

**Studies on the Effect of Single Stage and  
Double Stage Grinding on the Quality  
Attributes of Coriander Powder  
(*Coriandrum sativum L*)**

**THESIS**

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*By*

**MADHURI GAJABE**

**Department of Post-Harvest Process and Food Engineering**

**College of Agricultural Engineering**

**Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur**

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## CERTIFICATE – I

*This is to certify that the thesis entitled “**Studies on the Effect of Single Stage and Double Stage Grinding on the Quality Attributes of Coriander Powder (Coriandrum sativum L)**” submitted in partial fulfilment of the requirement for the degree of **MASTER OF TECHNOLOGY in Agricultural Engineering** in the Department of **POST HARVEST PROCESS AND FOOD ENGINEERING** of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur is a record of the bonafide research work carried out by **MISS MADHURI GAJABE** under my guidance and supervision. The subject of the thesis has been approved by the Student’s Advisory Committee and the Director of Instruction.*

No part of the thesis has been submitted for any other degree or diploma (Certificate awarded etc.) or has been published/published part has been fully acknowledged. All the assistance and help received during the course of the investigation has been acknowledged by her.

Place: Jabalpur

Date:

(Dr. A.K. Gupta)

**Chairman Advisory Committee**

**THESIS APPROVED BY THE STUDENT’S ADVISORY COMMITTEE**

Chairman : Dr. A. K. Gupta -----

Member : Dr. Mohan Singh -----

Member : Dr. B. M. Khandelwal -----

Member : Prof. C. M. Abroal -----

## CERTIFICATE – II

*This is to certify that the thesis entitled “**Studies on the Effect of Single Stage and Double Stage Grinding on the Quality Attributes of Coriander Powder (Coriandrum sativum L)**” submitted by **MISS MADHURI GAJABE** to the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur in partial fulfillment of the requirements 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 Advisory Committee

### MEMBERS OF ADVISORY COMMITTEE

Chairman                      Dr. A. K. Gupta                      -----

Head of Deptt.                Dr. G. S. Rajput                      -----

Director of Instruction      Dr. O. P. Veda                        -----

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**Date:**

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## LIST OF ABBREVIATIONS

|               |   |   |
|---------------|---|---|
| Agril.        | : | Agricultural                            |
| ANOVA         | : | Analysis of Variance                    |
| AOAC          | : | Association of analytical chemist       |
| BD            | : | Bulk density                            |
| CAE           | : | College of Agricultural Engineering     |
| Cm            | : | Centimeter                              |
| Df            | : | Degree of freedom                       |
| Dp            | : | Average particle size                   |
| DHM           | : | Double stage hammer mill                |
| e.g.          | : | Example                                 |
| Engg.         | : | Engineering                             |
| eq.           | : | Equation                                |
| etc.          | : | et cetera                               |
| <i>et al.</i> | : | and others                              |
| Fig.          | : | Figure                                  |
| G             | : | Gram                                    |
| g/ml          | : | Gram per millilitre                     |
| g/g           | : | Gram per Gram                           |
| H             | : | Hours                                   |
| Ha            | : | Hectare                                 |
| i.e.          | : | that is                                 |
| JNKVV         | : | Jawaharlal Nehru Krishi Vishwavidyalaya |
| <i>J.</i>     | : | Journal                                 |
| kg/h          | : | kilogram per hour                       |

|        |   |                         |
|--------|---|-------------------------|
| Kwh    | : | kilo watt hour          |
| Mc     | : | moisture content        |
| Min    | : | Minute                  |
| Mm     | : | Millimeter              |
| m/s    | : | meter per second        |
| MP     | : | Madhya Pradesh          |
| PHT    | : | Post Harvest Technology |
| Rpm    | : | Revolution per minute   |
| SPP.   | : | Spices                  |
| S. No. | : | Serial number           |
| SD     | : | Standard deviation      |
| T      | : | Temperature             |
| Tech.  | : | Technology              |
| Viz.   | : | Videlicet               |
| Wb     | : | wet basis               |
| Wt     | : | Weight basis            |
| %      | : | Percentage              |
| >      | : | Greater than            |
| <      | ; | Less than               |
|        | : | Less than equal to      |
| °C     | : | Degree Celsius          |
| &      | : | And                     |

## INTRODUCTION

India is leading producer of spices in the world. In India, area under spices cultivation is 185.32 lakh hectares with a total production of 701.66 lakh tones. Andhra Pradesh is a leading producer of spices with an area of 73.93 lakh hectares and production of 375.77 lakh tones. Major spices exported from India are coriander, pepper, turmeric, chilies, ginger and cumin.

Coriander (*Coriandrum sativum L.*), commonly known as Dhania, is a medicinal and culinary plant from the Umbelliferae family. It is one of the important spice crops grown in India (Gupta *et al.*, 1991). A native of Eastern Mediterranean region, coriander is now widely cultivated in many other parts of the world for its leaves, seeds and essential oil production.

Coriander is commonly grown in India, Pakistan, Bangladesh, Russia, Central Europe, Morocco, and China (Bhuiyan *et al.*, 2009). In India it is mainly cultivated in Andhra Pradesh, Madhya Pradesh, Tamil Nadu, Orissa, Karnataka, Bihar, Uttar Pradesh and Haryana. In 2012, area under coriander cultivation in India is 348.9 million hectare with total production of 248.0 million tonne.

The seeds of coriander are small, almost ovate globular, approximately 3 to 5 mm in diameter. Coriander seeds are brown coloured when dried. The seeds, either in whole form, or in the powder, possess a mild, sweet, and slight pungent odour and are extensively used as condiments. The seeds are also used as a flavoring agent in different foods namely pastries, cookies, buns, cakes and breads (Akgul, 1993; Karababa and Coskuner, 2007). In addition to the traditional food uses, these have been widely used in the folk medicine system as carminative, spasmolytic and digestive aid. Chemically, coriander seed comprises two important constituents viz. the essential oil and the fatty oil. Depending upon varieties and agro climatic factors, the essential oil content and fatty oil content from dried coriander seeds varies from 0.03 to 2.60% and 9.9 to 27.3%, respectively. Coriander seed essential oil is mainly composed of linalool, together with some other oxygenated monoterpenes and monoterpene hydrocarbons. The concentration of linalool, the major

component of essential oil, varies mostly between 50 and 70% (Argonosa *et al.*, 1998; Karababa and coskuner, 2007).

Coriander is consumed normally in powdered form. The size reduction of coriander is done by mechanical means without changing chemical properties of the ground product. Grinding' is basically a size reduction process. Enormous quantity of heat energy is generated during grinding which rises temperature of ground spices, the mill and the ambient air. A part of the heat energy is utilized in vaporising the moisture. The temperature of the product being grounded usually rise above 40<sup>0</sup>C (Perry and Hall, 1965).

The rise in temperature of spices subjected to grinding is mainly responsible for vaporising of volatile oil of spices, thus resulting in degradation of aromatic quality of spices. The grinding of coriander seed in India is usually done at small scale and all the size reduction machine involve high speed shearing and impact action as in attrition and hammer mill. Due to high temperature generated during grinding process ground spices rises quickly above the temperature of vaporization of volatile oils, thus reducing the quality of the product. To minimise this problem, spice milling is normally carried out under conditions which minimize both air flow rate and elevated temperature (McCabe, *et al* 1985).

Therefore, the present study is planned for comparative study of single stage and double stage grinding of coriander.

The objectives of proposed study are given below.

1. To study the physical properties of coriander at different moisture level.
2. To study the performance of selected single stage and double stage hammer mill on grinding, biochemical and sensory characteristics of coriander.
3. To work out economics of production of coriander powder.

## REVIEW OF LITERATURE

Grinding is an age-old technique and its main aim is to obtain a product of small size particles with good quality in terms of flavour and colour. During grinding, the temperature of product rises to a level of range of 42-45°C (Pruthi and Mishra,1963). Due to rise in temperature during spices grinding lose a significant fraction of their volatile oil or flavouring compounds. In this chapter the previous work done are presented in sequences.

### 2.1 Physical Properties of Spices

Visvanathan *et al.* (1989) studied the effect of moisture content on angle of repose and bulk density of selected food grains and reported that the angle of repose for sorghum, Pearle millet, kodo millet, fox tail millet and little millet increase linearly with the increase of moisture content and the bulk density decreased linearly for all the grain with the increase of moisture content. Regression equation was fitted and the correlation coefficient was found to vary from (0.90 to 0.99).

Goswami *et al* (2002) studied the effect of moisture content on major physical properties of black pepper (*Piper nigrum*) as a function of seed moisture content range of 5 to 25% (db). It was observed that the physical properties viz., average length, width, thickness and equivalent diameter increased with increase in moisture content. The surface area, seed volume, thousand seed mass and true density increased from 66.67 to 72.52 mm<sup>2</sup>, 46.38 to 52.43 mm<sup>3</sup>, 47.34 to 54.44 g and 1108 to 1509 kg/m<sup>3</sup>, respectively, with increase in moisture content. However, in case of sphericity and specific surface area of black pepper, reverse trend was obtained. Similarly, angle of repose, terminal velocity and porosity increased from 30.86° to 38.23°, 8.8 to 10.5 m.s<sup>-1</sup> and 52 to 67%, respectively, with increase in moisture content. The bulk density increased initially from 534.6 to 562.8 kg/m<sup>3</sup> and then decreased from 562 to 504.6 kg/m<sup>3</sup> with increase in moisture content.

Karababa and Coskuner (2007) evaluated the physical properties of coriander seeds as a function of seed moisture content, varying from 7.10% to 18.94% (d.b.). In the moisture range under investigation, seed length decrease linearly from 4.76 to 4.61 mm, and width, thickness, arithmetic mean diameter increased linearly from 3.67 to 3.93 mm, 3.39 to 4.03 mm and 3.88 to 3.99 mm, respectively with increase in moisture content. The true density increased nonlinearly with moisture content from 332 kg/m<sup>3</sup>, while the bulk density decreased linearly 234.1 to 220.2 kg/m<sup>3</sup>. Porosity of coriander seed increased nonlinearly from 33.03% to 35.79%.

Balasubramanian *et al.*, (2011) determined physical properties of coriander seeds at moisture content varying from 3.5 to 17.7%, d.b. The major axis and 1, 000 seeds mass were found to decrease nonlinearly with increase in seed moisture. The medium and minor axes, geometric mean diameter, sphericity, unit volume, surface area and angle of repose of coriander seed increased linearly. Bulk density decreased linearly, however the true density increased non-linearly. The coefficient of static friction increased nonlinearly for different surfaces with increase in moisture level and its maximum was found for plywood surface. The rupture force and energy absorbed decreased linearly with increasing moisture content.

