	7
8	X_{R3}	Y_{R2}	18	9
9	X_{R3}	Y_{R3}	18	11

Table 3.5 Experimental design matrix for single stage and double grinding method for dry ginger

S.No	Coded value		Actual value	
1	X_{G1}	Y_{G1}	5	7
2	X_{G1}	Y_{G2}	5	8
3	X_{G1}	Y_{G3}	5	9
4	X_{G2}	Y_{G1}	10	7
5	X_{G2}	Y_{G2}	10	8
6	X_{G2}	Y_{G3}	10	9
7	X_{G3}	Y_{G1}	15	7
8	X_{G3}	Y_{G2}	15	8
9	X_{G3}	Y_{G3}	15	9

Table 3.6 Experimental design matrix for single stage and double stage grinding method for fenugreek seed

S.No	Coded value		Actual value	
1	X_{F1}	Y_{F1}	12	7
2	X_{F1}	Y_{F2}	12	9
3	X_{F1}	Y_{F3}	12	11
4	X_{F2}	Y_{F1}	15	7
5	X_{F2}	Y_{F2}	15	9
6	X_{F2}	Y_{F3}	15	11
7	X_{F3}	Y_{F1}	18	7
8	X_{F3}	Y_{F2}	18	9
9	X_{F3}	Y_{F3}	18	11

3.3 Preparation of the samples

3.3.1 Preparation of sample at different moisture content

To obtain spices seeds with different moisture contents, a fine spray of water was applied using a spray gun. Time of spray was varied to obtained spices seeds with different moisture content. These seeds were kept in covered glass bottles at (40° C) for 48 hour with occasional gentle shaking to obtained uniform moisture distribution. A part of seed lot was also dried in a tray dryer at (40° C) for 2 hour to obtain seeds having moisture content less than that of the original seeds. The moisture contents of the dried or sprayed samples were obtained by knowing the initial and final weights of the treated seeds using the following equation

$$W1\ (100+M1) = W2\ (100+Mo) \qquad \text{…………. (3.1)}$$

Where,

Mo =Initial moisture content

M1= Final moisture content of dried & sprayed sample

W1= Initial weight of the seeds at Mo

W2= Final weight of seeds at M1

Spices Powder

Spices powder was prepared by using single stage and double stage hammer mill and Fig. 1 represents the process flow chart.

Process for the preparation of spices is discussed below:

1. Reception of raw material: The spices red chilli, dry ginger and fenugreek were procured from the local market of Jabalpur (Plate 3.1, 3.2, 3.3).

2. Grading: The material was graded into various fractions namely spices seed, grit and dust.

3. Cleaning and De-stoning: The material was cleaned or de-stoned using a sieve.

4. Storage: The material was stored for a period of one month at 25ºC.

5. Grinding: The seeds at different moisture content were ground into spices powder using single stage and double stage hammer mill

6. Packaging and storage: The powder of spices (Plate 3.4, 3.5, 3.6) so formed was packed and stored for the experimental purpose.

Plate 3.1 Red chilli

Plate 3.2 Dry ginger

Plate 3.3 Fenugreek seed

3.3.2 Flow chart for Preparation of the Spices Powder

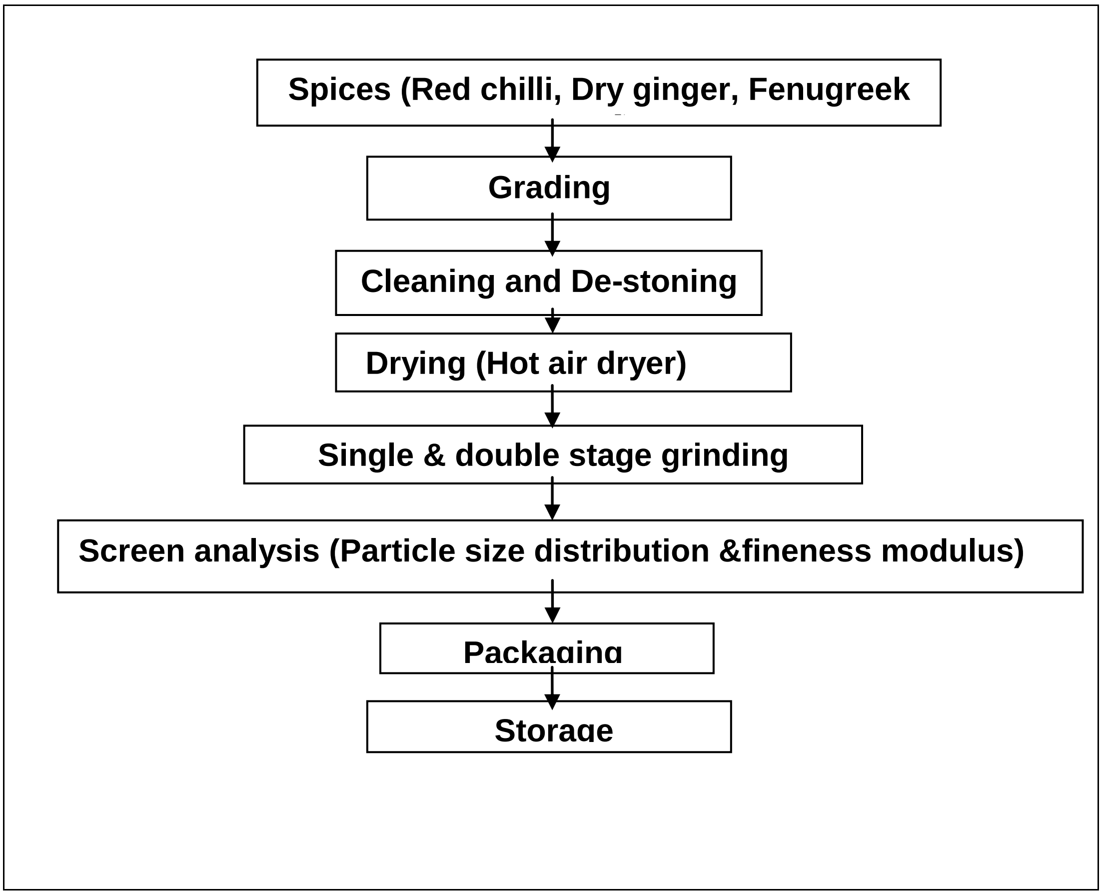


Fig 3.1 Flow chart for Preparation of the Spices Powder

3.4 Determination of experimental parameters

3.4.1 Physical properties of spices

3.4.1.1 Length, Width and Thickness

The Length, Width and Thickness of the red chilies, dry ginger, fenugreek seed was measured to ±0.01 mm accuracy using a dial-type thickness gauge at five different orientations of 10 seeds. The size distribution at 0.20 mm intervals was reported.

3.4.1.2 Bulk density

The bulk density is the mass of group of individual particle divided by the space occupied by entire mass, (Mohsenin, 1980) including the air space, and was measured with the help of 250 m flask. Spices were poured inside the flask and tapped 10 times manually to fill the pore spaces. It is calculated by

$$\text{Bulk density} = \frac{mass\ of\ the\ sample\ (gm)}{volume\ of\ flask\ occupied\ by\ the\ sample\ (cm3)} \quad \ldots\ldots\ldots\ldots\ldots..(3.2)$$

3.4.1.3 True density

The true density, defined as the ratio between the mass of material and the true volume of it, was determined using the toluene (C_7H_8) displacement method, (Mohsenin,1986).The True density was measured by the 500 ml toluene was used in place of water, because it is not absorbed by spices.

It is calculated by

$$\text{True density} = \frac{weight\ of\ sample\ (gm)}{volume\ displaced\ (cm3)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3.3)$$

3.4.1.4 Dynamic Angle of Repose

The angle of repose is the angle between the base and the slope of the cone formed on vertical fall of the granular material on a horizontal plane.

$$\text{Angle of repose} = \tan^{-1} (h/\ r)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.4)$$

Where h is height of heap, and r is radius of heap in base.

3.4.2 Physical properties of spices oil

The volatile oils obtained from the samples were analysed for their physical properties viz., specific gravity (AOAC method 1990), refractive index (AOAC method 1990)

3.4.2.1 Specific gravity

Specific or relative density at 27 ºC means the ratio of the densities of the liquid material at 27 ºC to that of distilled water at 27 ºC. The specific gravity bottle (10 ml capacity) was washed and cleaned with alcohol and diethyl ether. It was then dried in a current of dry air. The empty specific gravity bottle was weighed (m_i) accurately and was filled with distilled water at about 27 ºC, taking care to avoid the presence of air bubbles. It was then immersed in water bath maintained at 27 ± 0.2 ºC for 30 minutes. The temperature of the water bath was checked and the level of distilled water was adjusted to the mark. The specific gravity bottle was closed by using a stopper and the outer side was wiped carefully with a dry filter paper: It was then weighed (m_2) in the same balance. Then, the specific gravity bottle was emptied, washed with alcohol followed by diethyl ether, and finally dried by means of a current of dry air. The bottle was filled with volatile oil at about 27 ºC, avoiding the presence of air bubble. The bottle was immersed again in water bath maintained at 27 ±·0.2 ºC for 30 minutes. The volatile oil was adjusted to mark, and the procedure was repeated as stated for distilled water. The bottle with the volatile oil was then weighed (m_3) accurately.

Specific gravity was calculated $=\frac{m3-mi}{m2-mi}$ ……………….(3.5)

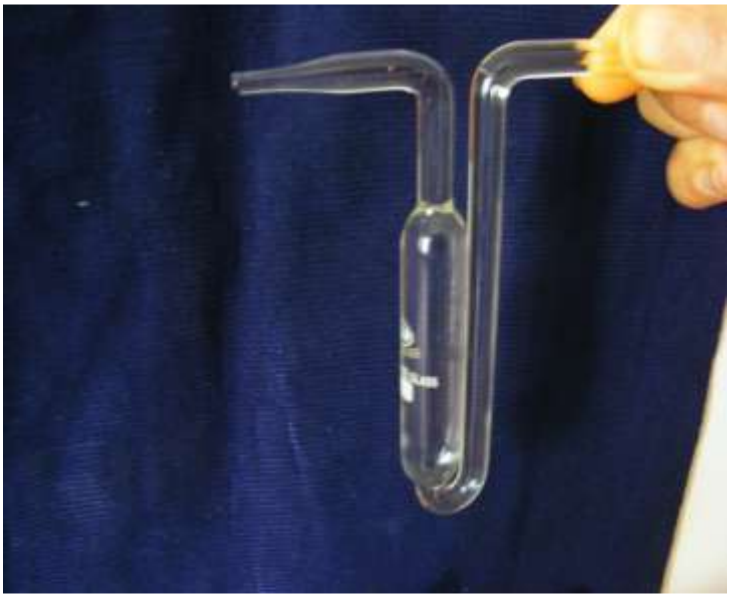


Plate 3.4 Pyconometer

3.4.2.2 Refractive index

Refractive index is the ratio of the sine of the angle of incidence to the sine of the angle of refraction when a ray of light of defined wavelength passes from air into test material kept at constant temperature. The wavelength normally used is 589.3±0.3 nm corresponding with 01 and 02 lines of sodium spectrum. The reference temperature is 27 ºC except those, which are not liquid at those temperatures in which case a higher temperature (say 30 ºC) depending on the melting point of the material should be used. Here, a recognized type of refractometer allowing direct readings of refractive indices between 1.3000 to 1.7000 with an accuracy of ±0.0002 was used. The instrument was calibrated with benzyl benzoate to obtain a refractive index. Sodium light, diffused day light or light from an electric lamp may be used for instruments fitted with an achromatic compensator.

3.4.3 Grinding characteristics

3.4.3.1 Particle diameters of powder samples

Particle diameters of powder samples were measured by sieve analysis technique. Sieve analysis of the powdered samples were conducted using a set of US standard sieves, mounting one above the other, with the sieve having the highest sieve opening at the top and pan (without sieve)at the bottom.

3.4.3.2 Fineness of the product

This was determined by standard sieve analysis, using 60 mesh sieve (Taylor series, with an opening of 0.250 mm) as per British standard method of test for spices and condiments (BS 4585:Part 8: 1977/ISO-3588-1977). Weight of particles passing through the sieve of 100 mesh to20 mesh with 5 minutes of shaking time was recorded. Fineness modulus was calculated from sieve analysis observations by means of given formula

Fineness modulus $=\frac{\sum Wi \times I}{\sum Wi}$ ………………..(3.6)

Where Wi = weight retained on i^{th} sieve.,i= No. of sieve from bottom of sieve

Plate 3.5 Red chilli Powder

Plate 3.6 Dry ginger Powder **Plate 3.7 Fenugreek Powder**

3.4.4 Colour analysis

Colour is an important quality parameter for the spices. It were analyzed by measuring the reflectance. A hunter colour colorimeter at 65% 10º was used as the light source. The colorimeter was calibrated against standard white plate (L=91.78, a=-0.28, b=0.07) before the sample measurement. A glass cylinder containing spices powder was placed above the light source and covered with a lid. Three hunter parameters, namely L (lightness),a (redness/greenness),and b (yellowness/blueness) were measured(hunter,1987).

3.4.4.1 Total colour change

The total colour change is given by the colour difference (ΔEab^*) in terms of the spatial distance between two colour points inenterpreted in the colour space (Hunter,1987);

$$\Delta E= [(L_o-L_i)+(a_o-a_i)+(b_o-b_i)]^{1/2} \quad ……………………………………(3.7)$$

The subscript o and I denote the colour parameters of dried spice powder after grinding in the mill, respectively. The higher ΔE represents greater colour changes from the dried spice powder.

Plate 3.8 Hunter colour lab

3.4.4.2 Hue angle

The hue angle is defined as a colour wheel, with red-purple at the angle of 0º, yellow at 90º, and bluish-green at 180º and blue at 270º. It is given by the ratio a/b or by one of the angles

$\theta = \tan^{-1}(b/a)$ or $\theta = \tan^{-1}(a/b)$ ……………………….(3.8)

3.4.4.3 Chorma

The chroma represents colour saturation which varies from dull at low chroma values to vivid colour at high chroma values (Hunter,1987). Chroma is saturation given by the distance from the colour point C to the white point which is

$C^*_{ab} = (a^2+b^2)^{1/2}$ ……………………………………(3.9)

3.4.4.4 Browning index

Browning index (BI) represent on the purity of brown colour and is considered as an important parameter associated with browning.

$BI = \frac{[100(X-0.31)]}{0.17}$ …………………………………(3.10)

$X = \frac{(a+1.75L)}{(5.645+a-3.012b)}$ ………..…………………….(3.11)

3.5 Experimental Setup

3.5.1 Hammer mill (single stage and double stage)

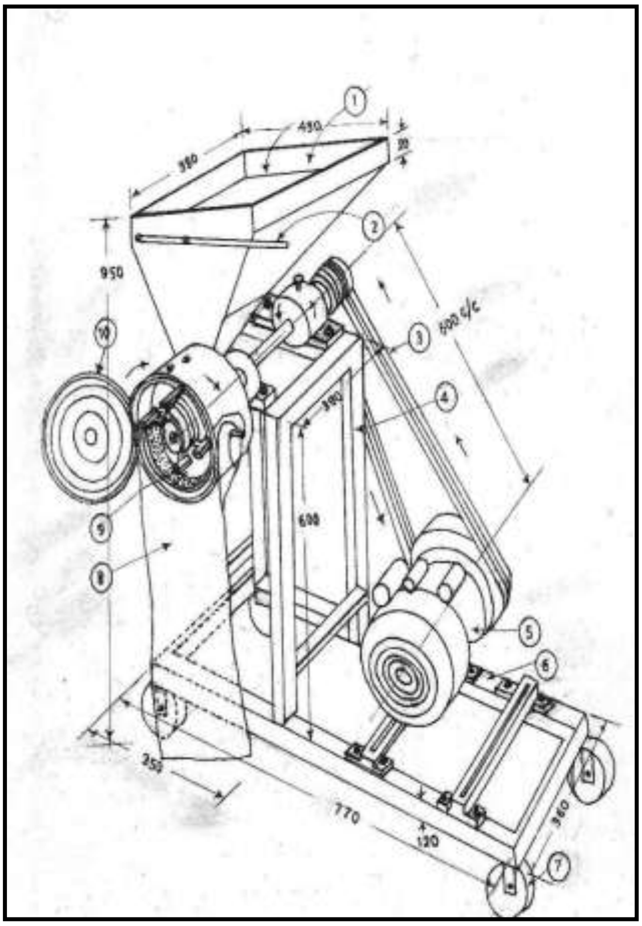
Hammer mills are used for various type of size reduction by impact forces, hammer mill operates on the principle that most of the material will grind or crush upon the impact of swinging hammer. These mills contain a high speed rotor, rotating inside a cylindrical casing thus shaft is usually kept horizontal. The material are fed into the mill from the top of the casing and is broken by the rotating hammer and fall out the screen at the bottom, The material or feed is broken by swinging (single stage) or fixed (double stage) hammers which are pinned to a rotor. The hammer are rotated at fixed 4540 rpm, strike and grind the material until it becomes small enough to pass through the bottom screen. The specification of single stage hammer mill and double stage hammer mill are given in (Table 3.7), and isometric view of single stage and double stage hammer mill show in Fig. 3.2 & 3.3 and plate 3.9 & 3.10.

Fineness of grinding is controlled by the sieve size. In Single stage hammer mill (SSG) the material pass through fine grinding stage directly, while in double stage hammer mill (DSG) material pass through a pre-crushing chamber where the materials undergoes a coarse grinding and then passes on to the fine powdering chamber.

Table 3.7 Specification of single stage and double stage hammer mill used for the preparation of spice powder.