## **2.2 Grinding Methods used for Spices**

The hand operated processes were used in India for house hold processing of spices. In such method generally deshi grinder and Khalbattas were commonly used. The first roller mill appeared in Russia as early as 1882 and was improved in later year for the processing of food grains and spices.

Wistriech and Schafer (1962) stated that in conventional grinding of spices, the mill and product temperature rises as high as 95°C and as a result of which there is considerable loss of volatile oil.

Kuprit (1967) has defined the various stages of grinding in case of grain. In first phase of grinding, elastic deformation occur which follows the Hooke's law. In the second phase mainly plastic deformation occur, with develop of cracks in the grain. In the third phase gain are partially ruptured and rupturing strength increases considerably, while the linear deformation of

the grain is only slight. Crusher and grinder are type of comminuting equipment used for the size reduction. Reducing the particle size increases the reactivity of the solids. It permits separation of unwanted ingredients by mechanical methods. It is also used to reduce the bulk of fibrous material for easier handling. It was also found that during the grinding period the particles are subjected to impact and friction against the screen, and depending on their size, they either pass through the screen holes or remain on it and then further ground till they become eligible to pass through the screen.

Anderson *et al.* (1971) developed an abrasive milling process in which 16-18 percent of the initial weight of the grain was removed by using an abrasive rice mill.

Rao *et al.* (1993) has reported that the energy required to grind the solids depends on the initial moisture content of the product. It is beneficial to dry solids before grinding to reduce the energy consumption during grinding. Development of spices processing made significant progress before the stage of our modern enterprises was reached. Many years have passed from the time of the simple equipment of the primitive man, to the modern, fully mechanized and automatic industries for processing grain. The performance mechanism, the power tool of the machine, was gradually modified from the primitive action on grain i.e. rubbing in a mortar, to splitting by millstones and complex deformation in the roller mill.

Murthy *et al.* (1998) studied that the loss of volatile oil during grinding could be overcome partly by lowering or maintaining the mill temperature as low as possible (less than the boiling temperature of the volatile constituents of the spices volatile oil). This could be achieved by grinding the spice in a cryogenic condition and to some extent by circulating the chilled water around the grinding zone.

Goswami *et al.* (2002) Experiment on grinding of cumin seed were carried out in a double disc, single rotating, attrition mill to find the effect of feed rate and temperature of cumin on some dependent variables such as rise of temperature and size of ground cumin, specific energy consumption and Bond's work index. Temperature was lowered with the help of liquid

nitrogen. There was a gradual increase in temperature rise, and decrease in size of the ground cumin, but the specific energy consumption and work index were decreased first and then increased with increase in feed rate of cumin in the attrition mill.

Sowbhagya *et al.* (2006) evaluated the effect of grinding/flaking with and without pre-cooling of celery seeds on the yield and physical and chemical characteristics of volatile oil. For smaller batches (200g) with pre-chilling and flaking, yields of oil were marginally but consistently higher (2.20%), compare to grinding celery at ambient temperature using a mini plate mill (1.9%) and with warring blender (1.8%). With flaking at room temperature the yield of oil was 2.0 %. However, in large batches (10Kg), with steam distillation the yield of steam distilled oil was significantly higher for flaking (1.76%) as compared to the hammer mill powdering (1.4%), both at room temperature. Extraction of volatile oil from celery powder or flakes follows first order kinetics with an variance value of 0.04. Gas Chromatograph-mass spectra (MS) analysis showed that in case of flaking, the volatile oil had higher levels of limonene, the major volatile compound, the major character impact compound being present in almost equal quantities in both the cases of flakes and powder.

Agrawal *et al.* (2007) has reported that the turmeric and coriander were ground in pin mill, burr mill, hammer mill, cool jacketed hammer mill and CIAE grain mill. Maximum temperature rise (60<sup>0</sup>C) during grinding was attained in pin mill and maximum (38<sup>0</sup>C) was in cool jacketed hammer mill. Grinding method, which showed the highest temperature rise during grinding, resulted in finest grinding of 0.0452 and 0.0652 mm for turmeric and coriander, respectively when ground in pin mill.

Choudhary (2012) studied that the effect of double stage grinding on quality attributes of turmeric powder. Physical properties like length, width, thickness were determine at three moisture content is 11,13 and 15% (wb) were measured as 4.48, 1.34, 1.23 cm, Bulk density(618 kg/m<sup>3</sup>), true density (1477 kg/m<sup>3</sup>) and angle of repose (30°). In single stage and double stage grinding the rise in temperature were observed 32 to 50 °C and 28 to 43 °C respectively. Volatile oil content of turmeric powder was found 1.9 to 3.1 ml

and 2.4 to 3.4 ml per 100g of powder during single stage and double stage grinding respectively, Fineness modulus 1.05 to 1.40 & 1.02 to 1.35. The particle size for turmeric powder varied from 0.187 to 0.215 and 0.185 to 0.205 for S.S.G and D.S.G respectively.

### **2.3 Colour analysis of spice powder**

Pesek *et al.* (1986) studied the effect of cryogenic and ambient milling on the colour of spices influencing spice quality. A Hunter lab color Difference Meter and sensory analyses were comparable to ambiently milled spices. Cryogenically milled spices are lighter in color than ambiently milled spices and untrained panelists were able to detect the differences ( $P = 0.038$ ).

Meghwal and Gosawami (2010) studied ambient and cryogenic grinding to test the novelty of cryogenic grinding and to pin point 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 (2.15ml/100g) content was found in cryogenic grinding and also powder of freshness and lower whiteness (40%) and higher yellowness (14%) indices found for cryogenic grinding.

### **2.4 Fineness modulus and particle size**

Jindal and Austin (1976) measured the kinetics of breakage of maize in a small laboratory hammer mill in which rigid blades were used as hammers. It was found that breakage was first order function and that the primary breakage was insensitive to mill condition or moisture content of the grain was reduced showing that the dried material was more brittle and a minimum rotation speed was necessary to get significant breakage.

Kapur (1982) proposed an improved method for estimating the feed size breakage distributions functions and found it to be highly accurate. The method was not restricted to the short grinding time data and was not subjected to any restrictive interrelationship between breakage functions. In case of grinding of grain one is mainly concerned with the size of the ground

product. There is several specification of the ground product according to the size of flour. A complete distribution is generally specified in terms of cumulative percent oversize or undersize in relation to the size of particle, or as the differential fraction present in different size ranges. It is commonly specified weight of total sample.

Singh and Sahay (2001) told that fineness modulus indicates the uniformity of grinding in resultant product. It is determined by adding the weight fractions retained above each sieve and dividing the sum by 100. The average practical in mm is represented in terms of fineness modulus and can be estimated by following standard equation

$$D_p = 0.135x (1.366)^{F_m}$$

Where,

$D_p$  = Average particle size diameter, mm

$F_m$  = Fineness modulus

Gautam (2002), the study was conducted on grinding experiment of commercial grade coriander in batches, semi-continuous and continuous grinding in hammer mill. In batch experiment, the effect of mass size, mill speed and time of grinding on power requirement, energy consumption and particle size distribution was studied. It was found that the case power consumption can be expressed by.  $P = at^b$

Zhao *et al.* (2009) studied the superfine grinding could produce a narrow and uniform particle size distribution in dry ginger. The physical chemical properties of five types of ginger powders with particle size of 300, 149, 74, 37 and 8.34  $\mu\text{m}$  were investigated. The size was smaller for ginger powders, greater for the surface area (from 0.331 to 1320  $\text{m}^2/\text{g}$ ) and bulk density (from 0.3096 to 0.3426g/ml) and smaller to angle of repose (from 51.50 to 46.33) and slide (from 45.80 to 39.50). 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  $\mu\text{m}$  during soaking reached 0.52g/g, 33.70% and 84.93% for 60 min.

## 2.5 Volatile oil

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

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

Sangani *et al.* (2005) have reported distillation of essential oil by hydro distillation from ground cumin having different particle size of mesh for the maximum yield of oil by hydro distillation.

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

Mohammad *et al.* (2006) compared subcritical water extraction (SCWE), hydrodistillation and soxhlet extraction for the extraction of essential oil from coriander seeds (*Coriandrum sativum* L.). The extraction efficiencies of different temperatures (100, 125, 150 and 175 °C), mean particle sizes (0.25, 0.50 and 1 mm), and water flow rates (1, 2 and 4 ml/min) were investigated. Separation and identification of the components were carried out by GC–FID and GC–MS. The results showed that the optimum temperature, mean particle size, and flow rate were 125 °C, 0.5 mm, and 2 ml/min. The SCWE was compared with both conventional methods in terms of the efficiency and the essential oil composition. Hydrodistillation and Soxhlet extraction showed higher extraction efficiencies, but the SCWE resulted to the essential oils more concentrated in valuable oxygenated components.

Mara *et al.* (2007) investigated that (*Curcuma longa* L.) is a common species among the aromatic plants in Brazil. The roots are used in dairy food

as colorant and flavoring substitute for saffron. Turmeric (*Curcuma longa L.*) contains curcuminoids that have ant mutagenic and antioxidant activities, and is thus used for the formulation of food for the prevention of cancer. Turmeric extracts rich in curcuminoids were obtained using a mixture of CO<sub>2</sub> and EtOH/IsoC<sub>3</sub>, and the assays were performed in a fixed bed extractor at 300 bar, 303 K. The bed's height effect was studied, maintaining constant the bed diameter and porosity, for the accelerated solvent extraction, the co solvent percentages used were 10, 50, and 90% (v/v), with or without a static period of 30 min. The curcuminoids content was monitored using a spectrophotometer, the volatile oil was analyzed by gas chromatography-flame. Ionization detector, and the extract chemical profile was observed by thin-layer chromatography. The overall extraction curves showed that by keeping the relation between solvent and raw material constant, maximum extraction yield was obtained in a shorter time using the lowest bed height ( $H_B/D_B= 1.8$ ). The supercritical fluid extraction using 50 % of the co solvent that employed the static period increased the curcuminoids content (0.72%) of curcuminoid.

Gantail *et al.* (2010) developed a method of an efficient, sensitive, and precise high-performance thin layer chromatography (HPTLC) for determination of curcumin in several marketed spices sample of turmeric powder and has been compared with an in house turmeric powder. Recovery values from 99.60 to 99.73 % showed that the reliability and reproducibility of the method were excellent.

Anwar *et al.* (2011) investigated that physicochemical composition of hydro-distilled essential oil from coriander (*Coriandrum sativum L.*) Hydrodistilled 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<sup>3</sup>, 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%), -terpinene (4.17%), -pinene (1.63%), anethol (1.15%) and *pcymene* (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.