Particular	**Single stage hammer mill**	**Double stage hammer mill**
Model No.	TW-488D	TW-84
Production capacity	20-25 kg/h	25-30 kg/h
Corse grinding chamber (width x diameter)	Not existed	10 cm x 25 cm
Fine grinding chamber (width x diameter)	10cm x 26 cm	14 cm x 30 cm
Number of hammer	4(swinging type)	4(fixed type)
Hammer size	7 cm x 2.5 cm x 2.5 cm	10 cm x 5 cm x 2.5 cm
Hammer diameter	7 cm	7.5 cm
Speed	4540 rpm	4540 rpm
Hopper size (length x width x depth)	45 cm x 38 cm x 20 cm	47 cm x 40 cm x 10 cm
Inclination angle	45º	10º
Sieve size (length x width)	30 cm x 8 cm	47.5 cm x 11 cm
Sieve perforation (mm)	0.188 mm	0.188 mm
Required motor	2 hp	Hp
Grinding speed(rpm)	1440	1440
Belt	B63 (V belt)	B73(V belt)
Total machine size	95 cm x 35 cm x 32 cm	100 cm x 48 cm x 40 cm
Foundation size	77cm x 36 cm x 12 cm	120 cm x 65 cm x 20 cm

Plate 3.9 Single stage hammer mill   **Plate 3.10 Double stage hammer mill**



S.No	Component
1	HOPPER
2	LEVER
3	BELT
4	FRAME
5	MOTER
6	FOUNDATION
7	WHEEL
8	CLOTH
9	GRINDING CHAMBER
10	COVER

Fig 3.2 Isometric view of single stage of hammer mill

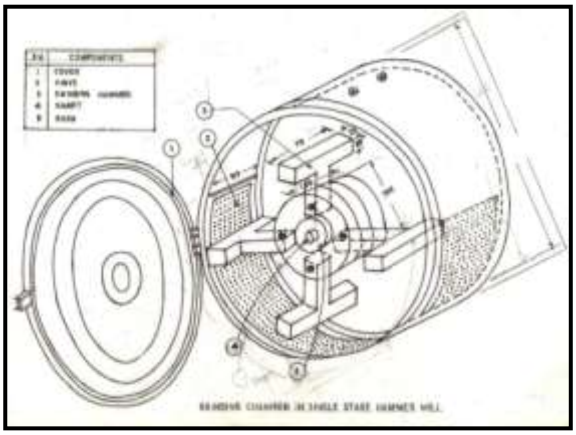
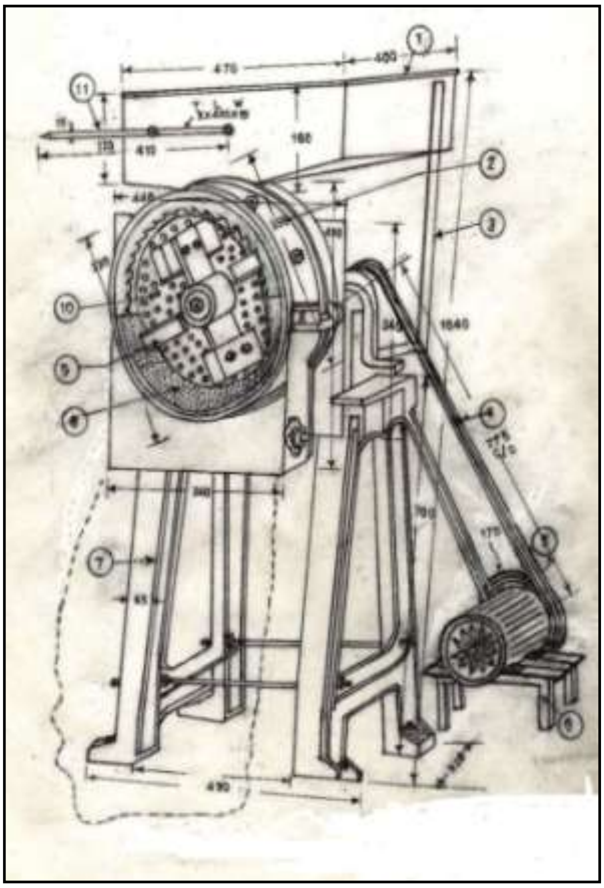


Fig 3.3 Grinding chamber of single stage hammer mill



S.No	Component
1	HOPPER
2	GRINDING CHAMBER
3	HOPPER FRAME
4	BELT
5	MOTER
6	FOUNDATION STAND
7	FRAME
8	SIEVE
9	FIXED CHAMBER
10	INNER SIEVE HOLES
11	LEVER

Fig 3.4 Isometric view of double stage hammer mill

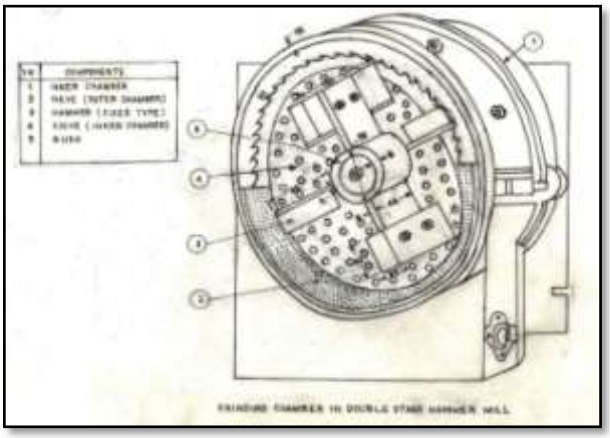


Fig 3.5 Grinding chamber of Double stage hammer mill

3.5.2 Sieve shaker

A set of sieves fitted on the sieve shaker consisted for sieves of ASTM mesh No. 100 (0.157 mm), 70 (0.211 mm), 50 (0.296 mm), 40 (0.420 mm)), 35 (0.500 mm), 25 (0.708 mm) and 20 (0.954 mm) with pan and cover was taken. These sieve-sets were placed in a mechanical sieve shaker. Powdered spices sample of 100 g was spread on the first top sieve of the sieve-set and the top lid was placed. The sieve shaker was operated for 5 minutes. The quantity retained on each sieve (W_i) was determined

Plate 3.11 sieve shaker

3.5.3 Hot air oven

Hot air ovens (Make - Labtech Instrument, Indore, M.P) was used to measure the moisture content of spices, which have the digital thermostat to control and measure the temperature and its operating temperature range between 50 to 300ºC.

3.5.4 Electronic weighing machine

Digital electronic weighing balance (Manufactured by-Citizen, Model No: CY-3600) with maximum- 360 g and minimum- 10 mg weighing capacity was used for weighing the spices for experiment. The least count of balance is 0.001 g.

3.5.5 Digital Vernier Caliper

The geometric dimensions of spices (mm) such as length, width, and thickness were measured by using a digital vernier caliper (Make – Workshop Innovation Ltd) with accuracy of 0.01 mm. The range is 1 to 150 mm.

3.5.6 Digital Tachometer

The speed of the hammer was measured by contact type digital tachometer (Make - Systems and Controls Bangalore, India). Operating range of digital tachometer is 30 to 5000 rpm.

3.5.7 Stopwatch

It was use for recording the duration of grinding of each Sample. The stopwatch has measuring range of 0-15 min and least count of 0.1 sec.

3.5.8 Digital Thermometer

A laboratory model of LCD portable digital multi thermometer (Model No-ST-9283A/B/C) was used to measure temperature of spices powder The thermometer had measuring range of 50 to 300 ºC and least count of 0.1ºC.

3.5.9 Clevenger's apparatus

The apparatus consists of a flask (shortneck, 1 or 2 L round-bottom) with an T.S.24/40 ground joint, an electric heating mantle or oil bath, variable voltage transformer to control heat, volatile oil traps, Clevenger with T.S. 24/40 ground joints, wet condenser, 400 mm length with drip tip and T.S. 24/40 ground joints Fig. 3.6 and Plate 3.12

Powder of spices (50 g) was weighed and transferred to a flask. About 500 ml of distilled water was added to the flask and antifoaming beads were also added. The flask was heated to boiling and maintained a reflux rate of 1 to 2 drops per second. Refluxing was continued until two consecutive readings taken at 1 hour interval, showed no change of oil volume in the trap. It was cooled to room temperature by immersing in a water bath. The volatile oil content (moisture free basis, ml/l00g) was calculated using the following equation (Eq. 3.12).

Volatile oil content

Volume of volatile oil x100/(Dry weight of sample) …………..(3.12)

where volume of volatile oil was measured in ml.

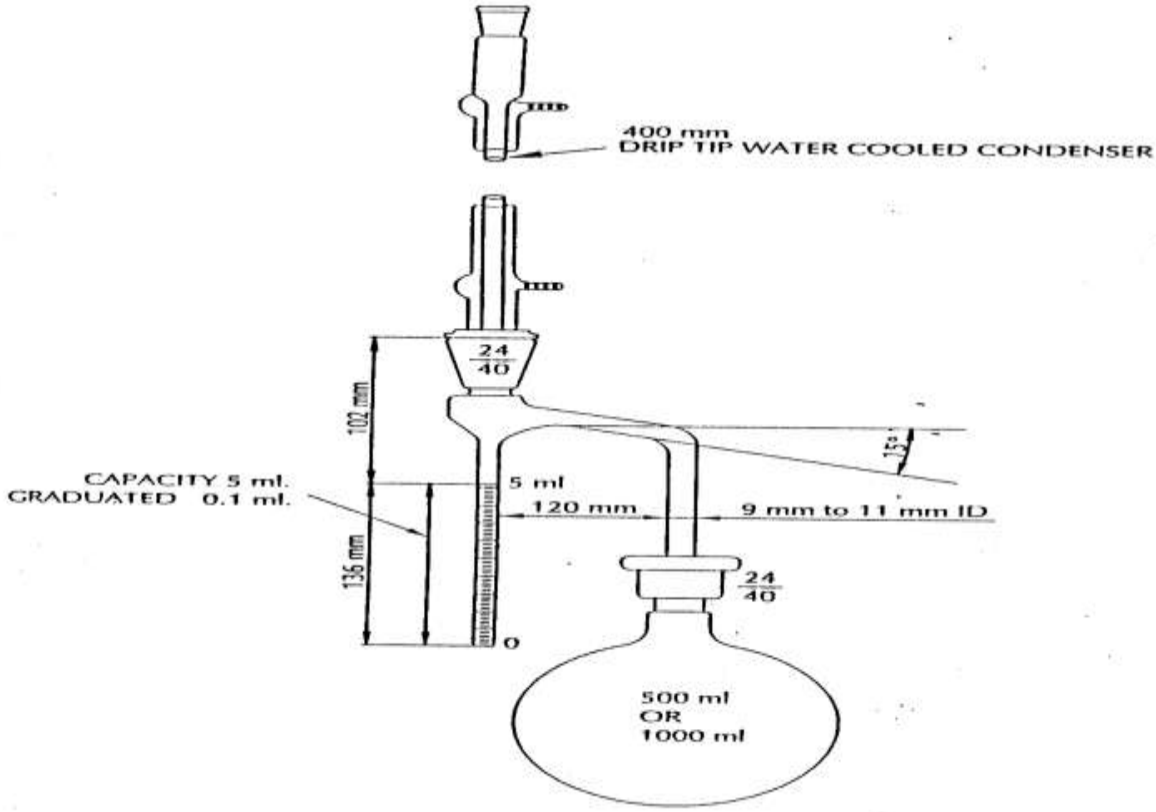


Fig 3.6 Clevenger's apparatus

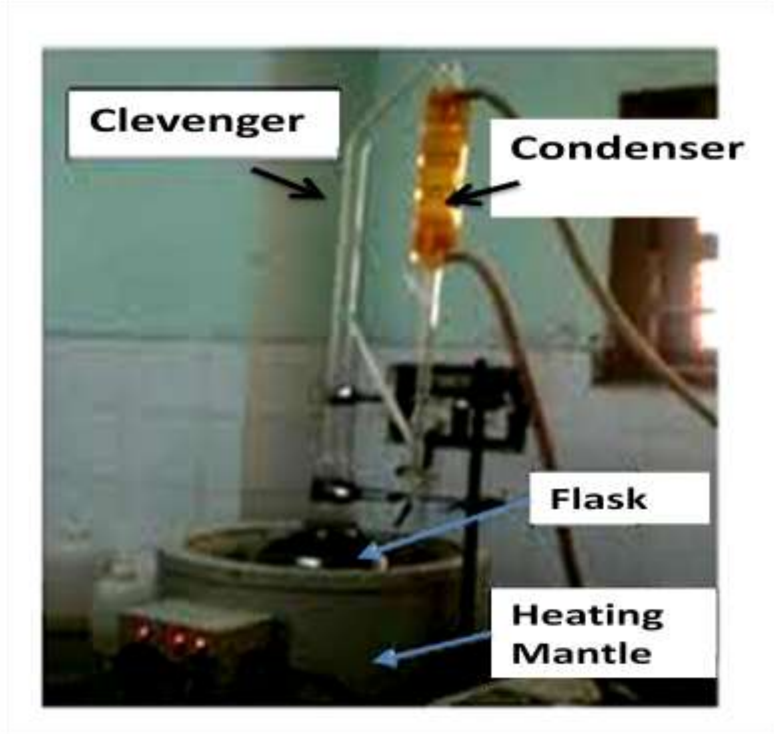


Plate 3.12 hydro distillation method

3.5.10 Other Miscellaneous Materials

a) Cloth sheet
b) Trays
c) Broom
d) Brush
e) Spanner sets

RESULTS AND DISCUSSION

Physical Characteristics of dried spices were measured by conducting various experiments. The effect of moisture content on dimension, bulk density, true density and dynamic angle of repose was studied at three moisture contents.

The grinding behavior of selected spices viz. red chilli, dry ginger, fenugreek seeds were studied in both single and double stage grinding in hammer mill under different operational condition. In both grinding process the speed of operation was fixed at 4540 rpm (784.05 m/sec). The feed rate at three levels spices are (red chilli - 6, 12, 18 kg/hr), (dry ginger - 5, 10 ,15 kg/hr) and (fenugreek seed- 12, 15, 18 kg/hr) and moisture content three levels (red chilli - 7, 9, 11 d.b%) ,(dry ginger - 7, 8, 9 d.b%) and (fenugreek seed- 7, 9, 11 d.b%) were selected for the present study. All the experiments were carried out with three replications. The observed output variables for the experiment were rise in temperature of spices powder during grinding, volatile oil content, fineness modulus, particle size and colour analysis. The cost economics of selected spices production was also studied for selected two methods of grinding. The results obtained are presented in following sections.

4.1 Physical Properties of spices

4.1.1 Physical Properties of red chilli

The average values of observed properties viz. length, width, thickness, bulk density, true density and angle of repose are presented in Table 4.1. The physical properties of red chilli are also presented in Appendix A-1 and A-2. The various dimensional parameters of red chill viz., length, width, thickness, were determine at three moisture levels i.e. 7, 9 and 11% (db). The average length of the red chilli was found to be 7.342, 7.663 and 7.986 mm at 7, 9 and 11 % moisture content (db), respectively. The average width of the red chilli, were found to be 1.573, 1.614 and 1.666 mm at 7, 9, 11 % moisture content (db), respectively. The average thickness of the red chilli was found to be 0.22, 0.24 and 0.26 mm at 7, 9 and 11 % moisture content (db), respectively.

The average values of bulk density of red chilli,were found to be 235, 249 and 259 kg/m^3 at 7, 9 and 11 % moisture content (db), respectively. However, average values of true density of red chilli were 989, 999 and 1099 kg/m^3 at 7, 9 and 11% moisture content (db), respectively. Dynamic angle of repose of red chilli was found to be 40.81°, 42.95° and 44.5° at 7, 9 and 11% moisture content (db), respectively. The dynamic angle of repose increased linearly with the increment in the moisture content of red chilli. Similar trends have been reported by Gajbe, Choudhary (2012).

Table 4.1 Physical properties of red chilli at different moisture content

Physical properties	**Moisture content (db %)**					
	7%		**9%**		**11%**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Length(mm)	7.342	0.722	7.663	0.770	7.986	0.761
Width(mm)	1.573	0.171	1.614	0.177	1.666	0.175
Thickness(mm)	0.220	0.056	0.24	0.056	0.266	0.052
Bulk density(kg/m^3)	235	3.162	249	6.053	259	6.053
True density(kg/m^3)	989	6.053	999	6.053	1099	6.053
Dynamic angle of repose(°)	40.814	1.196	42.95	0.552	44.5	0.701

4.1.2 Physical Properties of dry ginger

The average values of properties viz. length, width, thickness, bulk density, true density and angle of repose are presented in Table 4.2. The physical properties of dry ginger are also presented in Appendix A-3 and A-4. The various dimensional parameters of dry ginger viz., length, width, thickness, were determine at three moisture levels i.e. 7, 9 and 11%(db). The average length of the dry ginger was found to be 5.441, 5.467 and 5.498 mm at 7, 8 and 9% moisture content (db), respectively. The average width of the dry ginger were found to be 1.729, 1.754 and 1.781 mm at 7, 8, 9% moisture content (db), respectively. The average thickness of the dry ginger was found to be 1.067, 1.094 and 1.125 mm at 7, 8and 9% moisture content (db), respectively.

Dynamic angle of repose of dry ginger was found to be 46.20º, 48.39º and 50.23º at 7, 8 and 9% moisture content (db), respectively. The angle of repose increased linearly with the increment in the moisture content of dry ginger. Similar trends have been reported by Gajbe, Choudhary (2012).

Table 4.2 Physical properties of dry ginger at different moisture contents

Physical properties	**Moisture content (db %)**					
	7%		**8%**		**9%**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Length(mm)	5.441	0.983	5.467	0.977	5.498	0.982
Width(mm)	1.729	0.322	1.754	0.326	1.781	0.321
Thickness(mm)	1.067	0.218	1.094	0.213	1.125	0.214
Dynamic angle of repose(°)	46.20º	0.24º	48.39º	0.27º	50.23º	0.30º

4.1.3 Physical Properties of fenugreek seed

The average values of observed physical properties viz. length, width, thickness, bulk density, true density and angle of repose are presented in Table 4.3. The physical properties of fenugreek seeds are also presented in Appendix A-5 and A-6. The various dimensional parameters of fenugreek seed viz. length, width, thickness, were determine at three moisture levels i.e. 7, 9 and 11% (db). The average length of the fenugreek seeds was found to be 3.941, 4.054 and 4.113 mm at 7, 9 and 11% moisture content (db), respectively. The average width of the fenugreek seeds were found to be 2.198, 2.316 and 2.538 mm at 7, 9, 11% moisture content (db), respectively. The average thickness of the fenugreek seeds was found to be 1.672, 1.705 and 1.748 mm and at 7, 9 and 11% moisture content (db), respectively.

The average values of bulk density of fenugreek seeds were found to be 691.9, 657 and 641.9kg/m^3 7, 9 and 11% moisture content (db), respectively. However, average values of true density of fenugreek seeds were 1188.9, 1165.8 and 1147.5 kg/m^3 at 7, 9 and 11% moisture content (db), respectively. Dynamic angle of repose of fenugreek seeds was found to be

14.27º, 15.44º and 16.42º at 7, 9 and 11% moisture content (db), respectively. The angle of repose increased linearly with the increment in the moisture content of fenugreek seeds. Similar trends have been reported by Gajbe, Choudhary (2012).

Table 4.3 Physical properties of fenugreek at different moisture content

Physical properties	**Moisture content (db %)**					
	7%		**9%**		**11%**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Length(mm)	3.941	0.101	4.054	0.067	4.113	0.013
Width(mm)	2.198	0.025	2.316	0.029	2.538	0.051
Thickness(mm)	1.672	0.018	1.705	0.004	1.748	0.013
Bulk density (kg/m^3)	691.9	5.781	657	3.49	641.9	2.514
True density (kg/m^3)	1188.9	6.065	1165.8	4.775	1147.5	5.406
Dynamic angle of repose(°)	14.27º	0.041	15.44º	0.024	16.42º	0.045

4.2 Effect of process variables on grinding characteristics of spices powder

The objective of this experiment was to study the effect of feed rate and moisture content of the spices on temperature rise during grinding, particle size and fineness modulus of spices powder by using single and double stage grinding.

4.2.1 Effect of moisture content and feed rate on temperature rise of spices powder using single stage grinding and double stage grinding

Temperature of spices powder was recorded just after milling by using a digital thermometer. The rise of temperature of spices powder during grinding indicates the conversion of mechanical (frictional) energy into thermal energy which affects the quality the ground product. Initial temperature before grinding was 30°C. Temperature rise with respect to change in moisture content and feed rate of spices during single and double stage grinding are discussed in the following sections.

4.2.1.1 Effect of moisture content and feed rate on temperature rise of red chilli powder using single stage grinding and double stage grinding

In single stage grinding the effect of feed rate and moisture content of red chilli on the temperature rise of the red chilli powder was observed and is presented in Table 4.4. The average rise in temperature of red chilli powder during single stage grinding ranged from 38 to 46°C. Minimum temperature (38°C) was observed at 6 kg/h feed rate and 7% moisture content and maximum temperature (46°C) was observed at 18 kg/h feed rate and 11 % moisture content. It was also observed that there was a gradual increment in temperature during milling with increment in the feed rate irrespective of the moisture content of the red chilli. eg. at 9 % m.c. The temp rise was 40°C at 6 kg/hr feed rate and it increased to 44°C at 18 kg/hr feed rate.

The average rise in temperature of red chilli powder during double stage grinding ranged from 34 to 42°C. Minimum temperature (34°C) was observed at 6 kg/h feed rate and 7% moisture content and maximum temperature (42°C) was observed at 18 Kg/h feed rate and 11% moisture content Table 4.4. In this case also, there was a gradual increment in temperature during milling with increment in the feed rate irrespective of the moisture content of the red chilli.

Table 4.4 Effect of moisture content and feed rate on temperature rise of red chiili powder using Single stage grinding and double stage grinding

S.No	Grinding method	Spices	Feed rate (kg/hr)	Temperature(^oc)		
				Moisture content % (db)		
				7%	9%	11%
1	Single stage hammer mill	Red chilli	6	38	40	42
			12	40	42	44
			18	42	44	46
2	Double stage hammer mill	Red chilli	6	34	36	38
			12	36	38	40
			18	38	40	42

Amongst the two selected methods of grinding single stage grinding of red chilli exhibited the higher temperature rise compared with double stage grinding for selected combination of feed rate and moisture content. e.g. at 6 kg/h feed rate and red chilli with 7% moisture content the temperature rise were observed 38 ºC and 34 °C for single stage and double stage grinding, respectively. Similarly, the temperature rise were 46 and 42°C at 18 kg/h feed rate and red chilli with 11% moisture content for single stage and double stage grinding, respectively. The probable reason for this trend may be the lesser amount of air circulation in single stage hammer mill as compared with the double stage hammer mill. In double stage hammer mill red chilli pass through the pre milling chamber to the final stage grinding chamber. The coarse milled red chilli powder releases some amount of heat energy to the environment during the passage to the final milling chamber there by giving low temperature rise (Fig. 4.1) Among the three selected moisture content of red chilli 7% m.c. gave lesser temperature rise both in single stage and double stage grinding.

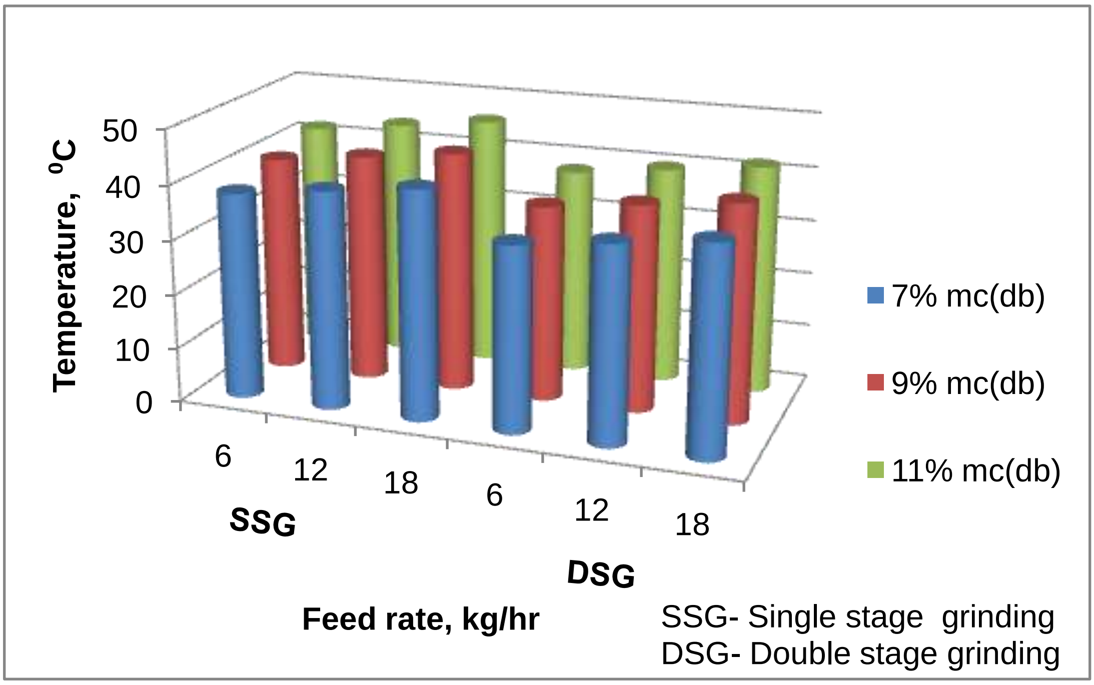


Fig.4.1 Effect of moisture content and feed rate on temperature rise during single stage and double stage grinding of red chilli.

The result of analysis of variance (ANOVA) for factorial CRD design was fitted which shows the moisture content as well as feed rate have significant effect on rise in temperature of red chilli powder during single stage and double stage hammer mill. (Appendix Table B-1a, 1b)

4.2.1.2 Effect of moisture content and feed rate on temperature rise of dry ginger powder using Single stage grinding and double stage grinding

The average rise in temperature of dry ginger powder during single stage grinding ranged from 44 to 52 °C. Minimum temperature (44°C) was observed at 5 kg/h feed rate and 7% moisture content and maximum temperature (52°C) was observed at 15 kg/h feed rate and 9% moisture content. There was a gradual increment in temperature during milling with increment in the feed rate irrespective of the moisture content of the dry ginger.

The average rise in temperature of dry ginger powder during double stage grinding ranged from 38 to 47.33 °C. Minimum temperature (38°C) was observed at 5 kg/h feed rate and 7% moisture content and maximum temperature (47.33°C) was observed at 15 Kg/h feed rate and 9% moisture content Table 4.5. In this case also, there was a gradual increment in temperature during milling with increment in the feed rate irrespective of the moisture content of the dry ginger.

Table 4.5 Effect of moisture content and feed rate on temperature rise of dry ginger powder using Single stage grinding and double stage grinding

S.No	Grinding method	Spices	Feed rate (kg/hr)	Temperature(^{o}c)		
				Moisture content % (db)		
				7%	8%	9%
1	Single stage hammer mill	Dry ginger	5	44	46	48
			10	46	48	50
			15	48	50	52
2	Double stage hammer mill	Dry ginger	5	38	40	42
			10	40	42	44
			15	43	45.33	47.33

Single stage grinding of dry ginger exhibited the higher temperature rise as compared with double stage grinding for selected combination of feed rate and moisture content e.g. at 10 kg/h feed rate and dry ginger with 7% moisture content the temperature rise were observed 46^{o}C and 40°C for single stage and double stage grinding, respectively. Similarly, the temperature rise were 52 and 47.33 °C at 15 kg/h feed rate and dry ginger with 9 % moisture content for single stage and double stage grinding, respectively.

Among the three selected moisture content of dry ginger 7% m.c. gave lesser temperature rise both in single stage and double stage grinding (Fig 4.2).

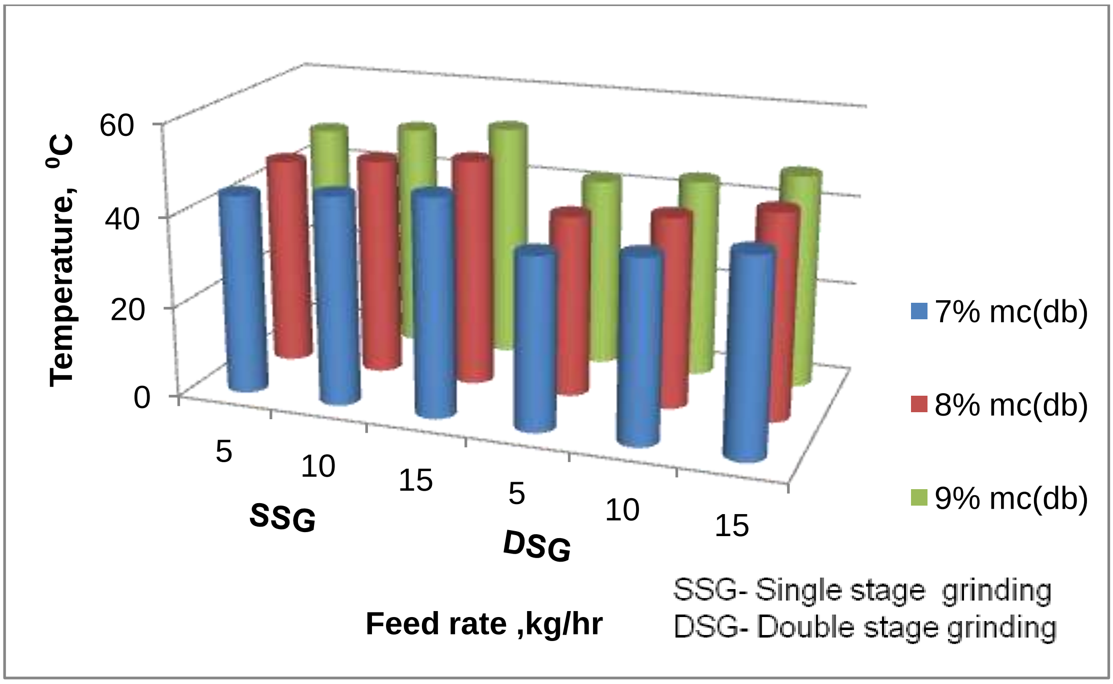


Fig.4.2 Effect of moisture content and feed rate on temperature rise using single stage and double stage grinding dry ginger

The result of analysis of variance (ANOVA) for factorial CRD Design was fitted which shows the moisture content as well as feed rate have significant effect on rise in temperature of Dry ginger powder during single stage and double stage hammer mill. (Appendix Table C-1a, 1b)

4.2.1.3 Effect of moisture content and feed rate on temperature rise of fenugreek powder using single stage grinding and double stage grinding

The average rise in temperature of fenugreek powder during single stage grinding ranged from 42 to 50°C. Minimum temperature (42°C) was observed at 12 kg/h feed rate and 7% moisture content and maximum temperature (50°C) was observed at 18 kg/h feed rate and 11% moisture content. It was also observed that there was a gradual increment in temperature during milling with increment in the feed rate irrespective of the moisture content of the fenugreek seed.

The average rise in temperature of fenugreek powder during double stage grinding ranged from 35 to 46°C. Minimum temperature (35°C) was observed at 12 kg/h feed rate and 7% moisture content and maximum temperature (46°C) was observed at 18 Kg/h feed rate and 11% moisture content Table 4.6. There was a gradual increment in temperature during milling with increment in the feed rate irrespective of the moisture content of the fenugreek seeds. It can also be observed that at the same feed rate temp rise during milling increases with increase in m.c. of the feed.

Table 4.6 Effect of moisture content and feed rate on temperature rise of fenugreek powder using single stage grinding and double stage grinding

S.No	Grinding method	Spices	Feed rate (kg/hr)	Temperature(^{o}c)		
				Moisture content % (db)		
				7%	9%	11%
1	Single stage hammer mill	Fenugreek seed	12	42	44	46
			15	44	46	48
			18	46	48	50
2	Double stage hammer mill	Fenugreek seed	12	35	38	42.33
			15	37.33	40	44
			18	39.33	42	46

Single stage grinding of fenugreek seeds exhibited the higher temperature rise compared with double stage grinding for selected combination of feed rate and moisture content. e.g. at 12 kg/h feed rate and fenugreek seeds with

7% moisture content the temperature rise were observed 42 ºC and 35°C for single stage and double stage grinding, respectively. Similarly, the temperature rise were 50 and 46°C at 18 kg/h feed rate and fenugreek seed with 11% moisture content for single stage and double stage grinding, respectively (Fig. 4.3).

Among the three selected moisture content of fenugreek seeds 7% m.c. gave lesser temperature rise both in single stage and double stage grinding.

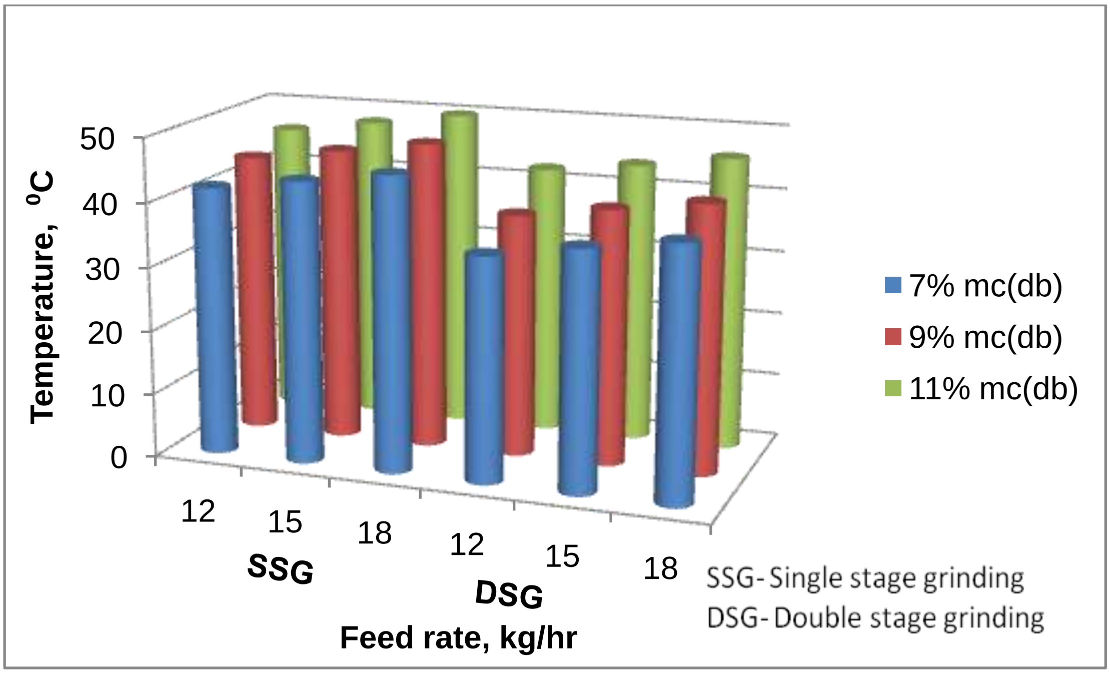


Fig.4.3 Effect of moisture content and feed rate on temperature rise during single stage and double stage grinding fenugreek seed

The result of analysis of variance (ANOVA) for factorial CRD Design was fitted which shows the moisture content as well as feed rate have significant effect on rise in temperature of fenugreek powder during single stage and double stage hammer mill. (Appendix Table D-1a, 1b)

4.2.2 Effect of moisture content and feed rate on fineness modulus of spices powder using single stage grinding and double stage grinding

Fineness modulus, an indicator of uniformity of grinding, was calculated to measure the effect of single stage grinding and double stage grinding on grinding characteristics and average particle size of spices powder. The fineness modulus was calculated by using sieve analysis as recommended by Singh and Sahay (1999).

4.2.2.1 Effect of moisture content and feed rate on fineness modulus of red chilli powder using single stage grinding and double stage grinding

In single stage hammer mill, when red chilli are fed into the grinding chamber the red chill are subjected to high energy impact of hammers rotating at high rotational speed. Inside the grinding chamber due to repeated high energy impact the red chilli strike with inner surface of the chamber and are reduced to finer size particles. As soon as dimension of particles reduces to dimension less than that of screen opening, the smaller particle pass though the screen and are collected in a receiving container placed below the screen. Fineness of the grinding is controlled by the sieve size. From Table 4.7, it is clear that the fineness modulus of ground sample increased with increment in the feed rate and moisture content of the red chilli. The maximum value of fineness modulus (2.39) was observed with red chilli having 11% moisture content (db) and 18 kg/h feed rate. The minimum value of fineness modulus (2.30) was observed with red chilli having 7% moisture content (db) and 6 kg/h feed rate. At a constant feed rate the fineness modulus of the ground sample increased progressively with increment in the moisture content of the sample.

A double stage hammer is provided with a pre-crushing chamber where the material undergoes of coarse grinding and then it passes to the fine grinding chamber. A double stage grinder does not have any separate joints between outlet and crushing chamber. So it provides very fine ground product of red chilli sample. The fineness modulus of ground sample increased with increment in the feed rate and moisture content of the red chilli. The maximum value of fineness modulus (2.336) was observed with red chilli having 11% moisture content (db) and 18 kg/h feed rate. The minimum value of fineness modulus (2.24) was observed with red chilli having 7% moisture content (db) and 6 kg/h feed rate Table 4.7. At a constant feed rate the fineness modulus of the ground sample increased progressively with increment in the moisture content of the sample.

Table 4.7 Effect of moisture content and feed rate on fineness modulus of red chilli powder using Single stage and double stage grinding

S.No	Grinding method	Spices	Feed rate (kg/hr)	fineness modulus mm		
				Moisture content % (db)		
				7%	9%	11%
1	Single stage hammer mill	Red chilli	6	2.30	2.323	2.346
			12	2.323	2.346	2.37
			18	2.346	2.37	2.39
2	Double stage hammer mill	Red chilli	6	2.24	2.263	2.286
			12	2.263	2.286	2.313
			18	2.286	2.313	2.336

Fineness modulus indicates the uniformity of grinding in resultant product. The fineness modulus of the ground sample increases with increases in the feed rate and moisture content of the sample in both single and double stage grinding. From Fig. 4.4, it is clear that at a particular combination of the feed rate and m.c the values of fineness modulus were higher during single stage grinding compared with the double stage grinding. Maximum values of fineness modulus 2.39 and 2.336 were observed during single stage and double stage grinding of the red chilli having 11% moisture content (db) and fed at a rate of 18 kg/h. However, minimum values of fineness modulus viz2.30 and 2.24 were observed at 6 kg/h feed rate and 7% moisture content (db) during single stage and double stage grinding, respectively

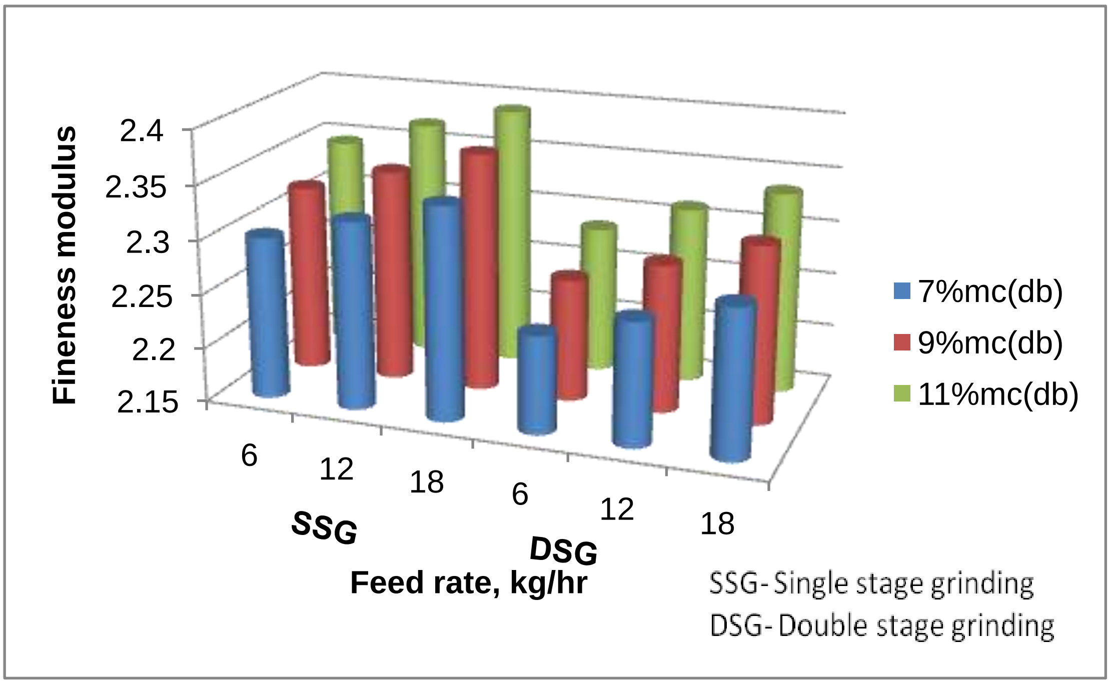


Fig.4.4 Effect of moisture content and feed rate on fineness modulus during single stage and double stage grinding of red chilli

The result of analysis of variance (ANOVA) for factorial CRD Design was fitted which shows the moisture content as well as feed rate have significant effect on rise in fineness modulus of red chilli powder during single stage and double stage hammer mill. (Appendix Table B-2a, 2b)

4.2.2.2 Effect of moisture content and feed rate on fineness modulus of dry ginger powder using single stage grinding and double stage grinding

It is clear from Table 4.8, that the fineness modulus of ground sample increased with increment in the feed rate and moisture content of the dry ginger in single stage hammer mill. The maximum value of fineness modulus (1.48) was observed with dry ginger having 9% moisture content (db) and 15 kg/h feed rate. The minimum value of fineness modulus (1.40) was observed with dry ginger having 7% moisture content (db) and 5 kg/h feed rate. At a constant feed rate the fineness modulus of the ground sample increased progressively with increment in the moisture content of the sample respectively.

The maximum value of fineness modulus (1.43) was observed with dry ginger having 9% moisture content (db) and 15 kg/h feed rate. The minimum value of fineness modulus (1.35) was observed with dry ginger having 7% moisture content (db) and 5 kg/h feed rate in double stage hammer mill (Table 4.8). At a constant feed rate the fineness modulus of the ground sample increased progressively with increment in the moisture content of the sample.

Table 4.8 Effect of moisture content and feed rate on fineness modulus of dry ginger powder using single stage grinding and double stage grinding.