## **MATERIAL AND METHODS**

The present chapter describes the details of materials used and the methods employed for the determination of various physical and grinding characteristics of whole coriander seeds using single stage and double stage grinding.

### **3.1 Material**

#### **3.1.1 Coriander**

The coriander seeds of CIMPOS-33 variety were procured in bulk from the Directorate Farms, JNKVV, Jabalpur. After cleaning seeds were stored at room temperature (25°C) for one month (August) for moisture equilibration in poly bags. The moisture content of the coriander seeds, after equilibration, as determined by the ASTA (1983) method, was observed to be 7.2 % (wb).

#### **3.1.2. Packaging material**

Low density polyethylene bags (LDPE), procured from the local market, was used for packaging of coriander powder.

#### **3.1.3. Chemicals**

All the chemicals viz. Sodium sulphate (anhydrous) and toluene required for conducting the present study were procured from the local market.

### **3.2 Methods**

#### **3.2.1 Experimental Plan**

The grinding behaviour of coriander was studied using single and double stage grinding in a hammer mill under different operational conditions. The experimental plan for the determination of physical and grinding characteristics of the coriander seed using single and double stage grinding is presented in Table 3.1. All the experiments were replicated thrice.

**Table 3.1 Experimental Plan**

| S. No | Independent variable  |       | Dependent variable  |
|-------|---|-------|---|
|       | Parameter   | Level | Measuring parameter   |
| 1     | Grinding method<br>a) Single stage hammer mill<br>b) Double stage hammer mill | 2     | <b>I) Physical properties of coriander</b><br><br>A. Size and Shape<br><br>B. One thousand seed weight<br><br>C. Bulk density<br><br>D. True density<br><br>E. Dynamic angle of repose<br><br><b>II) Grinding characteristics</b><br><br>A. Temperature of powder during grinding (°C)<br><br>B. Fineness modulus<br><br>C. Particle size analysis<br><br><b>III) Physical properties of coriander oil</b><br><br>A. Volatile oil<br><br>B. Specific gravity of oil<br><br>C. Refractive index of oil<br><br><b>IV) Colour analysis</b> |
| 2     | Feed rate<br><br>6, 8, 10, 12 kg/h.   | 4     |   |
| 3     | Moisture content (around)<br><br>7, 9, 11, 13% (wb)                           | 4     |   |

In all the experiments the speed of the hammers was 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 of the coriander seed. The level of coded variables, design matrix for single stage hammer mill and double stage hammer mill are presented in Table 3.2, 3.3 and 3.4, respectively. There are 48 experiments in each grinding mill along with three replication. The levels of different variable decided on the basis of previous work and preliminary experiments are given in table 3.2.

### 3.2.3 Data analysis

The symmetrical factorial CRD (completely randomized design) was used for the present set of experiments as it provides sufficient information for statistically acceptable results in terms of ANOVA. In this analysis two factor moisture content and feed rate with four level of each factor along with three replication. ANOVA table were prepared for determine the effect of feed rate and moisture content on temperature rise during milling, average particle size, volatile oil content and colour of the coriander powder during single and double stage grinding.

**Table: 3.2 Levels of coded variables**

| Experimental variable                    | No. of levels | Levels           |              |
|--|---------------|------------------|--------------|
|  |               | Coded            | Actual value |
| <b>Independent variable</b>              |               |                  |              |
| <b>A. Single Stage Hammer Mill (SHM)</b> |               |                  |              |
| Moisture Content (%)                     | 4             | X <sub>s</sub> 1 | 7            |
|  |               | X <sub>s</sub> 2 | 9            |
|  |               | X <sub>s</sub> 3 | 11           |
|  |               | X <sub>s</sub> 4 | 13           |
| Feed Rate (kg/h)                         | 4             | Y <sub>s</sub> 1 | 6            |
|  |               | Y <sub>s</sub> 2 | 8            |
|  |               | Y <sub>s</sub> 3 | 10           |
|  |               | Y <sub>s</sub> 4 | 12           |
| <b>B. Double Stage Hammer Mill (DHM)</b> |               |                  |              |
| Moisture Content (%)                     | 4             | X <sub>D</sub> 1 | 7            |
|  |               | X <sub>D</sub> 2 | 9            |
|  |               | X <sub>D</sub> 3 | 11           |
|  |               | X <sub>D</sub> 4 | 13           |
| Feed Rate (kg/h)                         | 4             | Y <sub>D</sub> 1 | 6            |
|  |               | Y <sub>D</sub> 2 | 8            |
|  |               | Y <sub>D</sub> 3 | 10           |
|  |               | Y <sub>D</sub> 4 | 12           |

**Table 3.3 Experimental design matrix for single stage grinding method**

| <b>S. No.</b> | <b>Coded value</b> |        | <b>Actual value</b> |    |
|---------------|--------------------|--------|---------------------|----|
| 1             | $X_s1$             | $Y_s1$ | 7                   | 6  |
| 2             | $X_s1$             | $Y_s2$ | 7                   | 8  |
| 3             | $X_s1$             | $Y_s3$ | 7                   | 10 |
| 4             | $X_s1$             | $Y_s4$ | 7                   | 12 |
| 5             | $X_s2$             | $Y_s1$ | 9                   | 6  |
| 6             | $X_s2$             | $Y_s2$ | 9                   | 8  |
| 7             | $X_s2$             | $Y_s3$ | 9                   | 10 |
| 8             | $X_s2$             | $Y_s4$ | 9                   | 12 |
| 9             | $X_s3$             | $Y_s1$ | 11                  | 6  |
| 10            | $X_s3$             | $Y_s2$ | 11                  | 8  |
| 11            | $X_s3$             | $Y_s3$ | 11                  | 10 |
| 12            | $X_s3$             | $Y_s4$ | 11                  | 12 |
| 13            | $X_s4$             | $Y_s1$ | 13                  | 6  |
| 14            | $X_s4$             | $Y_s2$ | 13                  | 8  |
| 15            | $X_s4$             | $Y_s3$ | 13                  | 10 |
| 16            | $X_s4$             | $Y_s4$ | 13                  | 12 |

**Table 3.4 Experimental design matrix for double stage grinding method**

| <b>S. No.</b> | <b>Coded value</b> |        | <b>Actual value</b> |    |
|---------------|--------------------|--------|---------------------|----|
| 1             | $X_D1$             | $Y_D1$ | 7                   | 6  |
| 2             | $X_D1$             | $Y_D2$ | 7                   | 8  |
| 3             | $X_D1$             | $Y_D3$ | 7                   | 10 |
| 4             | $X_D1$             | $Y_D4$ | 7                   | 12 |
| 5             | $X_D2$             | $Y_D1$ | 9                   | 6  |
| 6             | $X_D2$             | $Y_D2$ | 9                   | 8  |
| 7             | $X_D2$             | $Y_D3$ | 9                   | 10 |
| 8             | $X_D2$             | $Y_D4$ | 9                   | 12 |
| 9             | $X_D3$             | $Y_D1$ | 11                  | 6  |
| 10            | $X_D3$             | $Y_D2$ | 11                  | 8  |
| 11            | $X_D3$             | $Y_D3$ | 11                  | 10 |
| 12            | $X_D3$             | $Y_D4$ | 11                  | 12 |
| 13            | $X_D4$             | $Y_D1$ | 13                  | 6  |
| 14            | $X_D3$             | $Y_D2$ | 13                  | 8  |
| 15            | $X_D3$             | $Y_D3$ | 13                  | 10 |
| 16            | $X_D3$             | $Y_D4$ | 13                  | 12 |

### 3.2.4 Preparation of the samples

#### 3.2.4.1 Preparation of seed at different moisture content

To obtain coriander seeds with different moisture contents, a fine spray of water was applied using a spray gun. Time of spray was varied to obtain coriander 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

$$W_1 (100+M_1) = W_2 (100+M_0) \quad (3.1)$$

Where,

$M_0$  = Initial moisture content

$M_1$  = Final moisture content of dried & sprayed sample

$W_1$  = Initial weight of the seeds at  $M_0$

$W_2$  = Final weight of seeds at  $M_1$

#### 3.2.4.2 Coriander Powder

Coriander powder was prepared by using single stage and double stage hammer mill and Fig. 3.1 represents the process flow chart.

**Process for the preparation of coriander is discussed below:**

- 1. Reception of raw material:** The coriander seeds of variety (CIMPOS-33) were procured from the Directorate of Farms, JNKVV, Jabalpur (Plate 3.1).
- 2. Grading:** The material was graded into various fractions namely coriander seeds, grit and dust.
- 3. Cleaning and Destoning:** The material was cleaned or de-stoned using a sieve.
- 4. Storage:** The material was stored for a period of one month at 25°C.
- 5. Grinding:** The seeds at different moisture content were ground into coriander powder using single stage and double stage hammer mill.
- 6. Packaging and storage:** The powder of coriander (Plate 3.2) so formed was packed and stored for the experimental purpose.



**Plate 3.1 Coriander seed**



**Plate 3.2 Coriander Powder**

**Raw material (Coriander seed)**



**Grading**



**Cleaning & destoning**



**Storage (1 month at 25<sup>0</sup>C)**



**Grinding (Single stage and Double stage)**



**Coriander powder**



**Packaging & Storage**

**Fig.3.1 Process flow chart for the preparation of coriander powder**

### 3.2.4.3 Extraction of volatile oil from the coriander powder (Clevenger's method)

The experimental setup of Clevenger apparatus is shown in Plate 3.3. The total volatile oil contents of coriander powder were determined by ASTM (1965) method employing Clevenger apparatus with 50 g powder. The volatile oil distilled was measured at interval of 30 min. The heater of apparatus was put off for 2 minutes before taking each reading of the volatile oil distilled. The distillation was continued until two consecutive reading were almost the same. Average value of volatile oil content on moisture free basis (ml/100g) was reported with standard deviation. The volatile oil obtained from coriander sample were analysed for its physical properties with specific gravity.