S.No	Grinding method	Spices	Feed rate (kg/hr)	fineness modulus mm		
				Moisture content % (db)		
				7%	8%	9%
1	Single stage hammer mill	Dry ginger	5	1.40	1.42	1.44
			10	1.42	1.44	1.46
			15	1.44	1.46	1.48
2	Double stage hammer mill	Dry ginger	5	1.35	1.37	1.39
			10	1.37	1.39	1.41
			15	1.39	1.41	1.43

The fineness modulus of the ground sample increases with increases in the feed rate and moisture content of the sample in both single and double stage grinding. From Fig. 4.5, it is clear that at a particular combination of the feed rate and m.c the values of fineness modulus were higher during single stage grinding compared with the double stage grinding. Maximum values of fineness modulus 1.48 and 1.43 were observed during single stage and double stage grinding of the dry ginger having 9% moisture content (db) and fed at a rate of 15 kg/h. However, minimum values of fineness modulus viz 1.40 and 1.35 were observed at 5 kg/h feed rate and 7% moisture content (db) during single stage and double stage grinding, respectively.

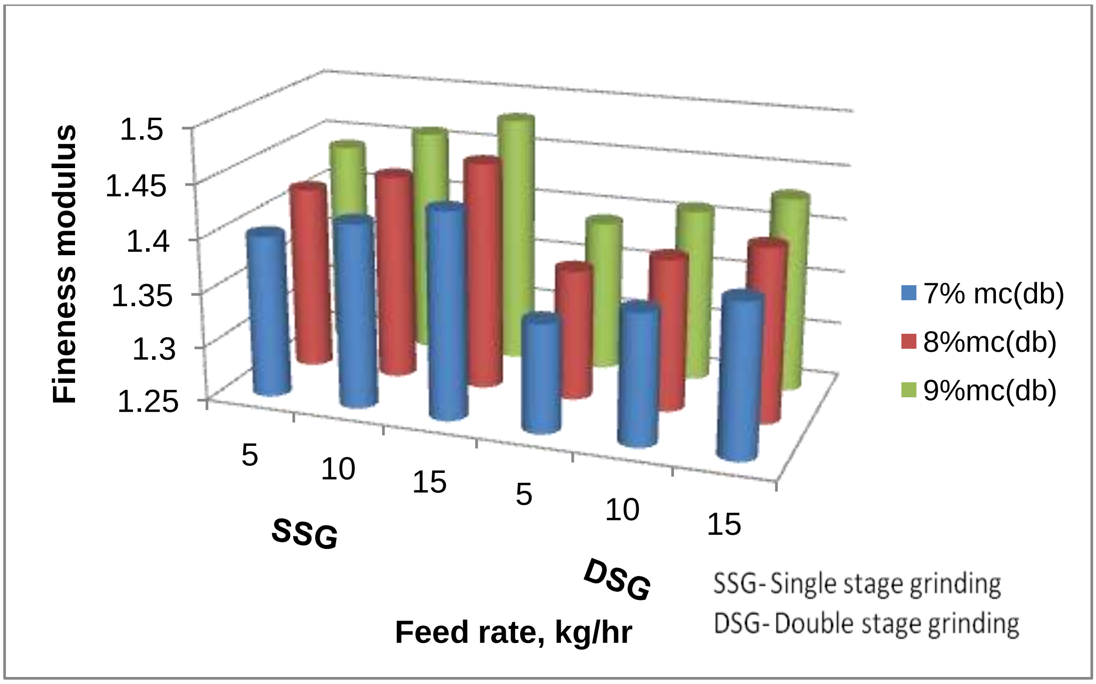


Fig 4.5 Effect of moisture content and feed rate on fineness modulus using single stage grinding and double stage grinding of dry ginger powder.

The result of analysis of variance (ANOVA) for factorial CRD Design was fitted which shows the moisture content as well as feed rate have a significant effect on rise in fineness modulus of dry ginger powder during single stage and double stage hammer mill. (Appendix Table C-2a, 2b)

4.2.2.3 Effect of moisture content and feed rate on fineness modulus of fenugreek seed using single stage grinding and double stage grinding

Table 4.9 reveals that the fineness modulus of ground sample increased with increment in the feed rate and moisture content of the fenugreek seed. The maximum value of fineness modulus (3.373) was observed with fenugreek seed having 11% moisture content (db) and 18 kg/h feed rate. The minimum value of fineness modulus (3.30) was observed with dry ginger having 7% moisture content (db) and 12 kg/h feed rate. At a constant feed rate the fineness modulus of the ground sample increased progressively with increment in the moisture content of the sample respectively.

The maximum value of fineness modulus (3.096) was observed with fenugreek seed having 11% moisture content (db) and 18 kg/h feed rate. The minimum value of fineness modulus (3.02) was observed with fenugreek seed having 7% moisture content (db) and 12 kg/h feed rate (Table 4.9). At a constant feed rate the fineness modulus of the ground sample increased progressively with increment in the moisture content of the sample.

Table 4.9 Effect of moisture content and feed rate on fineness modulus of fenugreek seed powder using Single stage grinding and double stage grinding

S.No	Grinding method	Spices	Feed rate (kg/hr)	fineness modulus mm		
				Moisture content % (db)		
				7%	9%	11%
1	Single stage hammer mill	fenugreek seed	12	3.30	3.32	3.34
			15	3.32	3.34	3.356
			18	3.34	3.356	3.373
2	Double stage hammer mill	fenugreek seed	12	3.02	3.04	3.06
			15	3.04	3.06	3.08
			18	3.06	3.08	3.096

The fineness modulus of the ground sample increases with increases in the feed rate and moisture content of the sample in both single and double stage grinding. From Fig. 4.6, it is clear that at a particular combination of the feed rate and m.c. the values of fineness modulus were higher during single stage grinding compared with the double stage grinding. Maximum values of fineness modulus 3.373 and 3.096 were observed during single stage and double stage grinding of the fenugreek having 11% moisture content (db) and fed at a rate of 18 kg/h. However, minimum values of fineness modulus viz 3.30 and 3.02 were observed at 12 kg/h feed rate and 7% moisture content (db) during single stage and double stage grinding, respectively.

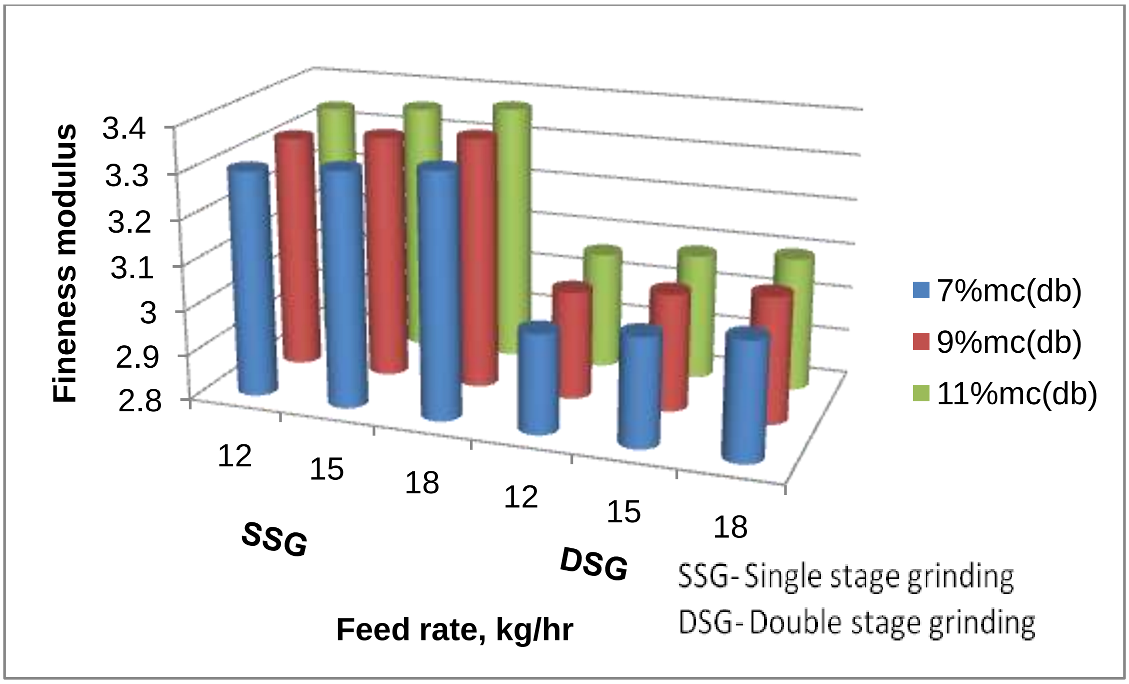


Fig 4.6 Effect of moisture content and feed rate on fineness modulus using single stage grinding and double stage grinding of fenugreek seed powder

The result of analysis of variance (ANOVA) for factorial CRD Design was fitted which shows the moisture content as well as feed rate have significant effect on rise in fineness modulus of fenugreek powder during single stage and double stage hammer mill. (Appendix Table D-2a, 2b)

4.2.3 Effect of moisture content and feed rate on particle size of spices powder during single stage grinding and double stage grinding

The particle size of the ground material affects the consumer acceptability and, hence is an important quality attribute. The particle size of powder was determined by 'sieve analysis technique as suggested by Singh and Sahay (1999). Fine particle size could be achieved with low feed rate because of longer residence time of the sample inside the grinding system

4.2.3.1 Effect of moisture content and feed rate on particle size of red chilli powder during single stage grinding and double stage grinding

It is clear from Table 4.10., that the particle size of ground sample increased with increment in the feed rate and moisture content of the red chilli. The maximum value of particle size (0.285 mm) was observed with red chilli having 11% moisture content (db) and 18 kg/h feed rate. The minimum value of particle size (0.277 mm) was observed with red chilli having 7% moisture content (db) and 6 kg/h feed rate. Table 4.10, At a constant feed rate the fineness modulus of the ground sample increased progressively with increment in the moisture content of the sample. It was also observed that there was a progressive increment in the particle size of the ground red chilli with increment in feed rate at constant moisture content.

In a double stage hammer mill. The particle size of ground sample increased with increment in the feed rate and moisture content of the red chilli. The maximum value of particle size (0.280 mm) was observed with red chilli having 11% moisture content (db) and 18kg/h feed rate. The minimum value of particle size (0.272 mm) was observed with red chilli having 7% moisture content (db) and 6 kg/h feed rate Table 4.10.

Table 4.10 Effect of moisture content and feed rate on particle size (mm) red chilli powder using single stage grinding and double stage grinding

S.No	Grinding method	Spices	Feed rate (kg/hr)	Particle size (mm)		
				Moisture content % (db)		
				7%	9%	11%
1	Single stage hammer mill	Red chilli	6	0.277	0.279	0.281
			12	0.279	0.281	0.283
			18	0.281	0.283	0.285
2	Double stage hammer mill	Red chilli	6	0.272	0.274	0.276
			12	0.274	0.276	0.278
			18	0.276	0.278	0.280

The particle size of the ground sample increases with increases in the feed rate and moisture content of the sample in both single and double stage grinding. From Fig. 4.7, it is clear that at a particular combination of the feed rate and m.c the values of particle size were higher during single stage grinding compared with the double stage grinding. Maximum values of particle size 0.285 and 0.280 mm were observed during single stage and double stage grinding of the red chilli having 11% moisture content (db) and fed at a rate of 18 kg/h. However, minimum values of particle size viz 0.277 and 0.272 mm were observed at 6 kg/h feed rate and 7% moisture content (db) during single stage and double stage grinding, respectively. Double stage hammer mill is provided with a pre-crushing chamber where the material undergoes a coarse grinding and passes on to fine powdering stage so double stage grinding produces finer particle sizes as compared to the single stage grinding.

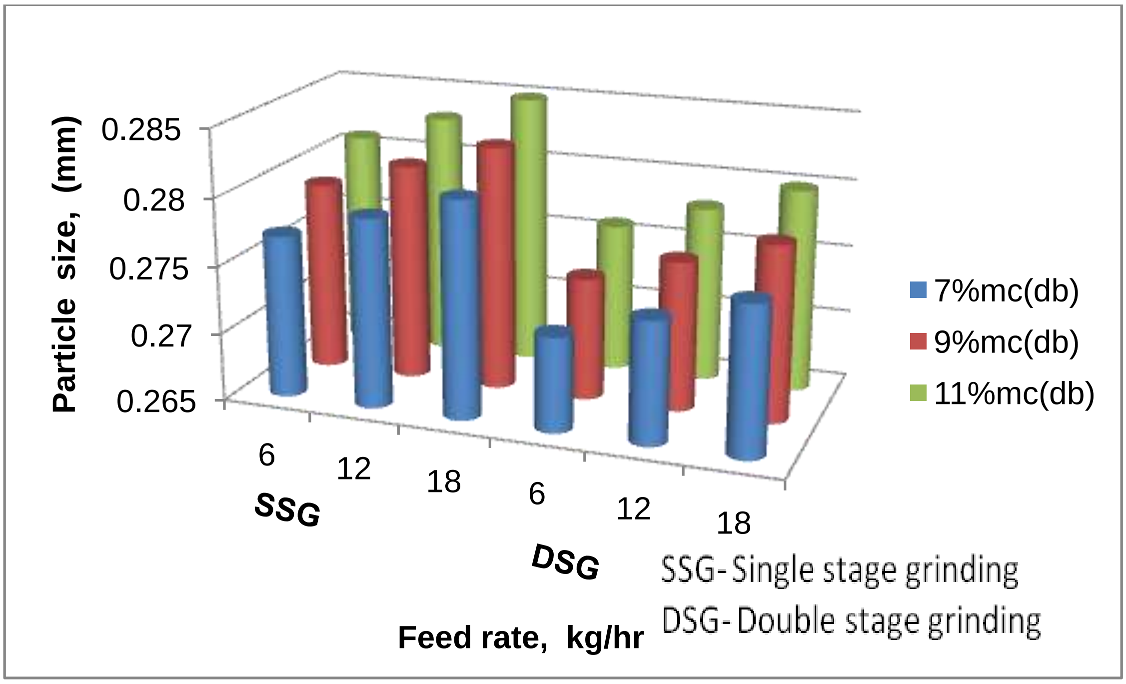


Fig 4.7 Effect of moisture content and feed rate on particle size (mm) red chilli powder using single stage grinding and double stage grinding

The result of analysis of variance (ANOVA) for factorial CRD Design was fitted which shows the moisture content as well as feed rate have significant effect on rise in particle size of red chilli powder during single stage and double stage hammer mill. (Appendix Table B-3a, 3b)

4.2.3.2 Effect of moisture content and feed rate on particle size of dry ginger powder during single stage grinding and double stage grinding

It is clear from Table 4.11., that the particle size of ground sample increased with increment in the feed rate and moisture content of the dry ginger. The maximum value of particle size (0.2141 mm) was observed with dry ginger having 9% moisture content (db) and 15 kg/h feed rate. The minimum value of particle size (0.2089 mm) was observed with dry ginger having 7% moisture content (db) and 5 kg/h feed rate. At a constant feed rate the fineness modulus of the ground sample increased progressively with increment in the moisture content of the sample. From Fig.4.8 it was also observed that there was a progressive increment in the particle size of the ground dry ginger with increment in feed rate and moisture content.

In a double stage hammer mill. The particle size of ground sample increased with increment in the feed rate and moisture content of the dry ginger. The maximum value of particle size (0.2108 mm) was observed with dry ginger having 9% moisture content (db) and 15 kg/h feed rate. The minimum value of particle size (0.2056 mm) was observed with dry ginger having 7% moisture content (db) and 5 kg/h feed rate (Table 4.11). At a constant feed rate the particle size of the ground sample increased progressively with increment in the moisture content of the sample. From Fig.4.8, it was also observed that at a constant m.c. the particle size of the ground dry ginger increased progressively with increment in feed rate.

Table 4.11 Effect of moisture content and feed rate on particle size (mm) ginger powder using single stage grinding and double stage grinding

S.no	Grinding method	Spices	Feed rate (kg/hr)	Particle size (mm)		
				Moisture content % (db)		
				7%	8%	9%
1	Single stage hammer mill	Dry ginger	5	0.2089	0.2102	0.2115
			10	0.2102	0.2115	0.2128
			15	0.2115	0.2128	0.2141
2	Double stage hammer mill	Dry ginger	5	0.2056	0.2069	0.2082
			10	0.2069	0.2082	0.2095
			15	0.2082	0.2095	0.2108

The particle size of the ground sample increases with increases in the feed rate and moisture content of the sample in both single and double stage grinding. From Fig. 4.8, it is clear that at a particular combination of the feed rate and m.c the values of particle size were higher during single stage grinding compared with the double stage grinding. Maximum values of particle size 0.2141 and 0.2108 mm were observed during single stage and double stage grinding of the dry ginger having 9% moisture content (db) and fed at a rate of 15 kg/h. However, minimum values of particle size viz 0.2089 and 0.2056 mm were observed at 5 kg/h feed rate and 7% moisture content (db) during single stage and double stage grinding, respectively. Double stage hammer mill it provided with a pre-crushing chamber where the material undergoes a coarse grinding and passes on to fine powdering stage so double stage grinding produces finer particle sizes as compared to the single stage grinding.

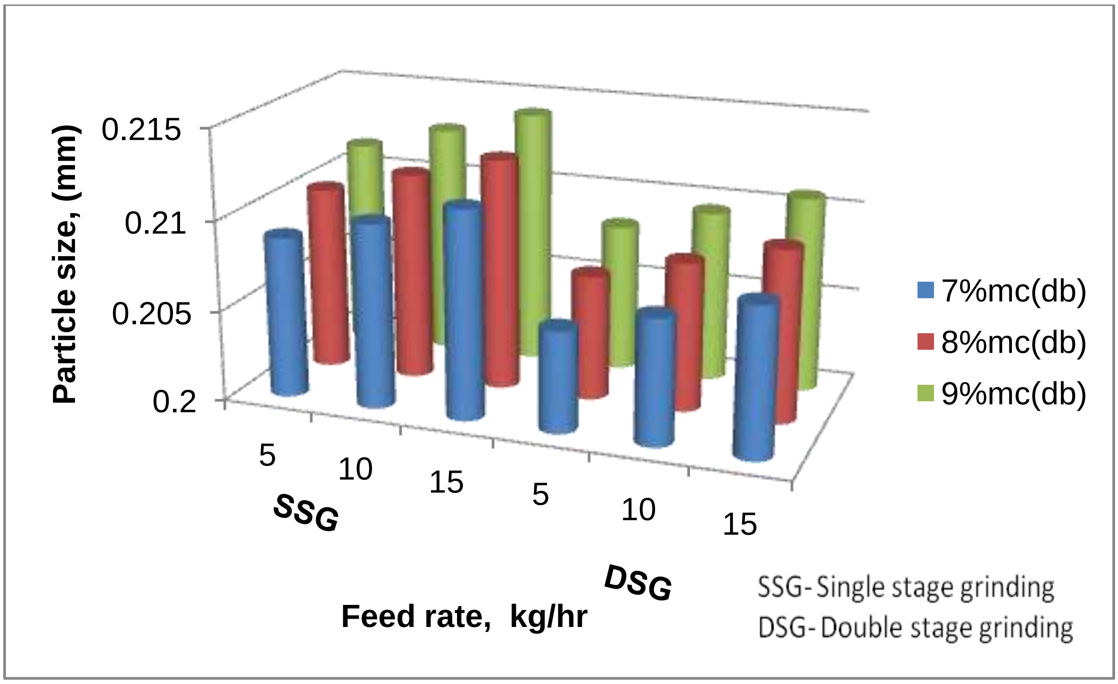


Fig 4.8 Effect of moisture content and feed rate on particle size (mm) using single stage grinding and double stage grinding of ginger powder

The result of analysis of variance (ANOVA) for factorial CRD Design was fitted which shows the moisture content as well as feed rate have significant effect on rise in particle size of Dry ginger powder during single stage and double stage hammer mill. (Appendix Table C-3a, 3b)

4.2.3.3 Effect of moisture content and feed rate on particle size of fenugreek seed powder during single stage grinding and double stage grinding

It is clear From Table 4.12., that the particle size of ground sample increased with increment in the feed rate and moisture content of the fenugreek seed. The maximum value of particle size (0.386 mm) was observed with fenugreek seed having 11% moisture content (db) and 18 kg/h feed rate. The minimum value of particle size (0.378 mm) was observed with fenugreek seed having 7% moisture content (db) and 12 kg/h feed rate. At a constant feed rate the fineness modulus of the ground sample increased progressively with increment in the moisture content of the sample. From Fig.4.9 it was also observed that there was a progressive increment in the particle size of the ground fenugreek seed with increment in feed rate at constant moisture content.

In a double stage hammer mill. The particle size of ground sample increased with increment in the feed rate and moisture content of the fenugreek seed. The maximum value of particle size (0.354mm) was observed with fenugreek having 11% moisture content (db) and 18 kg/h feed rate. The minimum value of particle size (0.346 mm) was observed with fenugreek seed having 7% moisture content (db) and 12 kg/h feed rate Table 4.12. At a constant feed rate the particle size of the ground sample increased progressively with increment in the moisture content of the sample. From Fig.4.9, it was also observed that at a constant m.c. the particle size of the ground fenugreek seed increased progressively with increment in feed rate.

Table 4.12 Effect of moisture content and feed rate on particle size (mm) fenugreek seed powder using single stage grinding and double stage grinding

S.No	Grinding method	Spices	Feed rate (kg/hr)	Particle size (mm)		
				Moisture content % (db)		
				7%	9%	11%
1	Single stage hammer mill	fenugreek seed	12	0.378	0.380	0.382
			15	0.380	0.382	0.384
			18	0.382	0.384	0.386
2	Double stage hammer mill	fenugreek seed	12	0.346	0.348	0.350
			15	0.348	0.350	0.352
			18	0.350	0.352	0.354

The particle size of the ground sample increases with increases in the feed rate and moisture content of the sample in both single and double stage grinding. From Fig. 4.9, it is clear that at a particular combination of the feed rate and m.c the values of particle size were higher during single stage grinding compared with the double stage grinding. Maximum values of particle size 0.386 and 0.354 mm were observed during single stage and double stage grinding of the fenugreek seed having 11% moisture content (db) and fed at a rate of 18 kg/h. However, minimum values of particle size viz 0.378 and 0.346 mm were observed at 12 kg/h feed rate and 7% moisture content (db) during single stage and double stage grinding, respectively. Double stage hammer mill it provided with a pre-crushing chamber where the material undergoes a coarse grinding and passes on to fine powdering stage so double stage grinding produces finer particle sizes as compared to the single stage grinding

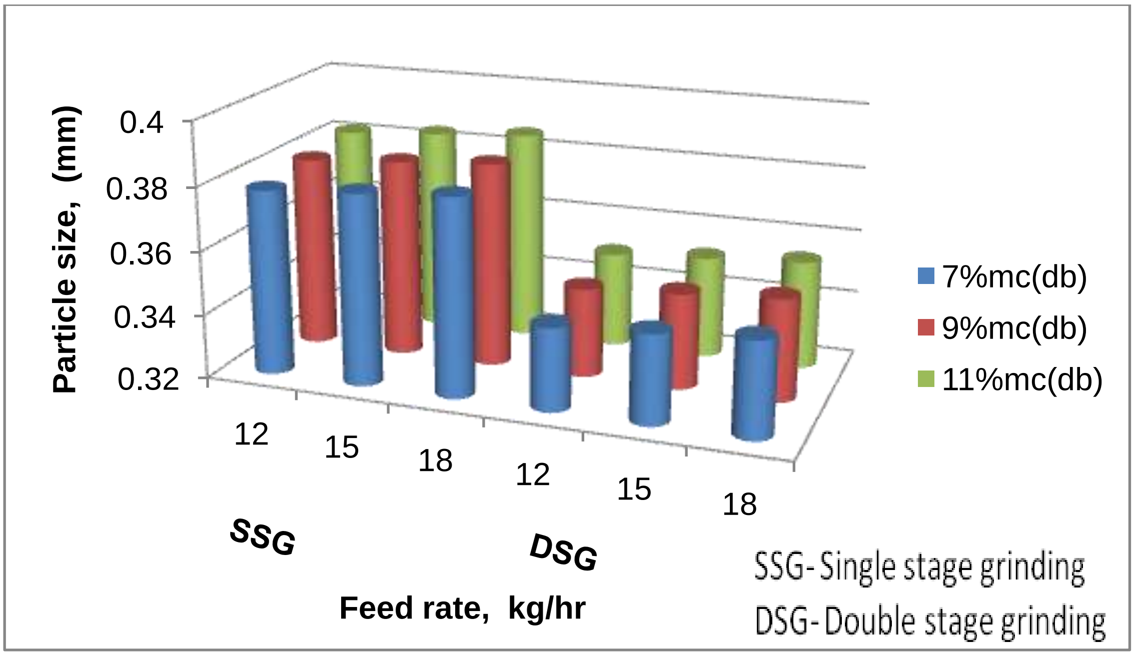


Fig 4.9 Effect of moisture content and feed rate on particle size (mm) using single stage grinding and double stage grinding of fenugreek seed powder

The result of analysis of variance (ANOVA) for factorial CRD Design was fitted which shows the moisture content as well as feed rate have significant effect on rise in particle size of fenugreek powder during single stage and double stage hammer mill. (Appendix Table D-3a, D-3b)

4.3 Effect of process variables on biochemical properties of spices powder during single stage and double stage grinding.

4.3.1 Effect of process variables on volatile oil content of spices powder during single stage and double stage grinding.

The volatile oil content or the yield of volatile oil distilled by using Clevenger's apparatus was determined to know the quality of ground spice samples.

The volatile oil was isolated from the spices powder (100 g) by using hydro distillation process as described in Section 3.2.4.3. A Clevenger apparatus was used for this purpose. The isolated essential oil was dried over sodium sulphate (Na_2SO_4), filtered using Millipore filter paper (45 μm pore size) and stored at -4°C, until analyzed (ASTM method, 1965).

4.3.1.1 Effect of moisture content and feed rate on volatile oil content of red chilli powder in single stage grinding and double stage grinding

In single stage grinding the effect of feed rate and moisture content was observed on the volatile content oil of red chilli powder. From Table 4.13, it is clear that as the moisture content of the red chilli was increased the volatile oil of the red chilli powder decreased. The maximum volatile oil content (0.1 ml/100g) was found for the red chilii having 7% moisture content (db) and fed at 6 kg/h. The minimum volatile oil (0.023 ml/100g) of the sample were found at 11% (db) moisture content and 18 kg/h feed rate in single stage grinding. The probable reason for the higher recovery of volatile oil at lower m.c. of the red chilli may be because of the lower temperature rise during the milling process Table 4.13. At 6 kg/h feed rate and 7% m.c. combination the temperature rise was 38°C giving 0.1 ml/100g volatile oil. However, the volatile oil content was observed 0.023 ml/100g at 11% m.c. of red chilli and 18 kg/h feed rate because of 46°C temperature rise during milling Fig- 4.4. The temperature rise during the milling process might have evaporated some amount of volatile oil thus giving lower recovery. In single stage grinding the average level of volatile oil content red chilli powder ranged from 0.023 to 0.1 ml/100g.

In double stage grinding the effect of feed rate and moisture content was observed on the volatile content oil of red chilli powder. From Table 4.13, it is clear that as the moisture content of the red chilli was increased the volatile oil of the red chilli powder decreased. The maximum volatile oil content (0.12 ml/100g) was found for the red chilli having 7% moisture content (db) and fed at 6 kg/h. The minimum volatile oil (0.05 ml/100g) of the sample were found at 11% (db) moisture content and 18 kg/h feed rate in double stage grinding. The probable reason for the higher recovery of volatile oil at lower m.c. of the red chilli may be because of the lower temperature rise during the milling process. At 6 kg/h feed rate and 7% m.c. combination the temperature rise was 34 °C giving 0.12 ml/100g volatile oil. However, the volatile oil content was observed 0.05 ml/100g at 11% m.c. of red chilli and 18 kg/h feed rate because of 42 °C temperature rise during milling Fig-4.10. The temperature rise during the milling process might have evaporated some amount of volatile oil thus giving lower recovery. In double stage grinding the average level of volatile oil content red chilli powder ranged from 0.05 to 0.12 ml/100g

Table 4.13 Effect of moisture content and feed rate on volatile oil of red chilli powder using single stage grinding

S.No	Grinding method	Spices	Feed rate (kg/hr)	Volatile oil content (ml/100g) red chilli single stage		
				Moisture content % (db)		
				7%	9%	11%
1	Single stage hammer mill	Red chilli	6	0.1	0.08	0.06
			12	0.086	0.063	0.043
			18	0.063	0.043	0.023
2	Double stage hammer mill	Red chilli	6	0.12	0.1	0.08
			12	0.10	0.08	0.06
			18	0.09	0.07	0.05

The volatile oil contents of the red chilli powder decreases with increases in the feed rate and moisture content of the sample in both single and double stage grinding. From Fig.10, it is clear that at a particular combination of the feed rate and m.c the values of volatile oil content were lower during single stage grinding compared with the double stage grinding. Maximum values of volatile oil content 0.1 ml/100g and 0.12 ml/100g were observed during single stage and double stage grinding of the red chilli having 7% moisture content (db) and fed at a rate of 6 kg/h. However, minimum values of volatile oil content viz 0.023 ml/100g and 0.05 ml/100g were observed at 18 kg/h feed rate and 11% moisture content (db) during single stage and double stage grinding, respectively. The loss of volatile oil content was high in single stage grinding as compare to double stage grinding. The volatile oil loss due to high grinding temperature leads the vaporization of volatile compounds.

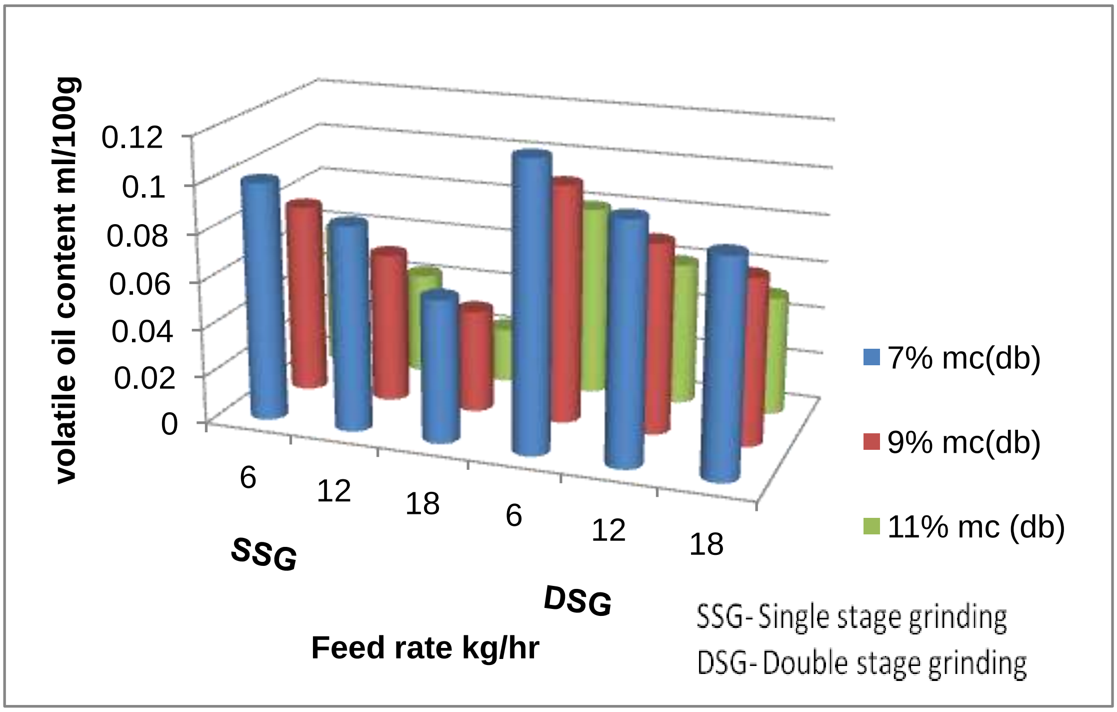


Fig. 4.10 Effect of moisture content and feed rate on volatile oil using single stage grinding and double stage grinding of red chilii powder

The result of analysis of variance (ANOVA) for factorial CRD Design was fitted which shows the moisture content as well as feed rate have significant effect on rise in volatile oil content of red chilli powder during single stage and double stage hammer mill. (Appendix Table B-4a, B-4b)

4.3.1.2 Effect of moisture content and feed rate on volatile oil content of dry ginger powder in single stage grinding and double stage grinding

It is clear from Table 4.14., that as the moisture content of the dry ginger was increased the volatile oil of the dry ginger powder decreased. The maximum volatile oil content (1.54 ml/100g) was found for the red chilii having 7% moisture content (db) and fed at 5kg/h. The minimum volatile oil (1.43 ml/100g) of the sample were found at 9% (db) moisture content and 15 kg/h feed rate in single stage grinding. The probable reason for the higher recovery of volatile oil at lower m.c. of the dry ginger may be because of the lower temperature rise during the milling process. At 5 kg/h feed rate and 7% m.c. Combination the temperature rise was 44 °C giving 1.54 ml/100g volatile oil. However, the volatile oil content was observed 1.43 ml/100g at 9% m.c. of dry ginger and 15 kg/h feed rate because of 52°C temperature rise during milling. The temperature rise during the milling process might have evaporated some amount of volatile oil thus giving lower recovery. In single stage grinding the average level of volatile oil content dry ginger powder ranged from 1.43 to 1.54 ml/100g.

In double stage grinding it is clear From Table 4.14 that as the moisture content of the dry ginger was increased the volatile oil of the dry ginger powder decreased. The maximum volatile oil content (1.65 ml/100g) was found for the dry ginger having 7% moisture content (db) and fed at 5 kg/h. The minimum volatile oil (1.52 ml/100g) of the sample were found at 9% (db) moisture content and 15 kg/h feed rate in double stage grinding. The probable reason for the higher recovery of volatile oil at lower m.c. of the dry ginger may be because of the lower temperature rise during the milling process . At 5 kg/h feed rate and 7% m.c. combination the temperature rise was 38 °C giving 1.65 ml/100g volatile oil. However, the volatile oil content was observed 1.52 ml/100g at 9% m.c. of dry ginger and 15 kg/h feed rate because of 47.33 °C temperature rise during milling. The temperature rise during the milling process might have evaporated some amount of volatile oil thus giving lower recovery. In double stage grinding the average level of volatile oil content dry ginger powder ranged from 1.52 to 1.65 ml/100g (Fig 4.11).

Table 4.14 Effect of moisture content and feed rate on volatile oil of ginger powder using single stage grinding and double stage grinding

S.No	Grinding method	Spices	Feed rate (kg/hr)	Volatile oil content (ml/100g) dry ginger		
				Moisture content % (db)		
				7%	8%	9%
1	Single stage hammer mill	Dry ginger	5	1.54	1.52	1.50
			10	1.51	1.49	1.47
			15	1.48	1.46	1.43
2	Double stage hammer mill	Dry ginger	5	1.65	1.63	1.60
			10	1.63	1.60	1.58
			15	1.56	1.54	1.52

The volatile oil contents of the dry ginger powder decreases with increases in the feed rate and moisture content of the sample in both single and double stage grinding. From Fig.4.11, it is clear that at a particular combination of the feed rate and m.c the values of volatile oil content were lower during single stage grinding compared with the double stage grinding. Maximum values of volatile oil content 1.54 ml/100g and 1.65 ml/100g were observed during single stage and double stage grinding of the dry ginger having 7% moisture content (db) and fed at a rate of 5 kg/h. However, minimum values of volatile oil content viz 1.43 ml/100g and 1.52 were observed at 15 kg/h feed rate and 9% moisture content (db) during single stage and double stage grinding, respectively. The loss of volatile oil content was high in single stage grinding as compare to double stage grinding. The volatile oil loss due to high grinding temperature leads the vaporization of volatile compounds

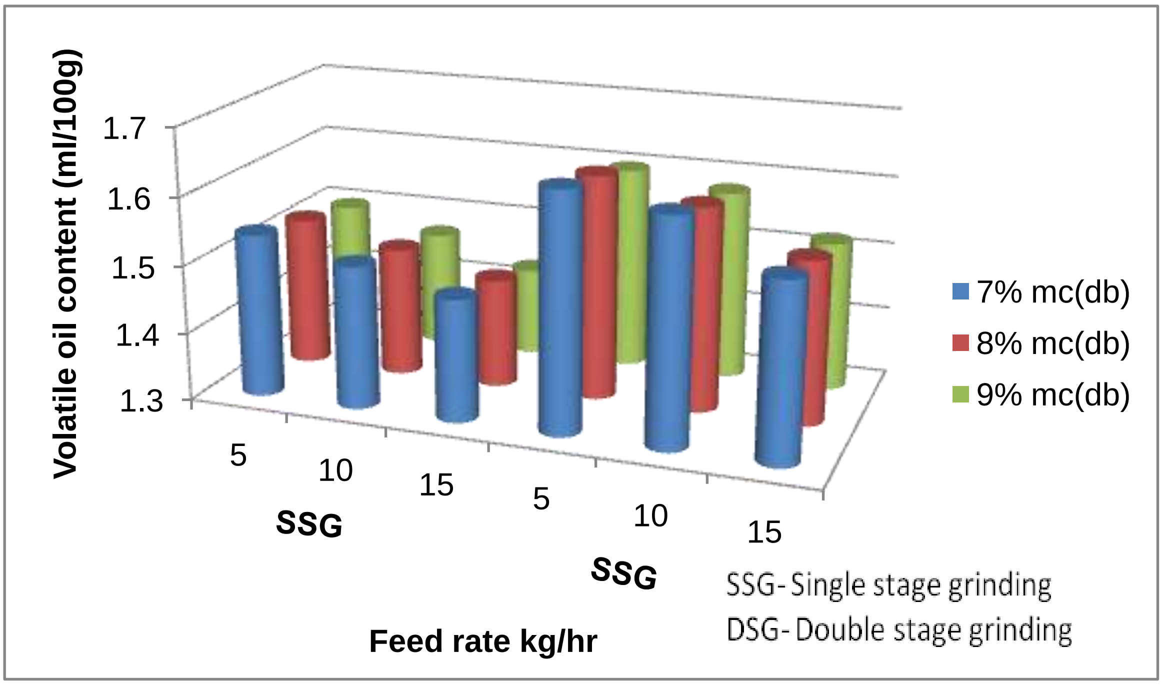


Fig 4.11 Effect of moisture content and feed rate on volatile oil content powder using single stage grinding and double stage grinding of dry ginger

The result of analysis of variance (ANOVA) for factorial CRD Design was fitted which shows the moisture content as well as feed rate have significant effect on rise in volatile oil content of dry ginger powder during single stage and double stage hammer mill. (Appendix Table C-4a, 4b)

4.3.2 Effect of process variables on specific gravity of spices oil during single stage and double stage grinding

The specific gravity was taken as a physical quality parameter for volatile oil obtained from spices powder. Specific gravity is a good indicator of adulteration, because if a particular oil is said to be pure, its specific gravity value will be close to an accepted value if it impure it varies.

4.3.2.1 Effect of process variables on specific gravity of red chilli powder oil during single stage and double stage grinding.

Specific gravity of the volatile oil obtained from red chilli powder using single stage and double stage grinding was estimated by the method as described in section 3.4.2.1. The specific gravity of volatile oil was 0.9550 for single stage as well as for double stage grinding method. There was effect of process variables on specific gravity of red chilli oil.

4.3.2.2 Effect of process variables on specific gravity of dry ginger powder oil during single stage and double stage grinding.

Specific gravity of the volatile oil obtained from dry ginger powder using single stage and double stage grinding was estimated by the method as described in section 3.4.2.1. The specific gravity of volatile oil was 0.870 for single stage as well as for double stage grinding method. There was effect of process variables on specific gravity of red chilli oil.

4.3.3 Effect of process variables on Refractive index of spices powder oil during single stage and double stage grinding.

Refractive index is related to ease with which light pass through an oil or fat. Temperature and degree of saturation affects the value of refractive index. The refractometer is the fastest and reliable technique in quality control assessments.

4.3.3.1 Effect of process variables on Refractive index of red chilli powder oil during single stage and double stage grinding

Refractive index of volatile oil obtained from red chilly powder was 1.4940 and 1.5009 for single stage grinding and double stage grinding method.

4.3.3.2 Effect of process variables on Refractive index of ginger powder oil during single stage and double stage grinding

Refractive index of volatile oil obtained from dry ginger powder was 1.4880 and 1.4940 for single stage grinding and double stage grinding method.