**Plate 3.3: Experimental set up of Clevenger apparatus**

### 3.2.5 Determination of experimental parameters

#### 3.2.5.1 Physical properties of the coriander seed

##### 3.2.5.1.1 Size and shape

The size (diameter) of the coriander seed was measured to  $\pm 0.01$  mm accuracy using a digital vernier calliper at five different orientations of 100 seeds. Size distribution at 0.20 mm interval was reported. The geometric mean diameter,  $D_g$  of the seed was calculated by using following relationship.

$$D_g = (\text{LWT})^{1/3} \quad (3.2)$$

The individual coriander seed was apparently spherical in shape, the sphericity was determined using as recommended by (Mohsenin, 1986).

$$\text{Sphericity } (\emptyset) = (\text{LWT})^{1/3} / L \quad (3.3)$$

##### 3.2.5.1.2 One thousand seed weight

The weight of 1000 seed was obtained by counting 250 seeds at desired moisture content and weighed on an electronic balance and then multiplied by 4 to give the mass of 1000 seeds. (Balasubramanian, 2011)

##### 3.2.5.1.3 Bulk density

The bulk density of the coriander seeds was determined by weighing a container filled with coriander seed (two gentle tapping were applied). The reported values were the mean  $\pm$  standard deviation (S.D) of three such replication.

$$\text{Bulk Density} = \frac{\text{Mass of sample}}{\text{Volume of flask occupied by the sample (cm}^3\text{)}} \quad (3.4)$$

##### 3.2.5.1.4 True density

The true density, as a function of water content, was determined using the liquid (toluene) displacement method in order to avoid absorption of water during experiment. The seeds were used to displace toluene in a measuring cylinder after their masses had been measured. The true density was found as an average of the ratio of their masses to the volume of toluene displaced by the seeds, (Jha, 1999; Singh & Goswami, 1996).

$$\text{True density} = \frac{\text{Weight of sample (g)}}{\text{Volume displaced (cm}^3\text{)}} \quad (3.5)$$

### 3.2.5.1.5 Dynamic angle of repose

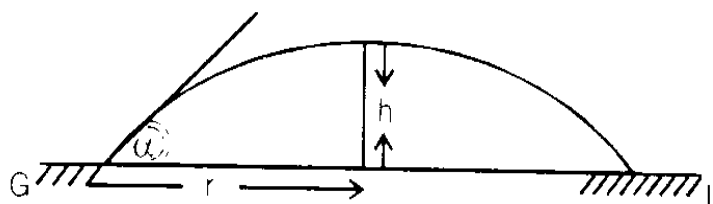
The angle of repose is the angle between the base and the slope of the cone formed on the vertical fall of the granular material on a horizontal plane. The size, shape, moisture content and orientation of kernel affect the angle of repose. Angle of repose was calculated by making the regular heap by dropping the coriander seed through funnel over smooth surface. The height and diameter of the heap were measured by measuring tape. Angle of repose was measured by following relation.

$$\text{Angle of repose (degree)} = \tan^{-1} (2h/D) \quad (3.6)$$

Where,

H = height of pile

D = the base (dia.)



**Fig 3.2 Angle of repose**

### 3.2.5.2 Physical properties of coriander oil

#### 3.2.5.2.1 Specific gravity of the coriander oil

Specific gravity or relative density at 27<sup>0</sup>C means the ratio of densities of the liquid material at 27<sup>0</sup>C to that of distilled water at 27<sup>0</sup>C. The specific gravity bottle (10 ml capacity) was washed and cleaned with alcohol and diethyl ether. It was then dried in a current dry air. The empty specific gravity bottle was weighed (measured accurately) and was filled with distilled water at 27<sup>0</sup>C taking care to avoid the presence of air bubble. It was then immersed in water bath maintained at 27 ± 0.2<sup>0</sup>C for 30 minutes. The temperature of water was checked and level of distilled water was adjusted to the mark. The specific gravity bottle was closed by using a stopper and the outer side was weighed carefully with dry filter paper. It was then weighed in the same balance.

$$\text{Specific gravity} = \frac{A-B}{C-B} \quad (3.4)$$

Where,

A = weight of specific gravity bottle with oil (g)

B = weight of empty specific gravity bottle (g)

C = weight of specific gravity bottle with water (g)

### 3.2.5.2.2 Refractive index of the coriander oil

The refractive index of coriander powder was determined by standard A.O.A.C. official 921.08 methods. Measurement of the refractive index of the sample is done by using butyro refractometer.

### 3.2.5.2.3 Grinding characteristics

Fineness modulus and particle size were calculated to show the effect of single stage grinding and double stage grinding on the average particle size of ground product. The fineness modulus indicates the uniformity of grinding in resultant product. It is determined by adding the weight fractions retained above each sieve and dividing the sum by 100. The average particle size in mm is represented in terms of fineness modulus and can be estimated by

$$FM = \frac{\sum M.FXW_i}{\sum W_i} \quad (3.8)$$

$$D = \log^{-1} \left[ \frac{\log d_i X W_i}{\sum W_i} \right] \quad (3.9)$$

Where,

D = Average particle size diameter (mm)

FM = Fineness modulus (dimensionless)

$d_i$  = Geometric mean diameter of particle on  $i^{\text{th}}$  sieve

$w_i$  = weight fraction of material on  $i^{\text{th}}$  sieve

### 3.2.5.4 Colour analysis

#### 3.2.5.4.1 Total Colour Change

The total colour change is given by the colour difference ( $E_{ab}^*$ ) in terms of the spatial distance between two colour points interpreted in the colour space (Hunter, 1987):

$$E = [(L_o - L_i) + (a_o - a_i) + (b_o - b_i)]^{1/2} \quad (3.10)$$

Where,

L= Lightness

a = Redness/ Greeness

b= Yellowness/ Bluness

The subscript o and i denote the colour parameters of dried coriander and coriander powder, respectively. The higher E represents greater colour change from the dried coriander.



Plate 3.4 Hunter colour lab

#### 3.2.5.4.2 Hue angle

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

$$= \tan^{-1}(b/a) \text{ or} \quad (3.11)$$

$$= \tan^{-1}(a/b) \quad (3.12)$$

### 3.2.5.4.3 Chroma

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

$$C^*_{ab} = (a^2 + b^2)^{1/2} \quad (3.13)$$

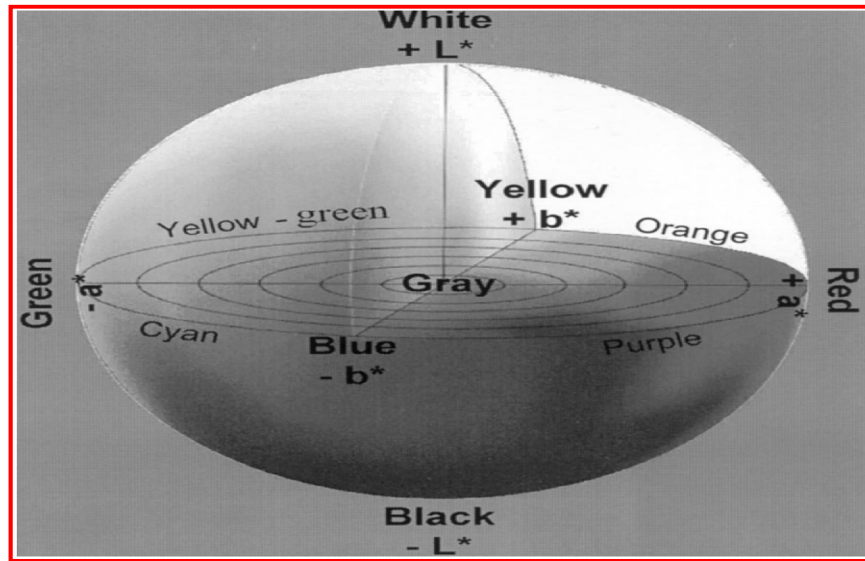


Fig. 3.3 Hunter Colour Wheel

### 3.2.5.4.4 Browning Index

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

$$Bi = \frac{100(X-0.31)}{0.71} \quad (3.14)$$

$$X = \frac{(a+1.75L)}{(5.645+a-3.012b)} \quad (3.15)$$

## 3.3 Experimental setup

### 3.3.1 Hammer mill (single stage and double stage)

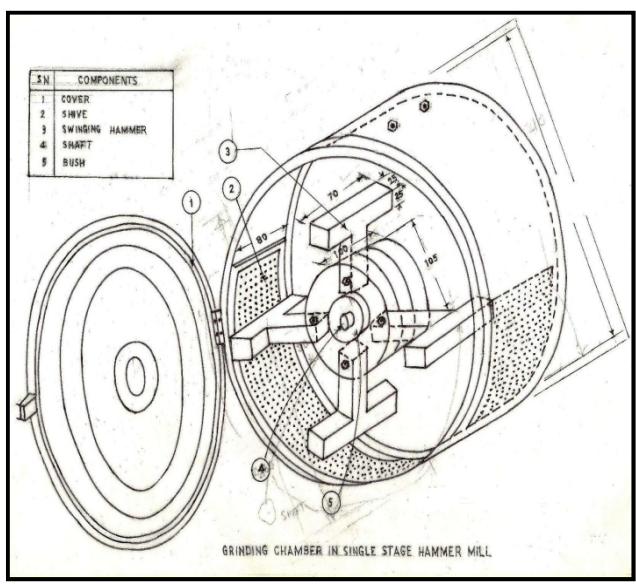
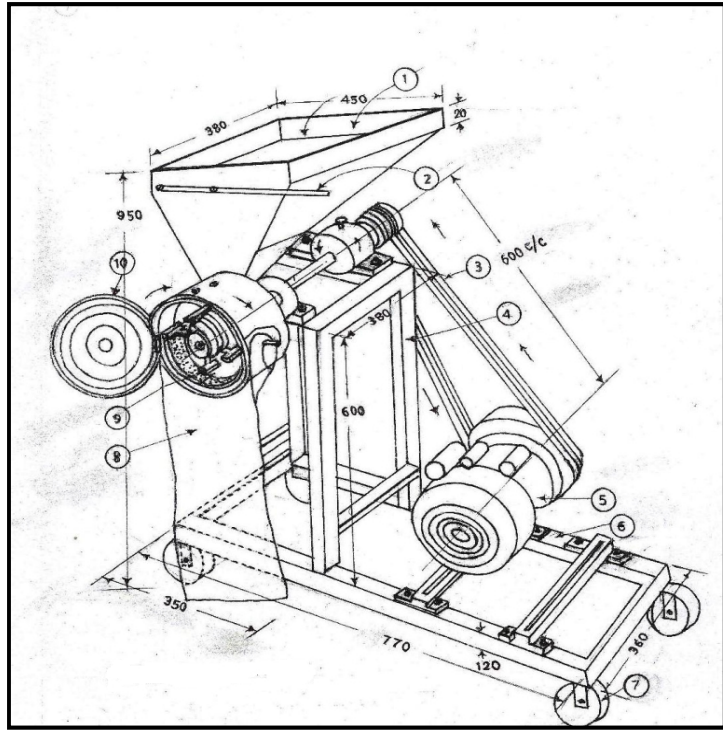
Hammer mills are used for various type of size reduction by impact forces. Hammer mills operate on the principle that most of the material will grind or crush upon the impact of swinging hammer. These mills contain a high speed rotor, rotating inside a cylindrical casing thus shaft is usually kept horizontal. 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 3.5). The isometric view of single stage and double stage hammer mill is show in Fig. 3.4 and 3.5 and plate 3.5 (a), (b).