4.4 Effect of process variables on colour of spices powder

4.4.1 Effect of moisture content and feed rate on colour analysis of red chilli powder in single stage grinding and double stage grinding

Hunter lab colour apparatus was used to observe the colour of the red chilli powder in single stage and double stage grinding. The total colour change is given by colour differences (ΔEab^*) in terms of special distance between two colour points interpreted in the colour space (Hunter, 1987)

$$\Delta E = [(L_o-L_i)+(a_o-a_i)+(b_o-b_i)]^{1/2} \qquad (4.1)$$

The subscript i and o denote the colour parameters of red chilli and red chilli powder after grinding, respectively. The L_i, a_i and b_i, values of red chilli were observed to be 40.56, 28.33 and 44.87 respectively.

The L_o, a_o and b_o values of red chilli podwer are shown in Appendices B-5, 6 , respectively. The value of different attributes vizL_o, a_o and b_o varied from 47.12 to 44.77, 35.74 to 33.26 and 49.62 to 47.32, respectively. From Fig 4.13 it is evident that the whiteness of the samples as shown by the hunter colour lab values (L) decreased with increase in temperature during grinding. The decrement in the lightness of red chilli powder may be because of the non-enzymatic browning reactions occurring during grinding at higher temperature. The higher ΔE represents greater colour change from the red chilli powder. Colour change of the sample range in 3.40 to 4.32Table 4.15. Results show that increase in colour loss increases with increase in moisture content.

The value of different attributes vizL_o, a_o and b_o varied from 45.92 to 43.77, 34.32 to 32.26 and 48.76 to 46.32, respectively. From Fig 4.13 it is evident that the whiteness of the samples as shown by the hunter colour lab values (L) decreased with increase in temperature during grinding. Colour change of the sample range in 3.90 to 2.96 Table 4.15. Results show that increase in colour loss increases with increase in moisture content. The higher ΔE represents greater colour change from the dried red chilli.

Table 4.15 Effect of moisture content and feed rate on colour change (E* ab) of red chilli powder using single stage & double stage grinding.

S.No	Grinding method	Spices	Feed rate (kg/hr)	Colour change (E* ab)		
				Moisture content % (db)		
				7%	9%	11%
1	Single stage hammer mill	Red chilli	6	3.40	3.70	4.10
			12	3.50	3.84	4.20
			18	3.69	4.07	4.32
2	Double stage hammer mill	Red chilli	6	2.96	3.28	3.71
			12	3.05	3.42	3.82
			18	3.25	3.54	3.90

The colour change value of red chilli powder was measured at different moisture content of sample and different feed rate in both single and double stage grinding. From Fig.4.13, it is evident that the colour change of red chilli powder during grinding of single stage hammer mill found to be in the range 3.40 to 4.32. While in double stage hammer mill colour change of red chilli powder was found in the range of 2.96 to 3.90. Appendices Table B- 5, 6.The average hue angle and chroma of red chilli powder were 35° 75’ to 35° 6’ and 61.15 to 57.83 in single stage hammer mill. While in double stage hammer mill it was observed that the average hue angle and chroma of red chilli powder were 35° 15’ to 34° 85’ and 59.63 to 56.44, respectively. The minimum colour losses were observed in double stage hammer mill as compared to single stage hammer mill. It was also observed that colour loss increased with increase in temperature.

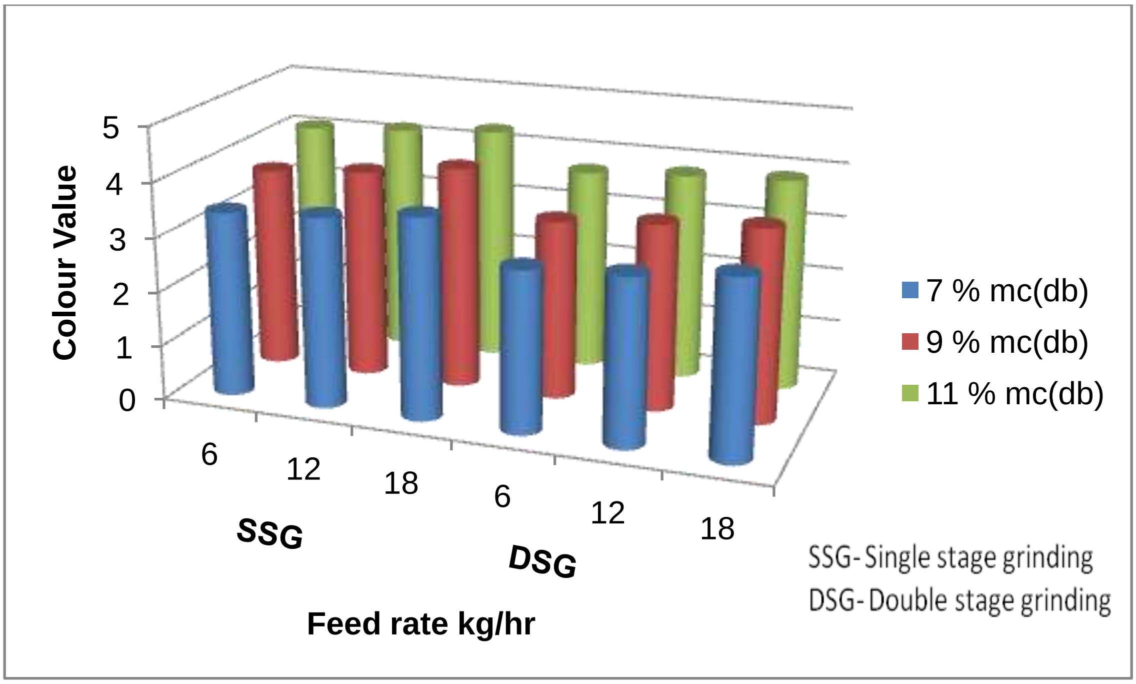


Fig4.12 Effect of moisture content and feed rate on colour change (E* ab) using single stage and double stage grinding of red chilli powder

The result of analysis of variance (ANOVA) for factorial CRD Design was fitted which shows the moisture content as well as feed rate have significant effect on rise in colour change of red chilli powder during single stage and double stage hammer mill. (Appendix TableB-7a, 7b)

4.3.2 Effect of moisture content and feed rate on colour analysis of dry ginger powder in single stage grinding and double stage grinding

Hunter lab colour apparatus was used to observe the colour of the dry ginger powder in single stage and double stage grinding. The total colour change is given by colour differences (ΔEab^*) in terms of special distance between two colour points interpreted in the colour space (Hunter, 1987)

$$\Delta E = [(L_o-L_i)+(a_o-a_i)+(b_o-b_i)]^{1/2} \qquad (4.2)$$

The subscript i and o denote the colour parameters of dry ginger and dry gingerpowder after grinding, respectively. The L_i, a_i and b_i values of dry gingerwere observed to be 62, 2.36 and 22.87 respectively.

The L_o, a_o and b_o values of dry gingerpowder shown in Appendices Table C-5, 6 respectively. The higher ∆E represents greater colour change from the dry ginger.

In single stage grinding the effect of feed rate and moisture content was observed on the colour of ground dry ginger powder. The value of different attributes vizL_o, a_o and b_o varied from 68.75 to 66.26, 6.75 to 4.42 and 28.76 to 26.30, respectively. From Fig 4.13, it is evident that the whiteness of the samples as shown by the hunter colour lab values (L) decreased with increase in temperature during grinding. The higher ∆E represents greater colour change from the dry ginger powder. Colour change of the sample range in 4.12 to 3.12 Table 4.16. Results show that increase in colour loss increases with increase in moisture content.

Similarly in double stage grinding, the value of different attributes vizL_o, a_o and b_o varied from 67.75 to 65.29, 5.70 to 3.22 and 27.76 to 25.50, respectively. From Fig 4.13, it is evident that the whiteness of the samples as shown by the hunter colour lab values (L) decreased with increase in temperature during grinding. Colour change of the sample range in 3.73 to 2.54 Table 4.16. Results show that increase in colour loss increases with increase in moisture content. The higher ∆E represents greater colour change from the dried ginger.

Table 4.16 Effect of moisture content and feed rate on colour change (E* ab) of dry ginger powder using single stage & double stage grinding.

S.No	Grinding method	Spices	Feed rate (kg/hr)	colour change (E* ab)		
				Moisture content % (db)		
				7%	8%	9%
1	Single stage hammer mill	Dry ginger	5	3.12	3.33	3.90
			10	3.27	3.69	4.01
			15	3.39	3.78	4.12
2	Double stage hammer mill	Dry ginger	5	2.54	3.01	3.51
			10	2.77	3.21	3.62
			15	2.91	3.36	3.73

The colour change value of dry ginger powder was measured at different moisture content of sample and different feed rate in both single and double stage grinding. From Fig.4.13, it is evident that the colour change of dry ginger powder during grinding of single stage hammer mill found to be in the range 4.12 to 3.12. While in double stage hammer mill colour change of dry ginger powder was found in the range of 3.73 to 2.54.Appendices Table C-5, 6.The average hue angle and chroma of dry ginger powder were 13° 17' to 9° 53' and 29.54 to 26.66 in single stage hammer mill. While in double stage hammer mill it was observed that the average hue angle and chroma of dry ginger powder were 11°58' to 7° 30' and 28.34 to 25.40, respectively. The minimum colour losses were observed in double stage hammer mill as compared to single stage hammer mill. It was also observed that colour loss increased with increase in temperature.

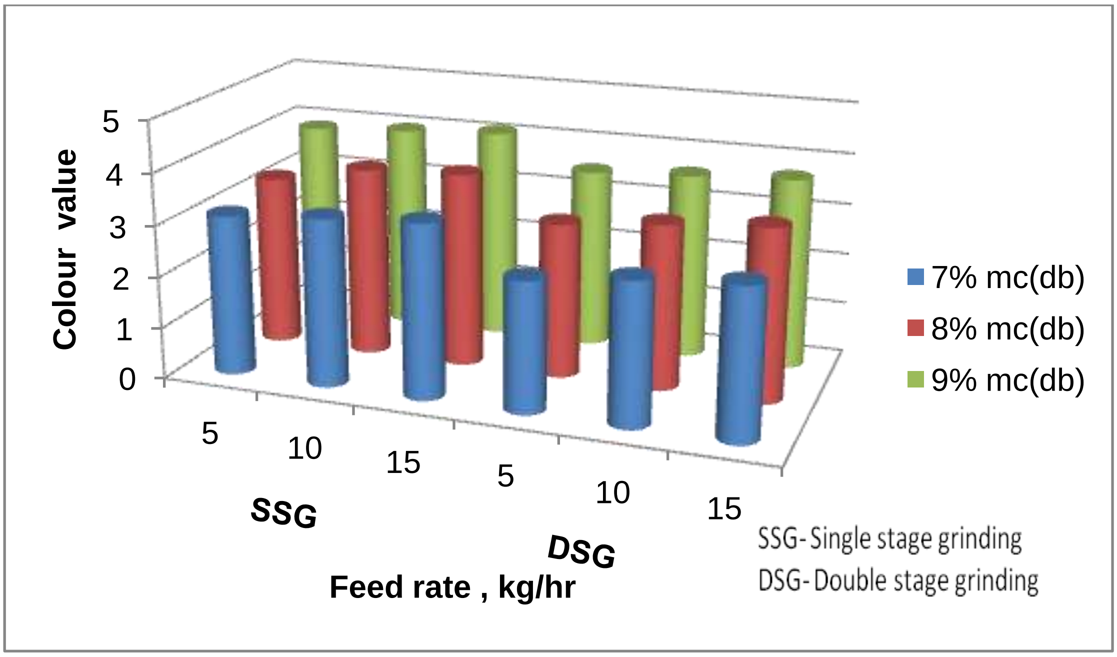


Fig 4.13 Effect of moisture content and feed rate on colour change (E* ab) of dry ginger powder using single stage and double stage grinding

The result of analysis of variance (ANOVA) for factorial CRD Design was fitted which shows the moisture content as well as feed rate have significant effect on rise in colour change of dry ginger powder during single stage and double stage hammer mill. (Appendix TableC-7a, 7b)

4.3.3 Effect of moisture content and feed rate on colour analysis of fenugreek powder in single stage grinding and double stage grinding

Hunter lab colour apparatus was used to observe the colour of the fenugreek powder in single stage and double stage grinding. The total colour change is given by colour differences (ΔEab^*) in terms of special distance between two colour points interpreted in the colour space (Hunter, 1987)

$\Delta E = [(L_o-L_i)+(a_o-a_i)+(b_o-b_i)]^{1/2}$ (4.3)

The subscript i and o denote the colour parameters of fenugreekandfenugreekpowder after grinding, respectively. The L_i, a_i and b_i, values of fenugreek were observed to be 68.16, 0.95 and 39.32 respectively.

The L_o, a_o and b_o values of fenugreek podwer shown in Appendices Table D-4, 5 respectively. The higher ΔE represents greater colour change from the fenugreek seed.

In single stage grinding, the effect of feed rate and moisture content was observed on the colour of ground fenugreek, the value of different attributes viz L_o, a_o and $b_o$varied from 74.75 to 72.26, 4.75 to 2.42 and 44.76 to 42.30 respectively. From Fig 4.14 it is evident that the whiteness of the samples as shown by the hunter colour lab values (L) decreased with increase in temperature during grinding. The higher ΔE represents greater colour change from the fenugreek powder. Colour change of the sample range in 3.97 to 2.92 Table 4.17. Results show that increase in colour loss increases with increase in moisture content.

Similarly in double stage grinding, the value of different attributes vizL_o, a_o and b_o varied from 73.75 to 71.12, 3.95 to 1.52 and 43.96 to 41.30, respectively. From Fig 4.14, it is evident that the whiteness of the samples as shown by the hunter colour lab values (L) decreased with increase in temperature during grinding. Colour change of the sample range in 3.63 to 2.34Table 4.17. Results show that increase in colour loss increases with increase in moisture content. The higher ΔE represents greater colour change from the dried fenugreek.

Table 4.17 Effect of moisture content and feed rate on colour change (E* ab) of fenugreek powder using single stage & double stage grinding.

S.No	Grinding method	Spices	Feed rate (kg/hr)	colour change (E* ab)		
				Moisture content % (db)		
				7%	9%	11%
1	Single stage hammer mill	Fenugreek	12	2.92	3.30	3.74
			15	3.10	3.48	3.85
			18	3.24	3.61	3.97
2	Double stage hammer mill	fenugreek	12	2.34	2.83	3.30
			15	2.78	3.08	3.45
			18	2.91	3.23	3.63

The colour change value of fenugreek powder was measured at different moisture content of sample and different feed rate in both single and double stage grinding. From Fig.4.14, it is evident that the colour change of fenugreek powder during grinding of single stage hammer mill found to be in the range 3.97 to 2.92. While in double stage hammer mill colour change of fenugreek powder was found in the range of 3.63 to 2.34.Appendices Table-4, 5.The average hue angle and chroma of fenugreek powder were 6° 05' to 3° 27' and 45.01 to 42.36 in single stage hammer mill. While in double stage hammer mill it was observed that the average hue angle and chroma of fenugreek powder were 5° 13' to 2° 10' and 44.13 to 41.32, respectively. The minimum colour losses were observed in double stage hammer mill as compared to single stage hammer mill. It was also observed that colour loss increased with increase in temperature.

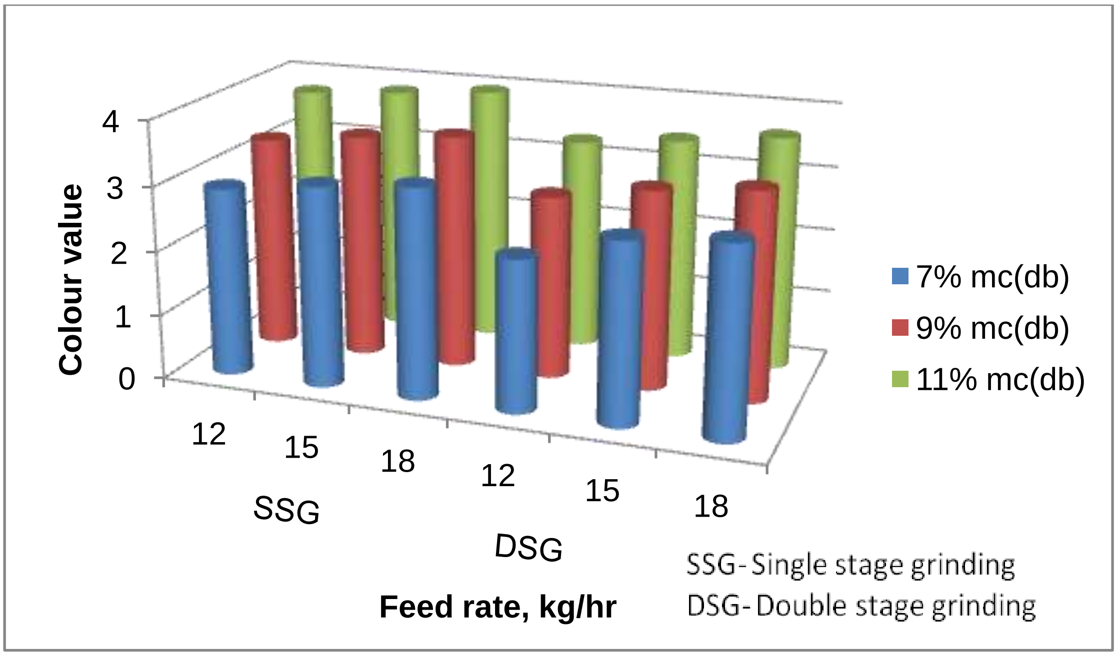


Fig 4.14 Effect of moisture content and feed rate on colour change (E* ab) of fenugreek powder using single stage and double stage grinding

The result of analysis of variance (ANOVA) for factorial CRD Design was fitted which shows the moisture content as well as feed rate have significant effect on rise in colour change of fenugreek powder during single stage and double stage hammer mill. (Appendix TableD-6a, 6b)

4.5 Cost economics for spices powder production

4.3.1 Cost analysis for preparing of red chilli, dry ginger, fenugreek powder from single stage hammer mill

Assumptions

• Working hours in one shift	8
• Number of working days in a month	25
• Total no. of working days in year	300
• Depreciation on machines and equipment	10% p.a.
• Rate of interest	12% p.a.
• Housing area requirement	30 ft x 15 ft
• Average Capacity of unit	10 kg/h
• Land and building on rent	2000/- per month

Fixed Capital

Machinery requirement

S.No.	**Equipment/machinery**	**Amount (Rs.)**
1	Single stage hammer mill	60,000
2	Digital balance	6,000
3	Miscellaneous	1,000
	Total	**67,000/-**

Total Working Capital (per month)

(A)	**Labour**	**Amount (Rs.)**
	skilled 2No. @ 5000	10,000
(B)	Raw material	
	1. Red chilli 1000kg 120Rs/kg	120000
	2. Dry ginger 1000kg 250Rs/kg	250000
	3. Fenugreek seed 1000kg 60 Rs/kg	60000
(C)	Building rent charges	2,000

(D)	Electricity (300kWh@Rs.7/kWh)	2,100
(E)	Repair & maintenance (1% cost of machines)	670
(F)	Transport charges	2,000
(G)	Miscellaneous expenses	500
	Total	**447,270/-**

Total Working capital for 3 month Rs. 1,341,810

Total capital investment

Fixed capital	67,000
Working capital(for 3 month)	1,341,810
Total	**1,408,810/-**

Annual Cost (Cost of production per year) or total working capital

Working capital @300days/year	5367240
Depreciation on machines/equipments @ 10% p.a.	6700
Interest on total capital investment @ 12% p.a.	169,057
Total	**5,542,997/-**

Total Annual Sales

Spices	Quantity (kg)	Sale rate (Rs.)	Amount (Rs.)
Red chilli powder Dry ginger powder Fenugreek seed powder	12000 12000 12000	160 360 145	19,20,000 4320000 1740000
Total			7980000/-

Profitability

Annual profit = (Total sales-Annual cost)

= (7980000- 5542997)

=2,437,002

Monthly profit = Annual profit/12

= 2, 43,7002 /12

= 203,083

$$\text{Profit on sale} = \frac{\text{Annual Profit}}{\text{Annual Sale}} \times 100$$

= (2,437,002 / 7980000) x 100

= 30.53%

$$\text{Return on capital investment} = \frac{\text{Annual profit}}{\text{Total capital investment}} \times 100$$