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

**Table 3.5 Specification of single stage and double stage hammer mill used for the preparation of coriander powder.**

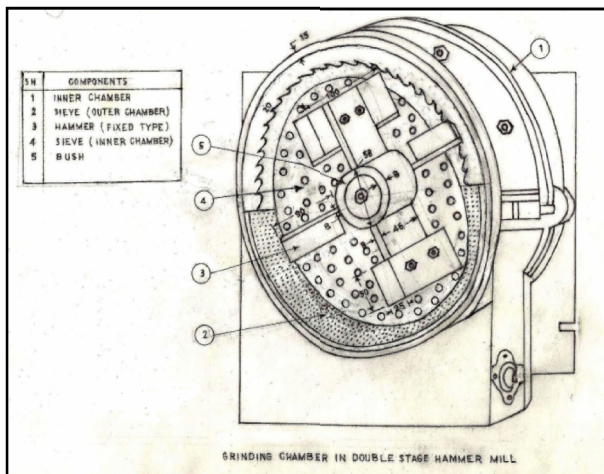
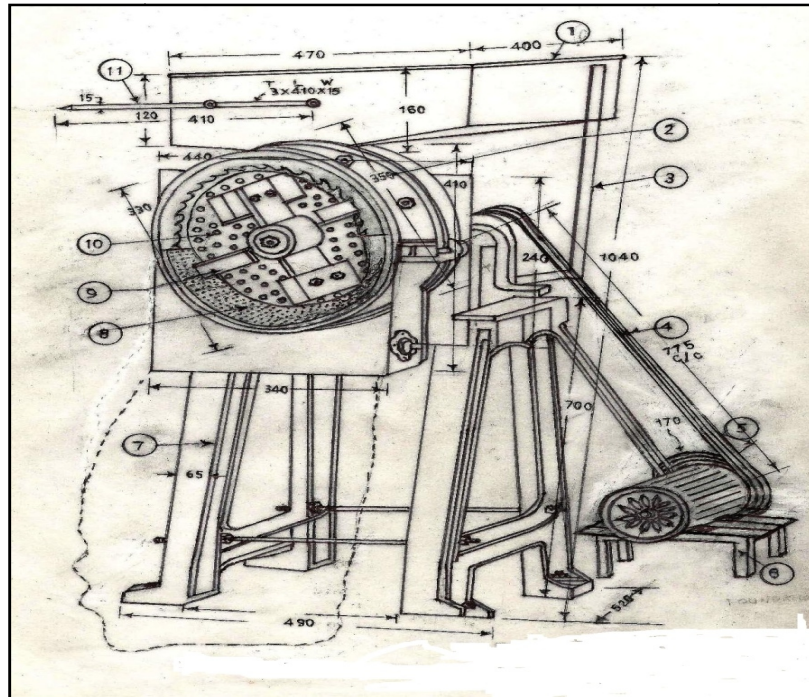
| Particular                                      | Single stage hammer mill | Double stage hammer mill |
|---|--------------------------|--------------------------|
| Model No.                                       | TW-488D                  | TW-84                    |
| Production capacity                             | 20-25 kg/h               | 25-30 kg/h               |
| Corse grinding chamber (width x diameter )      | Not existed              | 10 cm x 25 cm            |
| Fine grinding chamber                           | 10cm x 26 cm             | 14 cm x 30 cm            |
| Number of hammer                                | 4 (swinging type)        | 4 (fixed type)           |
| Hammer size (length x width x thickness)        | 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                               | 45°                      | 10°                      |
| 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                     | 2 hp                     |
| Grinding speed(rpm)                             | 1440                     | 1440                     |
| Belt  | B63 (V belt)             | B73(V belt)              |
| Total machine size (length x width x thickness) | 95 cm x 35 cm x 32 cm    | 100 cm x 48 cm x 40 cm   |
| Foundation size (length x width x depth)        | 77cm x 36 cm x 12 cm     | 120 cm x 65 cm x 20 cm   |



| S.N. | COMPONENTS       |
|------|------------------|
| 1    | HOPPER           |
| 2    | LEVER            |
| 3    | BELT             |
| 4    | FRAME            |
| 5    | MOTOR            |
| 6    | FOUNDATION       |
| 7    | WHEEL            |
| 8    | CLOTH            |
| 9    | GRINDING CHAMBER |
| 10   | COVER            |

(ALL DIMENSIONS IN MM)

Fig 3.4: Isometric view of single stage hammer mill



| S.N. | COMPONENTS        |
|------|-------------------|
| 1    | HOPPER            |
| 2    | GRINDING CHAMBER  |
| 3    | HOPPER FRAME      |
| 4    | BELT              |
| 5    | MOTOR             |
| 6    | FOUNDATION STAND  |
| 7    | FRAME             |
| 8    | SIEVE             |
| 9    | FIXED HAMMER      |
| 10   | INNER SIEVE HOLES |
| 11   | LEVER             |

(ALL DIMENSIONS IN MM)

Fig 3.5: Isometric view of d stage double hammer mill



**(a) Single stage hammer mill**



**(b) Double stage jammer mill**

**Plate 3.5 Single stage and double stage hammer mill**

### 3.3.2 Sieve shaker

The sieve analysis of ground coriander powder was performed using a gyratory sieve shaker. For determination of average particle size of ground coriander powder, a set of sieves fitted on the sieve shaker consisted for sieve of ASTM Mesh No 45 (0.351mm), 40 (0.420mm), 35 (0.500mm), 30 (0.592), 25 (0.708mm), 20 (0.954mm) with pan and cover was taken. A sample of 100 g of ground product is placed on the top most sieve and shaken for five minutes (Singh and Sahay, 1999).



**Plate 3.6 Sieve shaker**

### 3.3.3 Colour measurement

Colour is an important quality parameter for the coriander. It was analyzed by measuring the reflectance. A Hunter Colour Colorimeter at 65° 10° 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 coriander 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).

### **3.3.4 Cost economics of powder production**

The cost analysis of the prepared powder was also done using break even analysis technique (Selvam, 2001). Break even analysis or profit contribution analysis is an important analytical technique used to study the relationship between the total costs, total revenue and total profits and losses over the whole range of stipulated output. It integrates the cost and revenue estimates to ascertain the profits and losses associated with different levels of output. The break-even analysis provides a relationship between revenues and costs with respect to volume (quantity) of sales. It represents the level of sales at which costs and revenues are in equilibrium; the equilibrium point being known as the break-even point (BEP). At the break even point, total revenue is equal to the total cost; it is a no-loss point. This analysis assumes that the total costs can be separated into fixed costs and variable costs.

## **3.4 Instrument used for experiment**

### **3.4.1. Hot air oven**

Hot air oven (Make – Labtech Instrument, Indore) was used to measure the moisture content of coriander pods, which have digital thermostat to control and measure the temperature and its operating temperature range is between 50° to 300°C.

### **3.4.2 Hot Air Tray Dryer**

Hot air tray dryer is used for drying of coriander seed. It consisted of heating unit, drying chamber and centrifugal fan for providing air flow. Fresh air enters the cabinet by the fan through screen filter and heater coils, and is then blown across the trays to exhaust. The trays used were perforated from bottom in order to permit vertical movement of hot air. All trays were assembled in a column inside the hot air tray dryer.

### **3.4.3 Digital Weighing Balance**

Digital electronic balance (Model No: CY-3600, manufactured by – Citizen, India) with measuring scale showing maximum 360 g and minimum 20 mg, was used for weighing samples. The least count of balance is 0.001g.

### **3.4.3 Digital vernier calliper**

It was used to measure the Longitudinal and lateral dimensions of coriander (Aerospace digital vernier calliper, 0-150 mm range). The least count of vernier calliper was 0.01 mm.

### **3.4.4 Digital thermometer**

A laboratory model of LCD portal digital multi-thermometer (Model: ST-9283B, manufactured by–Globe instrument, India) was used to measure temperature. The thermometer had measuring range of -50° to 300°C.

### **3.4.5 Tachometer**

It is used for measuring speed of the motor shaft. Its range varies from 20 to 5000 rpm.

### **3.4.6 Pycnometer**

Pycnometer also called specific gravity bottle having capacity of 5 ml was used for measuring specific gravity of extracted coriander oil.

### **3.4.7 Butyro refractometer**

Butyro refractometer (Model No: BPL -191) was used for measuring refractive index of oils giving a reading directly in terms of the oil scale, also known as butyro scale. The micrometer eye piece allows accuracy on their scale of 0.1. This allows as measuring on materials with index of refraction in the range 1.42 to 1.49 to an accuracy of 0.001.

## RESULT AND DISCUSSION

Experiment were conducted to determine the physical properties of the coriander seed and the performance of selected single stage and double stage hammer mill, in the Department of Post Harvest Process and Food Engineering, College of Agricultural Engineering, JNKVV, Jabalpur.

Physical characteristics of coriander seed were measured by conducting various experiments. The effect of moisture content on length, width, thickness, one thousand seed weight, bulk density, true density and dynamic angle of repose of coriander seeds were studied at four level of moisture content.

In the present study the experiment were performed using the Symmetrical Factorial (CRD) Completely Randomize Design. The statistical analysis of the data in terms of ANOVA in between independent variables and dependent variables was conducted. The grinding behaviour of coriander seed was studied in both single and double stage grinding in hammer mill under different operational condition. In both grinding processes the speed of operation was fixed at 4540 rpm (784.05 m/sec). The feed rate at four levels (6, 8, 10 and 12 kg/h) and moisture content four levels (7, 9, 11 and 13%wb) 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 coriander powder during grinding, volatile oil content, fineness modulus, particle size and colour analysis. The cost economics of coriander powder production was also studied for selected two methods of grinding. The results obtained are presented in following sections.

### 4.1 Physical Properties of coriander seed

The average values of observed physical properties viz. length, width, thickness, bulk density, true density and angle of repose are presented in Table 4.1. The physical properties of 30 coriander seed of CIMPOS-33 variety are presented in Appendix A-1 and A-2. The various dimensional parameters of coriander viz., length, width, thickness, were determine at four moisture levels i.e. 7, 9, 11 and 13% (wb). The average length of the coriander seeds

was found to be 4.27, 4.19, 4.36 and 4.19 mm at 7, 9, 11 and 13% moisture content (wb), respectively. The average width of the coriander seeds were found to be 3.40, 3.26, 3.23 and 3.29 mm at 7, 9, 11, 13% moisture content (wb), respectively. The average thickness of the coriander was found to be 3.35, 3.51, 3.31 mm and 3.29 at 7, 9, 11 and 13% moisture content (wb), respectively. (Table 4.1)

The average values of bulk density of coriander seeds were found to be 227, 225, 225 and 224 at 7, 9, 11 and 13% moisture content (wb), respectively. However, average values of true density of coriander seeds were 336, 337, 339 and 337 at 7, 9, 11 and 13% moisture content (wb), respectively. Dynamic angle of repose of coriander was found to be 25°, 26°, 27° and 28° at 7, 9, 11 and 13% moisture content (wb), respectively. The angle of repose increased linearly with the increment in the moisture content of coriander seeds.

The 1000 seed weight increased linearly from 8.72 to 9.70 g as moisture content increased from 7% to 13%. Coriander seed has an almost globular shape, compared with other commonly grown crops for example gram, millet, okra seeds and rapeseed. Similar trends have been reported by Chaudhary, Sarker and Hossain (2001).

**Table 4.1 Physical properties of coriander seeds at different moisture content**

| Physical properties               | Moisture content, % (wb) |        |      |        |      |        |      |        |
|-----------------------------------|--------------------------|--------|------|--------|------|--------|------|--------|
|                                   | 7%                       |        | 9%   |        | 11%  |        | 13%  |        |
|                                   | Mean                     | SD     | Mean | SD     | Mean | SD     | Mean | SD     |
| Length (mm)                       | 4.27                     | 0.39   | 4.19 | 0.4409 | 4.36 | 0.3595 | 4.19 | 0.4446 |
| Width (mm)                        | 3.40                     | 0.2067 | 3.26 | 0.1378 | 3.23 | 0.1909 | 3.29 | 0.2161 |
| Thickness (mm)                    | 3.35                     | 0.1944 | 3.51 | 0.2381 | 3.31 | 0.1845 | 3.29 | 0.1787 |
| Bulk density (kg/m <sup>3</sup> ) | 227                      | 4.3991 | 225  | 3.4476 | 225  | 3.6636 | 224  | 3.3578 |
| True density (kg/m <sup>3</sup> ) | 336                      | 3.7428 | 337  | 2.9049 | 339  | 3.201  | 337  | 3.1001 |
| Dynamic angle of repose (°)       | 25                       | 1.3326 | 26   | 1.2617 | 27   | 1.070  | 28   | 1.2526 |

## **4.2 Effect of process variables on grinding characteristics of coriander powder**

Temperature of coriander powder was recorded just after milling using a digital thermometer. Temperature rise with respect to change in moisture content and feed rate of coriander seeds during single and double stage grinding are discussed in the following sections.

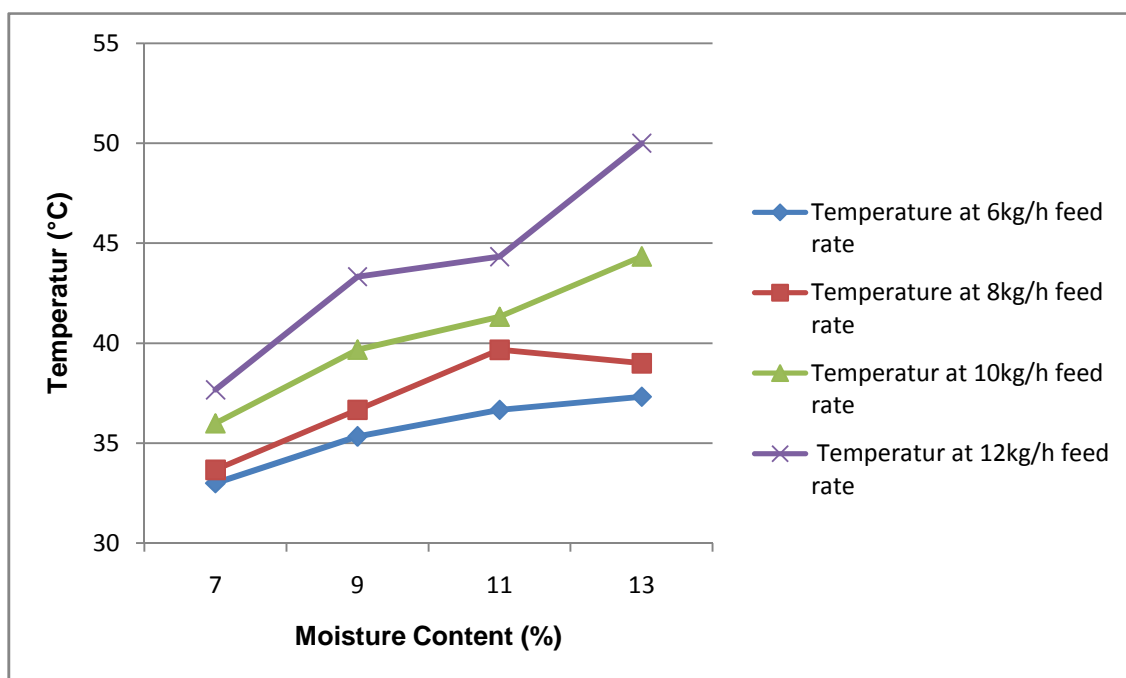
### **4.2.1 Effect of moisture content and feed rate on temperature rise of coriander powder using single stage grinding**

In single stage grinding the effect of feed rate and moisture content of coriander seeds on the temperature rise of the coriander powder was observed and is presented in Table 4.2. The average rise in temperature of coriander powder during single stage grinding ranged from 33 to 50 °C. Minimum temperature (33°C) was observed at 6 kg/h feed rate and 7 % moisture content and maximum temperature (50°C) was observed at 12 kg/h feed rate and 13 % 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 seed e.g. temperature rise was 33°C for coriander powder obtained by seeds with 7 % moisture content (wb) and 6 kg/h feed rate, however it increased to 33.67, 36 and 37.67°C at 8, 10 and 12 kg/h feed rate. Similarly, temperature rise was observed 37.33°C of coriander powder obtained by seed with 13 % moisture content (wb) and 6 kg/h feed rate, however it increased to 39, 44.33 and 50°C at 8, 10 and 12 kg/h feed rate, respectively.

From Fig. 4.1, it is evident that at a constant feed rate the temperature of coriander powder increased progressively with increment in the moisture content of the coriander seeds e.g. at a constant feed rate of 6 kg/h the temperature of the coriander seeds during single stage grinding were observed 33.00, 35.33 and 36.67 and 37.33°C at 7, 9, 11 and 13% moisture content, respectively.

**Table 4.2 Effect of moisture content and feed rate on temperature of coriander powder using Single stage grinding**

| Feed rate (kg/h) | Temperature in single stage grinding at different moisture content (%) |       |       |       |
|------------------|--|-------|-------|-------|
|                  | 7  | 9     | 11    | 13    |
| 6                | 33.00  | 35.33 | 36.67 | 37.33 |
| 8                | 33.67  | 36.67 | 39.67 | 39.00 |
| 10               | 36.00  | 39.67 | 41.33 | 44.33 |
| 12               | 37.67  | 43.33 | 44.33 | 50.00 |



**Fig.4.1 Effect of moisture content and feed rate on temperature of coriander powder using Single stage grinding**

The factorial CRD Design was fitted for the rise in temperature of the various sample of coriander. The moisture content as well as feed rate have significant effect on rise in temperature of coriander powder during single stage (Appendix B-1).

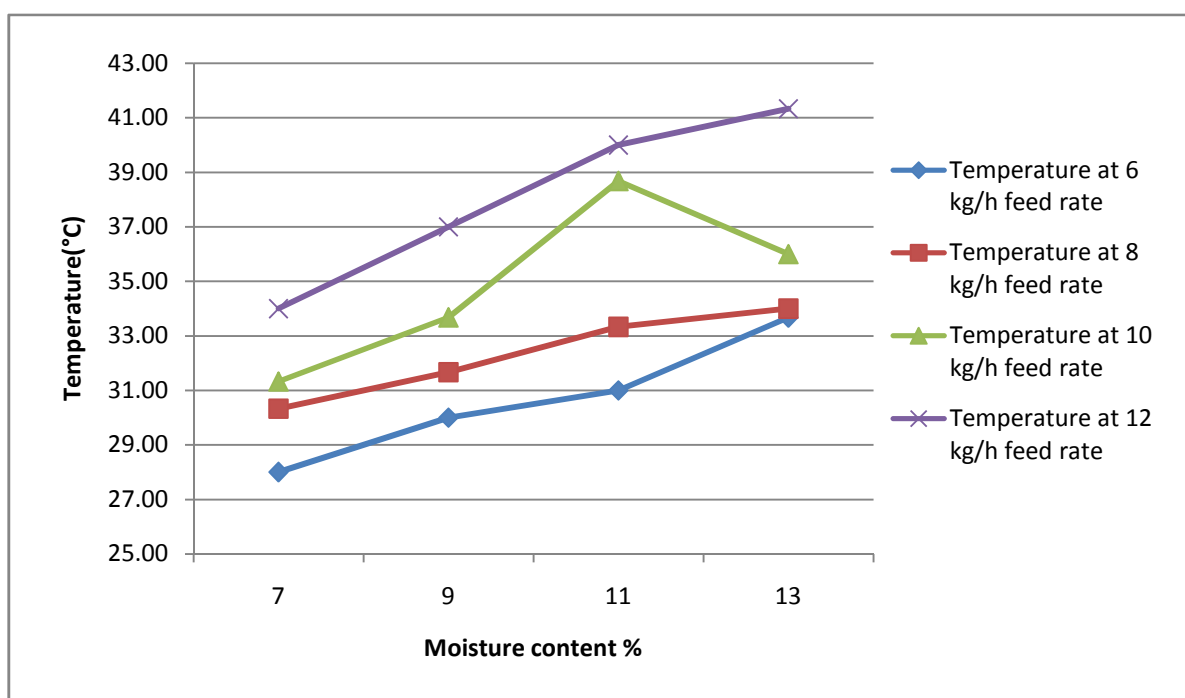
#### **4.2.2 Effect of moisture content and feed rate on temperature rise of coriander powder using double stage grinding**

The average rise in temperature of coriander powder during double stage grinding ranged from 28 to 41.33°C. Minimum temperature (28°C) was observed at 6 kg/h feed rate and at 7% moisture content. Maximum temperature (41.33°C) was observed at 12 kg/h feed rate and 13% moisture content (Table 4.3). 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 seeds e.g. temperature rise was 30°C for coriander powder obtained by seeds with 9% moisture content (wb) and 6 kg/h feed rate, however it increased to 31.67, 33.67 and 37.00°C at 8, 10 and 12 kg/h feed rate. Similarly, temperature rise was observed 33.67°C of coriander powder obtained by seed with 13% moisture content (wb) and 6 kg/h feed rate, however it increased to 34.00, 36.00 and 41.33°C at 8, 10 and 12 kg/h feed rate, respectively (Table 4.3).