= (Annual profit / Total annual cost) x 100

= (2,437,002 / 5542997)x 100

= 43.96%

Pay Back Period

$$PBP = \frac{\text{Total cost of project}}{\text{profit}}$$

PEP= fixed cost/profit

=67000/ 2,437,002

= 2.74years

4.5.2 Cost analysis for preparing of red chilli, dry ginger and fenugreek seed powder from double stage hammer mill

Assumptions

• Working hours in one shift	8
• Number of working days in a month	25
• Total no. of working days in year	300
• Depreciation on machines and equipment	10% p.a.
• Rate of interest	12% p.a.
• Housing area requirement	30 ft x 15 ft
• Average Capacity of unit	12 kg/h
• Land and building on rent	2000/- per month

Fixed Capital

Machinery requirement

S.No.	Equipment/machinery	Amount (Rs.)
1	Double stage hammer mill	80,000
2	Digital balance	6,000
3	Miscellaneous	1,000
	Total	**87,000/-**

Total Working Capital (per month)

(A)	**Labour**	**Amount (Rs.)**
	skilled 2No. @ 5000.00	10,000
(B)	**Raw material**	
	Fenugreek 1000kg @Rs. 60/kg	60000
	Dry red chilli1000kg@Rs.120/kg	120000
	Dry ginger 1000kg@Rs.250/kg	250000
(C)	Building rent charges	2,000
(D)	Electricity (500kWh@Rs.7/kWh)	3,500
(E)	Repair & maintenance (1% cost of machines)	870
(F)	Transport charges	2,000
(G)	Miscellaneous expenses	500
	Total	**448,870/-**

Total Working capital for 3 month Rs. 1,346,610

Total capital investment

Fixed capital	87,000
Working capital(for 3 month)	1,346,610
Total	**1,433,610/-**

Annual Cost (Cost of production per year) or total working capital

Working capital @300days/year	5,386,440
Depreciation on machines/equipments @ 10% p.a.	8700
Interest on total capital investment @ 12% p.a.	172,033
Total	5,567,173/-

Total Annual Sales

	Quantity (kg)	Sale rate (Rs.)	Amount (Rs.)
Red chilli powder	12000	170	20,40,000
Dry ginger powder	12000	370	4,440000
Fenugreek seed powder	12000	150	1800000
Total			8280000/-

Profitability

Annual profit = (Total sales-Annual cost)

= (8280000- 5,567,173)

= 2,712,826

Monthly profit = Annual profit/12

= 2,712,826 /12

= 226,068

$$\text{Profit on sale} = \frac{\text{Annual Profit}}{\text{Annual Sale}} \times 100$$

= (2,712,826 / 8280000) x 100

= 32.76%

$$\text{Return on capital investment} = \frac{\text{Annual profit}}{\text{Total capital investment}} \times 100$$

= (Annual profit / Total annual cost) x 100

= (2,712,826 / 5,567,173)x 100

= 48.72%

Pay Back Period

$$\text{PBP} = \frac{\text{Total cost of project}}{\text{profit}}$$

PEP= fixed cost/profit

=87000/ 2,712,826

= 3.20 years

SUMMARY, CONCLUSIONS AND SUGGESTION FOR FURTHER WORK

5.1 Summary

In our country, various spices are used as flavoring agents. They are also used for their various other properties and among red chilli, dry ginger, fenugreek is an important spice used for its flavor and medicinal properties.

Grinding characteristics of spices were observed by conducting experiments in single stage and double stage grinding process under different operational condition. In both grinding process red chilli, dry ginger and fenugreek seed observed the effect of grinding. Where two independent variable feed rate and moisture content with three replication were selected to observe the effect. Feed rate was kept at three level for red chilli (6, 12, 18), dry ginger(5, 10, 15) and fenugreek seed (12, 15, 18), the level of moisture content for red chilli (7 ,9, 11%mc(d.b.), dry ginger (7, 8, 9%mc(d.b.) and fenugreek seed (7, 9, 11%mc(d.b.) A symmetrical factorial completely randomized design was fitted for analysis of ANOVA. The quality of spices powder were studied in terms of the observed variables for experiments were temperature, volatile oil, fineness modulus, particle size and colour analysis by hunter colour colorimeter.

5.2 Conclusion

The following conclusion obtained in our study are :-

1. The average length, width, thickness and dynamic angle of repose of the spices slightly increase with increases of moisture content.
2. The bulk density and true density were found to be decrease with increase of moisture content.
3. There is steady rise in temperature with increase in moisture content and feed rate in both grinding machines. The maximum rise was observed in single stage hammer mill and minimum rise was observed in double stage hammer mill.
4. There is an initial fall in fineness modulus with increase in moisture content (from 7% to 9%) and then it is increase from 11% of moisture content (d. b). The best fineness modulus obtained in double stage hammer mill.

5. The average size of particle first decreases with moisture content (by 7%) and then there is an increase in average particle size from 9% moisture content to 11% moisture content (d.b). The smallest particle size has been obtained in double stage hammer mill.
6. The best milled productsare obtained at 7% moisture content (d. b) in double stage hammer mill.
7. Volatile oil content of the spice powder obtained by double stage grinding was found to be higher compared with single stage grinding.Result of the study showed that the better quality product obtained using double stage grinding.
8. After evaluation of all sensory attributes of spices powder in terms of rise in temperature at powder, volatile oil content, fineness modulus, particle size and colour analysis. It was concluded that the best quality product was obtained at low moisture content & minimum feed rate in double stage grinding over single stage grinding.

5.3 Suggestion for further work

The following suggestions should be considered in further work:

- Study on energy consumption should be carried out in both grinding hammer mill.
- The oleoresin content of spices powder can also be determined, which may be a future interest for further study.

BIBLIOGRAPHY

Akgul A. (1993). Baharal Bilimi Ve Teknolojisi, Gida Teknologisi Dernegi Yaymlari, No. 15:113-114.

AOAC (1990). Official Methods of Analysis of the Association of Official Analytical Chemists (AOAC), 15th edn. AOAC Inc., Virginia.

ASTA. (1985). Official analytical method of the American Spices Trade Association. 3rd ed. Engelwood Cliffs, New Jersey.

Altuntas E, E Ozgoz and O.F. Taser (2004). Some physical properties of fenugreek(Trigonella foenum-graceum L.) seeds. Journal of Food Engineering 71 (2005) 37–43.

Anwar F, S Muhammad, A.I. Hussain, S Nazamid, S Iqbal and U Rashid (2011). Physicochemical composition of hydro-distilled essential oil from coriander (*Coriandrum sativum* L.) seeds cultivated in Pakistan. Journal of Medicinal Plants Research,5(15): 3537-3544.

Barnwal P, K.K. Singh, A Sharma, A.K. Choudhary, C Hardik and S.N. Saxena (2013). Effect of moisture content, screw and grinder speed on physical and thermal properties of fenugreek powder. *International J. Seed Spices 3(2), July 2013:13-21.*

Bhuiyan MNI, J Begum and M Sultan (2009). Chemical composition of leafan seed essential oil of *Coriandrum sativum* L. from Bangladesh. Journal of Pharmacol., 4: 150-153.

Choudhary, A.K. (2012). Effect of double stage grinding on quality attribute of ground turmeric powder (Curcuma Longa L) M.Tech. Thesis, college of Agricultural Engineering, JNKVV, Jabalpur.

Dealy, J.M. (1982). Rheometers for molten plastics. Van Nostrand-Reinhold Co., New York.

Ertl f. (1997). Procedure modification of AOAC official method 962.17. volatile oil in spices. Journal of the association of official analytical chemist international, 80(4): 901-910.

Gajabe M. (2013). Studies on the effect of single stage and double stage grinding on the quality attributes of coriander powder. M.Tech. Thesis, college of Agricultural Engineering, JNKVV, Jabalpur.

Goswami T.K. and M Singh. (2002). Role of feed rate and temperature in attrition grinding of cumin. Journal of Food Engineering ,59: 285–290.

Hunter, T. (1987). A Thousand and One Protein Kinases. Cell., 50,823.

King C.J. and Judson. (1974). Physical and chemical properties governing volatilization of flavor and aroma component, Physical properties of food, basic symposium series 1983 by M peleg and E.B Bagley, P. 399-421, AVI Publishing Co. , INC. , West Port, Connecticut.

Manzan, M. F.S. Tonido, E. Bredow, N.P. Povth, (2003). Extraction of essential oil and pigments from Curcuma Longa (L) by steam distillation and extraction with volatile solvent. J. Agri. And Food chemistry, 51: 6802-6807.

Mc Cabe, W.L., J.C, Smith & P Harriot. (1985). Unit Operation of Chemical engineering (4^{th} ed.). New York: Mc. Graw-Hill.

Meghwal M and T.K. Goswami (2010). Cryogenic grinding of spices is a novel approach whereas ambient grinding needs improvement. Journal of Food Science and Technology 4: 24 – 37

Mishra A.K. and S.D Kulkarni. (2009). Engineering properties of turmeric rhizomes J.Agricultural Engineering Today 33(2): 26-31.

Mohasenin, N.N. (1980). Physical Properties of Plants and Animal Materials, Gordon and Breach Science Publishers. New York.

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

Narasihman, S., Nagin Chand., Rajalakshmi, D., and Indiramma, AR (1990). Quality of powdered black pepper (Piper nigrum L.) during storage. 1. Sensory and physicochemical analysis. Journal of Sensory Studies. 4: 229-240.

Perry J.S., C.W. Hall, (1965). Mechanical properties of pea bean under impact loading. Trans. Am. Soc Agri Engg. 8(2): 191-195.

Singh K.K. and K.M. Sahay (1996). Unit operations of Agricultural processing, Vikas Publishing House PVT. LTD. , New Delhi, India.

Silva. L.V., D.L. Nelson, Drummond. M.F.B, Dufosse, M.B.A Gloria. (2005). Comparison of hydrodistillation methods for the deoderization of turmeric. International J. of Food Research, 38 (8-9); 1087-1096

Steel, R.G.D and J.H. Torie (1980). Principal and procedure of Statistics. 2nd ed. Newyork, NY. McGrew-Hill Book Co. Ltd.

Szczesniak, A.S. (1983). Physical properties of foods: what they are and their relation to other food properties. In Physical Properties of Foods, Edited by M. Peleg and E.B. Bagley, A VI Publication Co., Westport. Connecticut. 1-41.

Topuz A, H Feng and M Kushad (2009). The effect of drying method and storage on color characteristics of paprika. Food Science and Technology 42: 1667–1673.

Waje, C.K., H.K. Kim, S Todoriki, & J.H. Kwon (2008). Physicochemical and microbiological qualities of steamed and irradiated ground black pepper (Piper nigrum L.). Journal of Agricultural and Food Chemistry, 56(12), 4592–4596.

Yalc ın and C. kuner (2007). Physical properties of coriander seeds (Coriandrum sativum L.). Journal of Food Engineering 80 408–416.

Yang Y, X Zhao, Z Yang and G Gai (2008). Effect of superfine grinding on properties of ginger powder, Journal of Food Engineering 91 217–222.

Yusof Y. A., N.L Chin, R.A. Talib and M.G. Aziz (2012). Size reduction of selected spices using knife mill. Experimental investigation and model fitting *Journal of sFood, Agriculture & Environment Vol.10 (1): 102-106. 2012*

Zeng F, H Liu, Q Wang and G Fenglin (2013). The effect of cryogenic grinding and hammer milling on the flavor quality of ground pepper (Piper nigrum L.), Journal of food chemistry 141 3402-3208.

APPENDICES-A

Table A-1 Physical properties of red chilli

S.No	Length (mm)			Width(mm)			Thickness(mm)		
	7% mc(db)	9% mc(db)	11% mc(db)	7% mc(db)	9% mc(db)	11% mc(db)	7% mc(db)	9% Mc(db)	11% mc(db)
1.	7.98	8.11	8.31	1.80	1.85	1.91	0.18	0.20	0.22
2.	8.42	8.97	9.10	1.45	1.50	1.55	0.28	0.30	0.33
3.	6.70	6.95	7.04	1.55	1.60	1.64	0.18	0.20	0.23
4.	6.98	7.22	7.55	1.28	1.31	1.35	0.28	0.30	0.33
5.	7.21	7.85	8.04	1.45	1.50	1.55	0.18	0.20	0.22
6.	6.95	7.10	7.54	1.54	1.60	1.67	0.28	0.30	0.33
7.	7.98	8.41	8.97	1.48	1.50	1.58	0.18	0.20	0.22
8.	6.11	6.42	6.87	1.78	1.82	1.85	0.18	0.20	0.23
9.	7.11	7.45	7.87	1.80	1.84	1.88	0.28	0.30	0.33
10.	7.98	8.15	8.57	1.60	1.62	1.68	0.18	0.20	0.22
Mean	7.342	7.663	7.986	1.573	1.614	1.666	0.22	0.24	0.266
SD	0.722	0.770	0.761	0.171	0.177	0.175	0.056	0.056	0.052

Table A- 2 Physical properties of red chilli

S.No	Bulk density(kg/m3)			True density(kg/m3)			Angle of repose(^{0})		
	7% mc(db)	9% mc(db)	11% mc(db)	7% mc(db)	9% mc(db)	11% mc(db)	7% mc(db)	9% Mc(db)	11% mc(db)
1.	260	250	240	1100	1000	990	39.0	43	45
2.	258	248	238	1098	998	988	38.5	42.5	44.5
3.	256	246	236	1096	996	986	42.0	43.0	44.0
4.	254	244	234	1094	994	984	41.5	43.5	45.5
5.	252	242	232	1092	992	982	40.5	42.0	44.5
6.	250	240	230	1090	990	980	41.52	43.5	43.5
7.	262	252	232	1102	1002	992	41.51	43.5	44.5
8.	264	254	234	1104	1004	994	40.52	42.5	43.5
9.	266	256	236	1106	1006	996	41.55	43.5	45.5
10.	268	258	238	1108	1008	998	41.54	42.5	44.3
Mean	259	249	235	1099	999	989	40.814	42.95	44.5
SD	6.053	6.053	3.162	6.053	6.053	6.053	1.196	0.552	0.701

Table A-3 Physical properties of dry ginger

S.No	Length (mm)			Width(mm)			Thickness(mm)		
	7% mc(db)	8% mc(db)	9% Mc(db)	7% mc(db)	8% mc(db)	9% mc(db)	7% mc(db)	8% Mc(db)	9% mc(db)
	4.45	4.48	5.50	1.40	1.43	1.45	0.68	0.70	0.72
1.	4.40	4.43	4.45	1.50	1.52	1.54	0.78	0.80	0.82
2.	4.40	4.45	4.48	1.70	1.72	1.75	1.18	1.20	1.22
3.	5.60	5.62	5.65	2.19	2.21	2.23	0.98	1.00	1.10
4.	4.28	4.30	4.32	2.17	2.19	2.21	1.00	1.08	1.12
5.	6.48	6.51	6.54	2.18	2.20	2.23	1.16	1.18	1.20
6.	5.50	5.52	5.55	1.38	1.41	1.43	1.17	1.19	1.21
7.	6.74	6.76	6.78	1.59	1.62	1.65	1.15	1.17	1.19
8.	6.38	6.40	6.43	1.48	1.51	1.56	1.18	1.20	1.22
9.	6.18	6.20	6.23	1.70	1.73	1.76	1.39	1.42	1.45
Mean	5.441	5.467	5.498	1.729	1.754	1.781	1.067	1.094	1.125
SD	0.983	0.977	0.982	0.322	0.326	0.321	0.218	0.213	0.214

Table A-4 Physical properties of dry ginger

S.No	Angle of repose (^{0})		
	7% mc(db)	8% Mc(db)	9% mc(db)
1	46.0	48	50.0
2	46.2	48.4	51.00
3	46.4	48.5	50.5
4	46.8	48.2	50.2
5	46.02	48.1	50.12
6	46.12	48.3	50.08
7	46.10	48.8	50.11
8	46.30	48.7	50.30
9	46.11	48.2	50
10	46.03	48.7	50.06
Mean	46.208	48.390	50.237
SD	0.248	0.276	0.301

Table A-5 Physical properties of fenugreek seed

S.No	Length (mm)			Width(mm)			Thickness(mm)		
	7% mc(db)	9% mc(db)	11% mc(db)	7% mc(db)	9% mc(db)	11% mc(db)	7% mc(db)	9% Mc(db)	11% mc(db)
1	3.95	4.02	4.11	2.21	2.28	2.58	1.68	1.70	1.75
2	3.99	4.01	4.10	2.25	2.29	2.59	1.65	1.71	1.74
3	4.05	3.91	4.12	2.19	2.30	2.60	1.69	1.70	1.75
4	4.10	4.12	4.13	2.20	2.31	2.60	1.63	1.70	1.76
5	3.85	4.08	4.10	2.23	2.29	2.55	1.67	1.69	1.74
6	3.79	4.09	4.09	2.20	2.32	2.48	1.66	1.71	1.74
7	3.99	4.10	4.12	2.18	2.33	2.45	1.68	1.71	1.74
8	3.90	4.06	4.11	2.20	2.34	2.48	1.69	1.72	1.77
9	3.82	4.08	4.12	2.17	2.35	2.50	1.68	1.70	1.75
10	3.97	4.07	4.13	2.15	2.35	2.55	1.69	1.71	1.74
Mean	3.941	4.054	4.113	2.198	2.316	2.538	1.672	1.705	1.748
SD	0.101	0.067	0.013	0.025	0.029	0.051	0.018	0.004	0.013

Table A-6 Physical properties of fenugreek seed

S.No	Bulk density (kg/m3)			True density(kg/m3)			Angle of repose(^{0})		
	7% mc(db)	9% mc(db)	11% mc(db)	7% mc(db)	9% mc(db)	11% mc(db)	7% mc(db)	9% Mc(db)	11% mc(db)
1	680	650	640	1180	1160	1140	14.20	15.40	16.38
2	685	660	638	1185	1165	1150	14.23	15.45	16.38
3	690	655	639	1188	1167	1145	14.25	15.43	16.48
4	695	660	640	1188	1163	1150	14.27	15.45	16.35
5	690	655	642	1182	1170	1145	14.28	15.47	16.40
6	698	655	643	1190	1175	1155	14.27	15.48	16.45
7	695	660	644	1189	1163	1140	14.30	15.43	16.47
8	698	660	645	1190	1170	1145	14.31	15.45	16.43
9	695	655	643	1199	1160	1150	14.32	15.48	16.45
10	693	660	645	1198	1165	1155	14.33	15.43	16.47
Mean	691.9	657	641.9	1188.9	1165.8	1147.5	14.276	15.447	16.426
SD	5.781	3.49	2.514	6.065	4.775	5.406	0.041	0.024	0.045

APPENDICES-B

Table B-1a ANNOVA analysis for temperature rise of red chilli in single stage grinding

Moisture content=3 Coefficient of Variation = 0.069

Feed rate = 3 Replication=3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	0.428	0.219	10467.195	1.152	S
Treatments	8	0.857	0.104	5234.590	7.465	S
Factor A	2	0.428	0.219	10467.195	1.152	S
Factor B	2	0.428	0.219	10467.195	1.152	S
A X B	4	0.001	4.092	1.995	0.146	S
Error	16	0.003	2.051	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1%)

Table B-1b ANNOVA analysis for temperature rise of red chilli in double stage grinding

Moisture content=3 Coefficient of Variation = 0.086

Feed rate= 3 Replication =3

ANOVATable						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	0.473	0.236	8547.127	5.846	S
Treatments	8	0.959	0.118	4274.562	3.777	S
Factor A	2	0.473	0.236	8547.127	5.846	S
Factor B	2	0.473	0.236	8547.127	5.846	S
A X B	4	0.002	5.550	1.997	0.147	S
Error	16	0.004	2.788	-	-	-
yTotal	26	-	-	-	-	-

S- significant Significant at (0.1%)

Table B-2a ANOVA analysis for fineness modulus of red chilli in single stage grinding

Moisture content= 3 Coefficient of Variation = 0.078
Feed rate= 3 Replication= 3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	0.009	0.004	378.596	3.365	S
Treatments	8	0.009	0.002	189.467	2.279	S
Factor A	2	0.009	0.004	378.596	3.365	S
Factor B	2	0.009	0.004	378.596	3.365	S
A X B	4	1.803	4.504	0.347	0.841	-
Error	16	2.105	1.313	-	-	-
Total	26	-	-	-	-	-