From Fig. 4.2, it can be inferred that at a constant feed rate the temperature of coriander powder increased progressively with increment in the moisture content of the coriander seeds e.g. at a constant feed rate of 8 kg/h the temperature of the coriander seeds during double stage grinding were observed 30.33, 31.67 and 33.33 and 34°C at 7, 9, 11 and 13% moisture content, respectively. The moisture content as well as feed rate has significant effect on rise in temperature of coriander powder. (Appendix B-2)

**Table 4.3 Effect of moisture content and feed rate on temperature of coriander powder using double stage grinding**

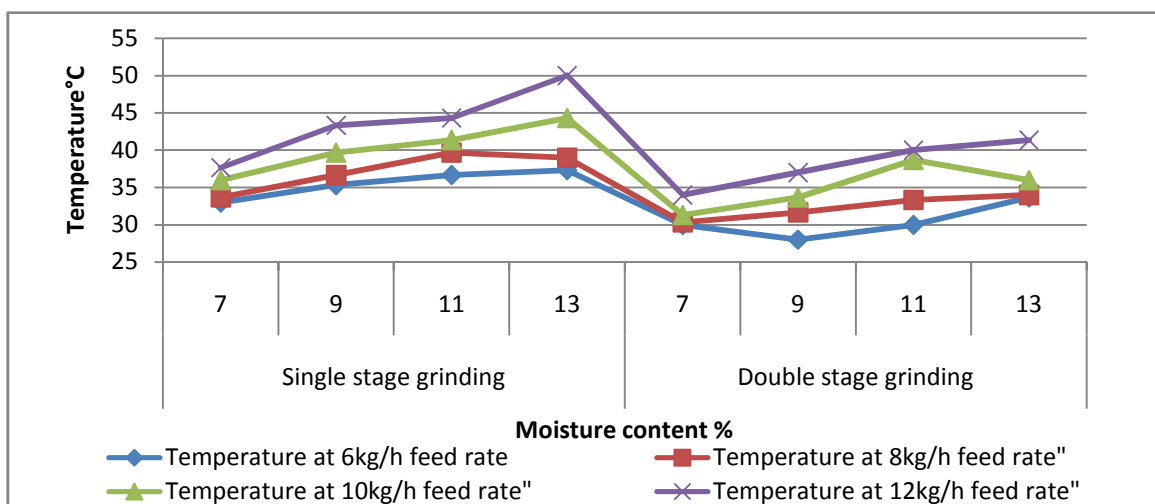
| feed rate<br>(kg/h) | Temperature in double stage grinding at different moisture content (%) |       |       |       |
|---------------------|--|-------|-------|-------|
|                     | 7  | 9     | 11    | 13    |
| 6                   | 28.00  | 30.00 | 31.00 | 33.67 |
| 8                   | 30.33  | 31.67 | 33.33 | 34.00 |
| 10                  | 31.33  | 33.67 | 38.67 | 36.00 |
| 12                  | 34.00  | 37.00 | 40.00 | 41.33 |



**Fig.4.2 Effect of moisture content and feed rate on temperature of powder using double stage grinding**

Among the two selected methods of grinding single stage grinding of coriander seeds 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 coriander seeds with 7% moisture content the temperature rise were observed 33 and 28°C for single stage and double stage grinding, respectively. Similarly, the temperature rise were 41.33 and 38.67°C at 10 kg/h feed rate and coriander seeds 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 compared with the double stage hammer mill. In double stage hammer mill coriander seeds pass through the pre milling chamber to the final stage grinding chamber. The coarse milled coriander powder releases some of its heat energy to the environment during the passage to the final milling chamber there by giving low temperature rise (Fig. 4.3).

Among the four selected moisture content of coriander seeds, the seeds with 7% m.c. gave lesser temperature both in single stage and double stage grinding. e.g. the temperature rise in single stage grinding of coriander seeds with 13% m.c. were observed 37.33, 39, 44.33 and 50°C at 6, 8, 10 and 12 kg/h feed rate however the corresponding temperature with coriander seeds at 7% m.c. were 33, 36.67, 36 and 37.67°C respectively. Similar trends were also observed by Chaudhary (2012).



**Fig.4.3 Effect of moisture content and feed rate on temperature rise during grinding of coriander seeds using single stage and double stage hammer mill**

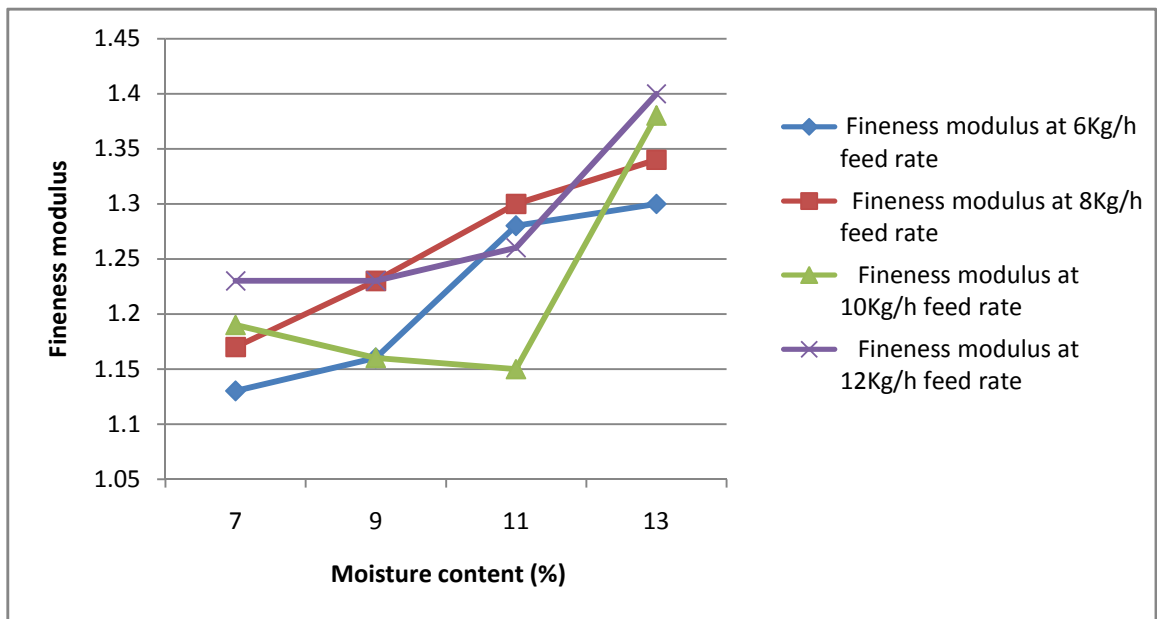
### **4.2.3 Effect of moisture content and feed rate on fineness modulus of coriander powder in single stage grinding**

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 coriander powder. The fineness modulus was calculated by using sieve analysis as recommended by Singh and Sahay (1999).

From Table 4.4, it is clear that the fineness modulus of ground sample increased with increment in the feed rate and moisture content of the coriander seeds. The maximum value of fineness modulus (1.40) was observed with coriander seed having 13% moisture content (wb) and 12 kg/h feed rate. The minimum value of fineness modulus (1.13) was observed with coriander seed having 7% moisture content (wb) 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. e.g. at 8 kg/h feed rate the fineness modulus increased from 1.17 to 1.23, 1.30 and 1.13 at 7, 9, 11 and 13% m.c., respectively. From Fig.4.4 it was also observed that there was a progressive increment in the fineness modulus of the ground coriander powder with increment in feed rate at constant moisture content. e.g. fineness modulus of the coriander powder obtained from coriander seeds having 13% m.c. were recorded 1.30, 1.34, 1.38 and 1.40 at 6, 8, 10 and 12 kg/h, respectively. The moisture content as well as feed rate has a significant effect on the fineness modulus of coriander powder (Appendix B-3).

**Table 4.4 Effect of moisture content and feed rate on fineness modulus of coriander powder using Single stage grinding.**

| Feed rate (kg/h) | Fineness modulus in single stage grinding at different moisture content (% wb) |      |      |      |
|------------------|--|------|------|------|
|                  | 7  | 9    | 11   | 13   |
| 6                | 1.13   | 1.16 | 1.28 | 1.30 |
| 8                | 1.17   | 1.23 | 1.30 | 1.34 |
| 10               | 1.19   | 1.16 | 1.15 | 1.38 |
| 12               | 1.23   | 1.23 | 1.26 | 1.40 |



**Fig.4.4 Effect of moisture content and feed rate on fineness modules of coriander powder using single stage grinding**

In single stage hammer mill, when coriander seeds are fed into the grinding chamber the seeds are subjected to high energy impact of hammers rotating at high rotational speed. Inside the grinding chamber due to repeated high energy impact, the coriander seeds 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 through the screen and are collected in a receiving container placed below the screen. Fineness of the grinding is controlled by the sieve size.