S- significant Significant at (0.1%)

Table B-2b ANOVA analysis for fineness modulus of red chilli in double stage grinding

Moisture content= 3 Coefficient of Variation = 0.074

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	0.001	0.005	431.296	1.205	S
Treatments	8	0.002	0.002	220.844	6.787	S
Factor A	2	0.001	0.005	451.552	8.434	S
Factor B	2	0.001	0.005	431.296	1.205	S
A X B	4	1.354	3.391	0.268	0.897	S
Error	16	2.088	1.307	-	-	-
Total	26	-	-	-	-	-

S- significant Significant at (0.1%)

Table B-3a ANOVA analysis for average particle size of red chilli in single stage grinding

Moisture content= 3 Coefficient of Variation = 0.005

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	6.401	3.200	473650.325	6.621	S
Treatments	8	0.001	1.605	236826.167	4.262	S
Factor A	2	6.401	3.200	473650.325	6.621	S
Factor B	2	6.401	3.200	473650.325	6.621	S
A X B	4	5.407	1.354	1.999	0.140	S
Error	16	1.089	6.764	-	-	-
Total	26	-	-	-	-	-

S- significant Significant at (0.1%)

Table b-3b ANOVA analysis for average particle size of red chilli in double stage grinding

Moisture content= 3 Coefficient of Variation = 0.006

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	6.521	3.260	456939.195	8.825	S
Treatments	8	0.001	1.635	228470.597	5.680	S
Factor A	2	6.521	3.260	456939.195	8.825	S
Factor B	2	6.521	3.260	456939.195	8.825	S
A X B	4	5.701	1.422	1.999	0.140	S
Error	16	1.148	7.138	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1%)

Table B-4a ANOVA analysis for volatile oil content of red chilli in single stage grinding

Moisture content= 3 Coefficient of Variation = 6.575

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	0.001	0.000	8.027	0.008	S
Treatments	8	0.066	0.005	29.379	3.775	S
Factor A	2	0.027	0.013	51.847	1.015	S
Factor B	2	0.033	0.016	64.535	2.183	S
A X B	4	0.005	0.001	0.558	0.698	S
Error	16	0.001	0.002	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1%)

Table B-4b ANOVA analysis for volatile oil content of red chilli in double stage grinding

Moisture content= 3 Coefficient of Variation = 3.462

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	0.017	0.008	101.193	8.306	S
Treatments	8	0.035	0.008	49.289	7.947	S
Factor A	2	0.010	0.000	81.926	3.920	S
Factor B	2	0.023	0.011	114.269	3.355	S
A X B	4	0.001	4.652	0.476	0.754	S
Error	16	0.005	9.774	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1%

Table B-5 Colour value (L_O, a_O, b_O)of red chilli in single stage and double stage grinding for feed rate and moisture content

S.N 0	Grinding method	Spice	Feed rate(kg/hr)	Colour analysis								
				7%mc(db)			9%mc(db)			11%mc(db)		
				L_o	a_o	b_o	L_o	a_o	b_o	L_o	a_o	b_o
1	Single stage hammer mill	Red chilli	6	44.77	33.26	47.32	45.20	34.20	48.12	46.30	35.18	49.10
			12	44.98	33.52	47.53	45.56	34.54	48.42	46.70	35.44	49.32
			18	45.70	33.78	47.90	46.90	34.80	48.60	47.12	35.74	49.62
2	Double stage hammer mill	Red chilli	6	43.77	32.26	46.32	44.20	33.20	47.12	45.30	34.18	48.10
			12	43.98	32.52	46.53	44.56	33.54	47.42	45.70	34.24	48.45
			18	44.70	32.78	46.90	44.90	33.80	47.60	45.92	34.34	48.76

Table B-6 Colour value (E_{ab}), Hue angle and chroma of red chilli in single stage and double stage grinding for feed rate and moisture content

S.No	Grinding Method	Spice	Feed rate(kg/hr)	Colour Change(E_{ab}^*)			Hue angle(h^*_{ab})			Choma (C^*_{ab})		
				Moisture content % (db)			Moisture content % (db)			Moisture content % (db)		
				7%	9%	11%	7%	9%	11%	7%	9%	11%
1	Single stage hammer mill	Red chilli	6	3.40	3.70	4.10	35.06	35.37	35.60	57.839	59.035	60.32
			12	3.50	3.84	4.20	35 .19	35.50	35.62	58.160	59.476	60.73
			18	3.69	4.07	4.32	35.20	35.60	35.75	58.612	59.77	61.15
2	Double stage hammer mill	Red chilli	6	2.96	3.28	3.71	34.85	35.19	35.39	56.446	57.64	59.00
			12	3.05	3.42	3.82	34.94	35.20	35.24	56.767	58.08	59.32
			18	3.25	3.54	3.90	34.95	35.37	35.15	57.219	58.37	59.63

Table B- 7a ANOVA analysis of colour value of red chilli in single stage grinding

Moisture content= 3 Coefficient of Variation = 0.018

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	0.004	0.002	5136.787	3.410	S
Treatments	8	0.166	0.020	441335.227	2.936	S
Factor A	2	0.026	0.018	281506.504	4.251	S
Factor B	2	0.136	0.068	1469162.728	7.723	S
A X B	4	0.003	0.003	7335.848	6.996	S
Error	16	7.275	4.546	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1%)

Table B - 7b ANOVA analysis of colour value of red chilli in double stage grinding

Moisture content= 3 Coefficient of Variation = 0.012

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	0.005	0.002	3793.454	3.840	S
Treatments	8	0.195	0.021	348229.419	1.953	S
Factor A	2	0.023	0.011	146329.530	7.976	S
Factor B	2	0.178	0.089	1236952.233	3.060	S
A X B	4	0.003	0.003	4817.947	2.016	S
Error	16	1.115	6.941	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1%)

APPENDICES-C

Table C-1a ANOVA analysis of temperature of dry ginger in single stage grinding

Moisture content= 3 Coefficient of Variation = 0.054

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	0.378	0.189	13707.269	1.339	S
Treatments	8	0.757	0.099	6854.636	8.637	S
Factor A	2	0.378	0.189	13707.269	1.339	S
Factor B	2	0.378	0.189	13707.269	1.339	S
A X B	4	0.001	2.732	1.993	0.144	S
Error	16	0.002	1.379	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1%)

Table C-1b ANOVA analysis of temperature of dry ginger in double stage grinding

Moisture content= 3 Coefficient of Variation = 0.232

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	0.474	0.237	978.868	1.868	S
Treatments	8	1.171	0.147	606.908	2.217	S
Factor A	2	0.636	0.313	1316.411	1.772	S
Factor B	2	0.525	0.262	1088.779	8.018	S
A X B	4	0.018	0.007	11.216	0.001	S
Error	16	0.008	0.002	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1%)

Table C-2a ANOVA analysis of fineness modulus of dry ginger in single stage grinding

Moisture content= 3 Coefficient of Variation = 0.009

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	0.002	0.006	124299.487	2.946	S
Treatments	8	0.005	0.003	62150.747	1.897	S
Factor A	2	0.002	0.006	124299.487	2.946	S
Factor B	2	0.002	0.006	124299.487	2.946	S
sA X B	4	4.029	1.007	1.997	0.141	S
Error	16	8.040	5.024	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1%)

Table C-2b ANOVA analysis for fineness modulus of dry ginger in double stage grinding

Moisture content= 3 Coefficient of Variation = 0.003

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	0.002	0.006	115809.474	5.183	S
Treatments	8	0.005	0.003	57905.735	3.343	S
Factor A	2	0.002	0.006	115809.474	5.183	S
Factor B	2	0.002	0.006	115809.474	5.183	S
A X B	4	4.472	1.113	1.996	0.141	S
Error	16	8.948	5.593	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1%)

Table C-3a ANOVA analysis of average particle size of dry ginger in single stage grinding

Moisture content= 3 Coefficient of Variation = 0.112

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	1.446	7.201	2.436	0.112	S
Treatments	8	6.544	8.178	27.620	5.907	S
Factor A	2	3.832	1.911	64.777	2.134	S
Factor B	2	2.236	1.118	37.730	8.764	S
A X B	4	4.735	1.188	4.003	0.015	S
Error	16	4.731	2.954	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1%)

Table C-3b ANOVA analysis of average particle size of dry ginger in double stage grinding

Moisture content= 3 Coefficient of Variation = 0.001

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	8.648	4.329	615516.085	8.145	S
Treatments	8	7.307	9.131	13002706.164	5.165	S
Factor A	2	3.658	1.824	26005327.839	8.028	S
Factor B	2	3.658	1.824	26005327.839	8.028	S
A X B	4	2.378	5.935	84.499	1.506	S
Error	16	1.127	7.022	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1)

Table C-4a ANOVA analysis of volatile oil content of dry ginger in Single stage grinding

Moisture content= 3 Coefficient of Variation = 0.510

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	0.005	0.002	7.524	0.009	S
Treatments	8	0.001	0.003	10.129	5.638	S
Factor A	2	0.009	0.009	25.279	1.118	S
Factor B	2	0.000	0.005	13.132	0.004	S
A X B	4	0.001	4.058	1.033	0.410	S
Error	16	0.006	3.900	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1)

Table C-4b ANOVA analysis of volatile oil content of dry ginger in double stage grinding

Moisture content= 3 Coefficient of Variation = 0.007

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	0.001	0.005	46773.422	7.316	S
Treatments	8	0.002	0.009	75253.244	4.108	S
Factor A	2	0.007	0.008	236333.284	1.724	S
Factor B	2	0.005	0.007	63517.894	6.327	S
A X B	4	2.815	7.038	580.904	4.275	S
Error	16	1.933	1.218	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1)

Table C-5 Colour value (L_O, a_O, b_O)of dry ginger powder in single stage and double stage grinding for feed rate and moisture content

S.N0	Grinding method	Spice	Feed rate (kg/h)	Colour analysis								
				7%mc(db)			8%mc(db)			9%mc(db)		
				L_o	a_o	b_o	L_o	a_o	b_o	L_o	a_o	b_o
1	Single stage hammer mill	Dry ginger	5	66.26	4.42	26.30	67.12	5.12	27.11	68.10	6.13	28.23
			10	66.63	4.78	26.56	67.48	5.55	27.54	68.45	6.45	28.45
			15	66.93	4.92	26.88	67.87	5.88	27.83	68.75	6.75	28.76
2	double stage hammer mill	Dry ginger	5	65.29	3.22	25.20	66.12	4.12	26.11	67.10	5.23	27.23
			10	65.70	3.68	25.56	66.48	4.55	26.54	67.45	5.48	27.45
			15	65.93	3.92	25.88	66.87	4.88	26.83	67.75	5.70	27.76

Table C-6 Colour value (E_{ab}), Hue angle and chroma of dry ginger powder in single stage and double stage grinding for different feed rate and moisture content

S.No	Grinding method	Spice	Feed rate (kg/hr)	Colour change (E_{ab}^*)			Hue angle(h^*_{ab})			Choma (C^*_{ab})		
				Moisture content % (db)			Moisture content % (db)			Moisture content % (db)		
				7%	8%	9%	7%	8%	9%	7%	8%	9%
1	Single stage hammer mill	Dry ginger	5	3.12	3.33	3.90	9.53	10.70	12.24	26.66	27.58	28.88
			10	3.27	3.69	4.01	10.20	11.60	12.73	26.98	28.09	29.17
			15	3.39	3.78	4.12	10.37	11.91	13.17	27.32	28.44	29.54
2	double stage hammer mill	Dry ginger	5	2.54	3.01	3.51	7.30	8.97	10.86	25.40	26.43	27.72
			10	2.77	3.21	3.62	8.25	9.70	11.25	25.82	26.92	28.02
			15	2.91	3.36	3.73	8.58	10.25	11.58	26.17	27.26	28.34

Table C-7a ANOVA analysis for colour value of dry ginger in single stage grinding

Moisture content= 3 Coefficient of Variation = 0.017

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	0.005	0.002	3651.297	5.214	S
Treatments	8	0.211	0.025	387201.929	8.358	S
Factor A	2	0.031	0.010	234922.501	1.800	S
Factor B	2	0.171	0.085	1278598.428	2.346	S
A X B	4	0.008	0.002	17643.382	6.268	S
Error	16	1.095	6.844	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1)

Table C-7b ANOVA analysis of colour value of dry ginger in double stage grinding

Moisture content= 3 Coefficient of Variation = 0.027

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	0.005	0.002	2091.823	4.436	S
Treatments	8	0.316	0.034	288772.037	8.737	S
Factor A	2	0.032	0.011	132698.603	1.741	S
Factor B	2	0.277	0.133	1012913.632	1.519	S
A X B	4	0.005	0.006	4737.951	2.303	S
Error	16	2.180	1.363	-	-	-
Total	26	-	-	-	-	-

S- significant Significant at (0.1)

APPENDICES-D

Table D-1a ANOVA analysis of temperature of fenugreek in single stage grinding

Moisture content= 3 Coefficient of Variation = 0.052

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	0.392	0.191	12579.249	2.664	S
Treatments	8	0.786	0.090	6290.620	1.717	S
Factor A	2	0.392	0.191	12579.249	2.664	S
Factor B	2	0.392	0.191	12579.249	2.664	S
A X B	4	0.001	3.117	1.991	0.145	S
Error	16	0.002	1.551	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1)

Table D-1b ANOVA analysis of temperature of fenugreek in double stage grinding

Moisture content= 3 Coefficient of Variation = 0.630

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	80.292	40.141	619.425	6.986	S
Treatments	8	285.181	35.641	550.000	4.859	S
Factor A	2	76.070	38.030	586.851	1.070	S
Factor B	2	208.969	104.484	1612.000	3.537	S
A X B	4	0.141	0.030	0.574	0.682	S
Error	16	1.030	0.068	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1)

Table D-2a ANOVA analysis of fineness modulus of fenugreek seed in single stage

Moisture content= 3 Coefficient of Variation = 0.979

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	Df	SS	MS	F_{cal}	Fprob	
Replications	2	0.008	0.004	1.409	0.271	S
Treatments	8	0.001	0.006	2.021	0.109	S
Factor A	2	0.007	0.008	2.693	0.090	S
Factor B	2	0.005	0.002	3.966	0.038	S
A X B	4	0.009	0.002	0.727	0.580	S
Error	16	0.000	0.003	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1)

Table D-2b ANOVA analysis of fineness modulus of fenugreek seed in double stage

Moisture content= 3 Coefficient of Variation = 0.166

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	Df	SS	MS	Fcal	Fprob	
Replications	2	0.004	0.002	29.637	4.173	S
Treatments	8	0.001	0.001	17.130	1.754	S
Factor A	2	0.007	0.003	42.273	4.107	S
Factor B	2	0.003	0.001	22.649	2.155	S
A X B	4	6.077	1.514	1.804	0.179	S
Error	16	0.001	8.407	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1%)

Table D-3a ANOVA analysis of average particle size of fenugreek seed in single stage

Moisture content= 3 Coefficient of Variation = 0.008

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	4.712	2.351	875436.315	4.868	S
Treatments	8	9.424	1.170	437719.157	3.132	S
Factor A	2	4.712	2.351	875436.315	4.868	S
Factor B	2	4.712	2.351	875436.315	4.868	S
A X B	4	2.150	5.386	1.999	0.140	S
Error	16	4.301	2.693	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1%)

Table D-3b ANOVA analysis of average particle size of fenugreek seed in double stage grinding

Moisture content= 3 Coefficient of Variation = 0.050

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	5.741	2.870	260.796	6.153	S
Treatments	8	0.001	1.441	130.903	4.161	S
Factor A	2	5.741	2.870	260.796	6.153	S
Factor B	2	5.741	2.870	260.796	6.153	S
A X B	4	4.484	1.128	1.010	0.421	S
Error	16	1.764	1.109	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1%)

Table D-5 Colour value (L_O, a_O, b_O)of fenugreek in single stage and double stage grinding for different feed rate and moisture content

S. No	Grinding method	Spice	Feed rate (kg/hr)	Colour analysis								
				7%mc(db)			9%mc(db)			11%mc(db)		
				L_o	a_o	b_o	L_o	a_o	b_o	L_o	a_o	b_o
	Single stage hammer mill	Fenugreek seed	12	72.26	2.42	42.30	73.12	3.12	43.11	74.10	4.13	44.23
			15	72.63	2.88	42.56	73.48	3.55	43.54	74.45	4.45	44.45
			18	72.93	3.12	42.88	73.87	3.88	43.83	74.75	4.75	44.76
2	Double stage hammer mill	Fenugreek seed	12	71.12	1.52	41.30	72.15	2.18	42.11	73.10	3.13	43.13
			15	71.63	1.98	42.56	72.58	2.85	42.54	73.45	3.55	43.45
			18	71.93	2.12	42.88	72.97	3.10	42.83	73.75	3.95	43.96

Table D-6 Colour value (E_{ab}), Hue angle and chroma of fenugreek seed powder in single stage and double stage

grinding for different feed rate and moisture content

S.No	Grinding method	Spice	Feed rate(kg/hr)	Colour change (E_{ab}^{*})			Hue angle(h^{*}_{ab})			Choma (C^{*}_{ab})		
				Moisture content % (db)			Moisture content % (db)			Moisture content % (db)		
				7%	9%	11%	7%	9%	11%	7%	9%	11%
1	Single stage hammer mill	Fenugreek seed	12	2.92	3.30	3.74	3.27	4.13	5.33	42.36	43.22	44.42
			15	3.10	3.48	3.85	3.86	4.65	5.71	42.65	43.68	44.67
			18	3.24	3.61	3.97	4.15	5.05	6.05	42.99	44	45.01
2	Double stage hammer mill	Fenugreek seed	12	2.34	2.83	3.30	2.10	2.95	4.12	41.32	42.16	43.24
			15	2.78	3.08	3.45	2.66	3.82	4.67	42.60	42.63	43.59
			18	2.91	3.23	3.63	2.82	4.13	5.13	42.93	42.94	44.13

Table D-6a ANOVA analysis of colour value of fenugreek seed in single stage grinding

Moisture content= 3 Coefficient of Variation = 0.010

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MS**	**Fcal**	**Fprob**	
Replications	2	0.005	0.002	3335.758	1.076	S
Treatments	8	0.218	0.024	350737.460	1.843	S
Factor A	2	0.022	0.016	174142.801	1.989	S
Factor B	2	0.196	0.098	1222729.887	3.357	S
A X B	4	0.009	0.002	3038.581	8.028	S
Error	16	1.257	7.838	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1%)

Table D-6b ANOVA analysis of colour value of fenugreek seed in double stage grinding

Moisture content= 3 Coefficient of Variation = 0.065

Feed rate= 3 Replication =3

ANOVA Table						
Source of variation	**Df**	**SS**	**MSM**	**Fcal**	**Fprob**	
Replications	2	0.005	0.002	201.851	4.461	S
Treatments	8	0.311	0.031	29849.191	6.691	S
Factor A	2	0.074	0.037	28776.398	3.561	S
Factor B	2	0.227	0.113	87242.597	4.994	S
A X B	4	0.008	0.002	1688.885	8.723	S
Error	16	2.098	1.311	-	-	
Total	26	-	-	-	-	

S- significant Significant at (0.1%)

CURRICULUM VITAE

The author of this thesis is Er. Swati Mahobiya, D/O Shri Rajesh Kumar Mahobiya, was born on 21st December 1989 at Ranjhi (Jabalpur). She passed her high school with 72 % from MP Board and Higher Secondary with 62 % from MP Board.

She admitted to B.Tech. degree in College of Agricultural Engineering, J. N. K. V. V. Jabalpur (Madhya Pradesh) in the year 2006 and successfully completed the degree in the year 2011 with an OGPA of 6.95 out of 10 point scale.

In the year 2012 she joined "Master of Technology" two year post graduation in the Department of Post Harvest Process & Food Engineering, at College of Agricultural Engineering, J. N. K. V. V., Jabalpur (M.P.). After completing the entire prescribed course work successfully, she has submitted the thesis entitled "Performance Evaluation of Single Stage and Multi Stage Grinder**"** in the partial fulfillment of the requirements for the award of "Master of Technology".

s