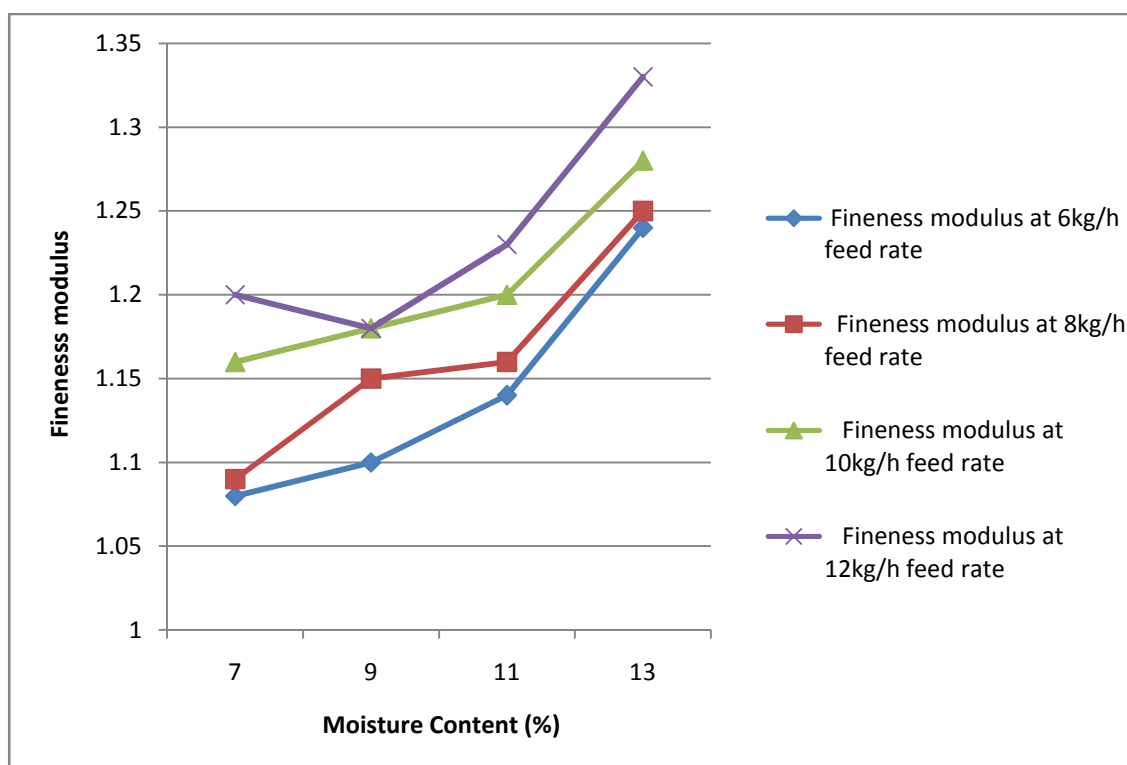
#### **4.2.4 Effect of moisture content and feed rate on fineness modulus of coriander powder in double stage grinding**

The fineness modulus of ground sample increased with increment in the feed rate and moisture content of the coriander seeds. The maximum value of fineness modulus (1.33) was observed with coriander seed having 13% moisture content (wb) and 12 kg/h feed rate. The minimum value of fineness modulus (1.08) was observed with coriander seed having 7% moisture content (wb) and 6 kg/h feed rate (Table 4.5). At a constant feed rate the fineness modulus of the ground sample increased progressively with increment in the moisture content of the sample. e.g. at a constant feed rate of 10 kg/h the fineness modulus increased from 1.16 to 1.18, 1.20 and 1.28 with increment in moisture content from 7 to 9, 11 and 13% m.c. respectively. From Fig.4.5, it was also observed that at a constant m.c. the fineness modulus of the ground coriander powder increased progressively with increment in feed rate. e.g. fineness modulus of the coriander powder obtained from coriander seeds having 11% m.c. were recorded 1.14, 1.16, 1.20 and 1.23 at a feed rate of 6, 8, 10 and 12 kg/h, respectively. The moisture content as well as feed rate has a significant effect on the fineness modulus of coriander powder (Appendix B-4).

A double stage hammer is provided with a pre-crushing chamber where the material undergoes of coarse grinding and then 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 coriander sample.

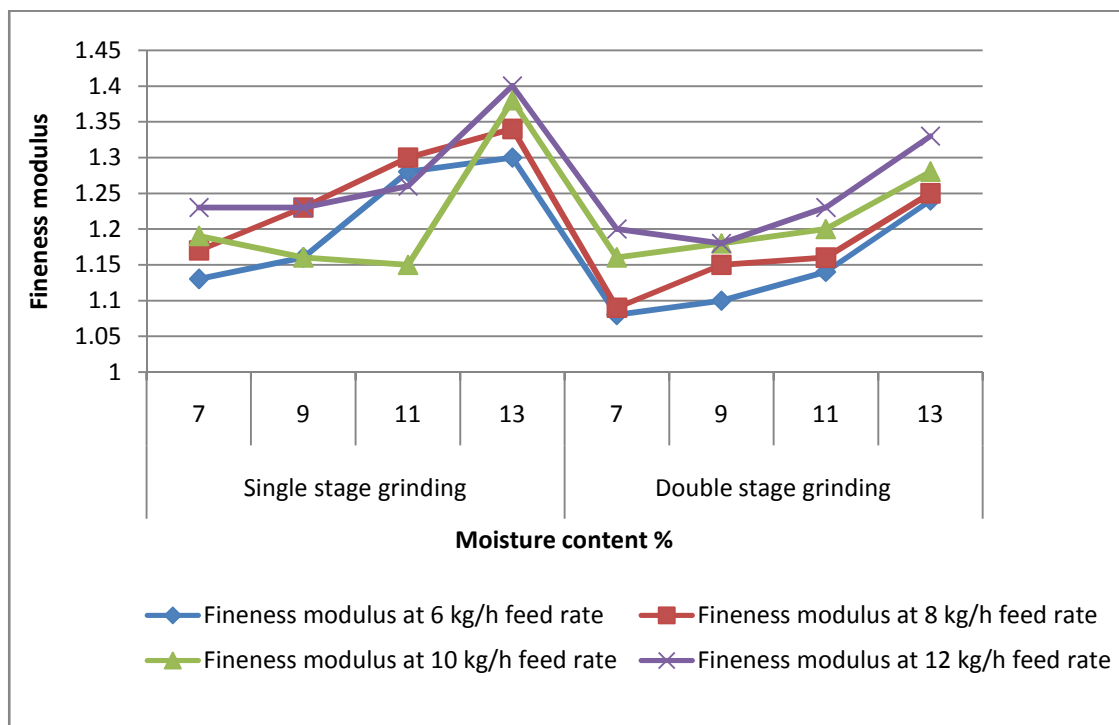
**Table 4.5 Effect of moisture content and feed rate on fineness modulus of coriander powder using double stage grinding**

| Feed rate (kg/h) | Fineness modulus in double stage grinding at different moisture content (%) |      |      |      |
|------------------|---|------|------|------|
|                  | 7   | 9    | 11   | 13   |
| 6                | 1.08  | 1.1  | 1.14 | 1.24 |
| 8                | 1.09  | 1.15 | 1.16 | 1.25 |
| 10               | 1.16  | 1.18 | 1.2  | 1.28 |
| 12               | 1.2   | 1.18 | 1.23 | 1.33 |



**Fig.4.5 Effect of moisture content and feed rate on fineness modules of coriander powder using double stage grinding**

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. 4.6, 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 1.4 and 1.33 were observed during single stage and double stage grinding of the coriander seeds having 13% moisture content (wb) and fed at a rate of 12 kg/h. However, minimum values of fineness modulus viz 1.13 and 1.08 were observed at 6 kg/h feed rate and 7% moisture content (wb) during single stage and double stage grinding, respectively.



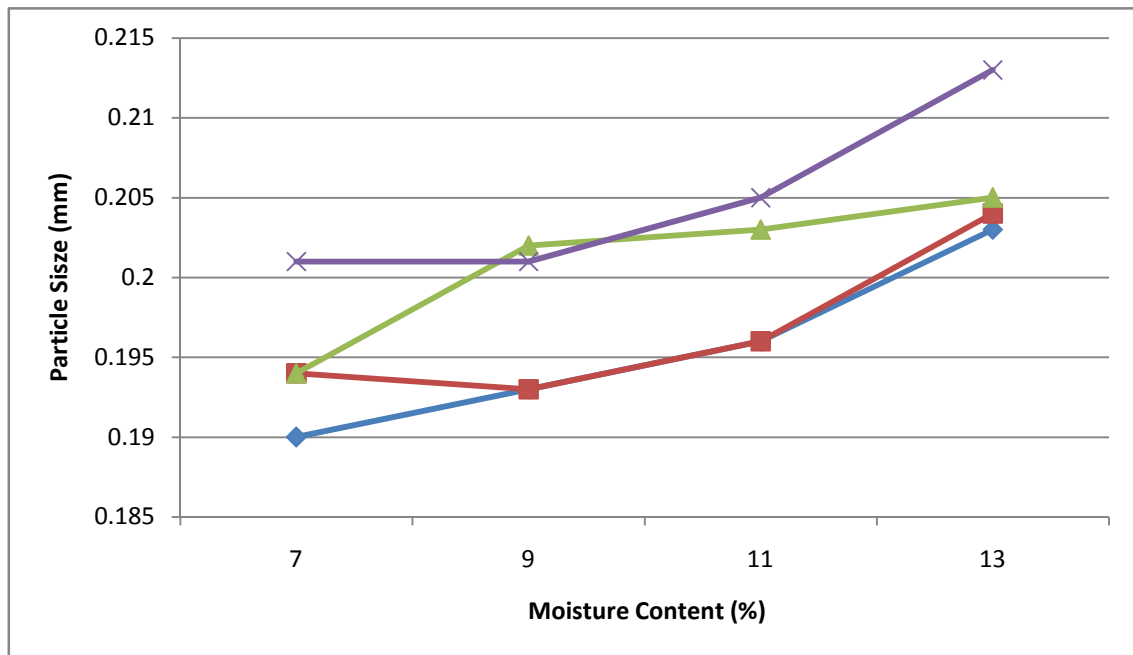
**Fig 4.6 Effect of moisture content and feed rate on fineness modulus of coriander powder using Single and Double Stage grinding**

#### 4.2.5 Effect of moisture content and feed rate on particle size of coriander powder during single stage grinding

The particle size was calculated from sieve analysis (Singh and Sahay, 1999). From Table 4.6, it is clear that the particle size of ground sample increased with increment in the feed rate and moisture content of the coriander seeds. The maximum value of particle size (0.213) was observed with coriander seed having 13% moisture content (wb) and 12 kg/h feed rate. The minimum value of particle size (0.190) was observed with coriander seed having 7% moisture content (wb) 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. e.g. at 10 kg/h feed rate the fineness modulus increased from 0.194 to 0.202, 0.203 and 0.205 at 7, 9, 11 and 13% m.c., respectively. From Fig.4.7 it was also observed that there was a progressive increment in the particle size of the ground coriander powder with increment in feed rate at constant moisture content. e.g. particle size of the coriander powder obtained from coriander seeds having 13% m.c. were recorded 0.203, 0.204, 0.205 and 0.213 at 6, 8, 10 and 12 kg/h, respectively. The moisture content as well as feed rate has an insignificant effect on particle size of coriander powder (Appendix B-5).

**Table 4.6 Effect of moisture content and feed rate on particle size (mm) coriander powder using single stage grinding**

| Feed rate (kg/h) | Particle size (mm) in single stage grinding at different moisture content (%) |       |       |       |
|------------------|---|-------|-------|-------|
|                  | 7   | 9     | 11    | 13    |
| 6                | 0.190   | 0.193 | 0.196 | 0.203 |
| 8                | 0.194   | 0.195 | 0.196 | 0.204 |
| 10               | 0.194   | 0.202 | 0.203 | 0.205 |
| 12               | 0.201   | 0.201 | 0.205 | 0.213 |



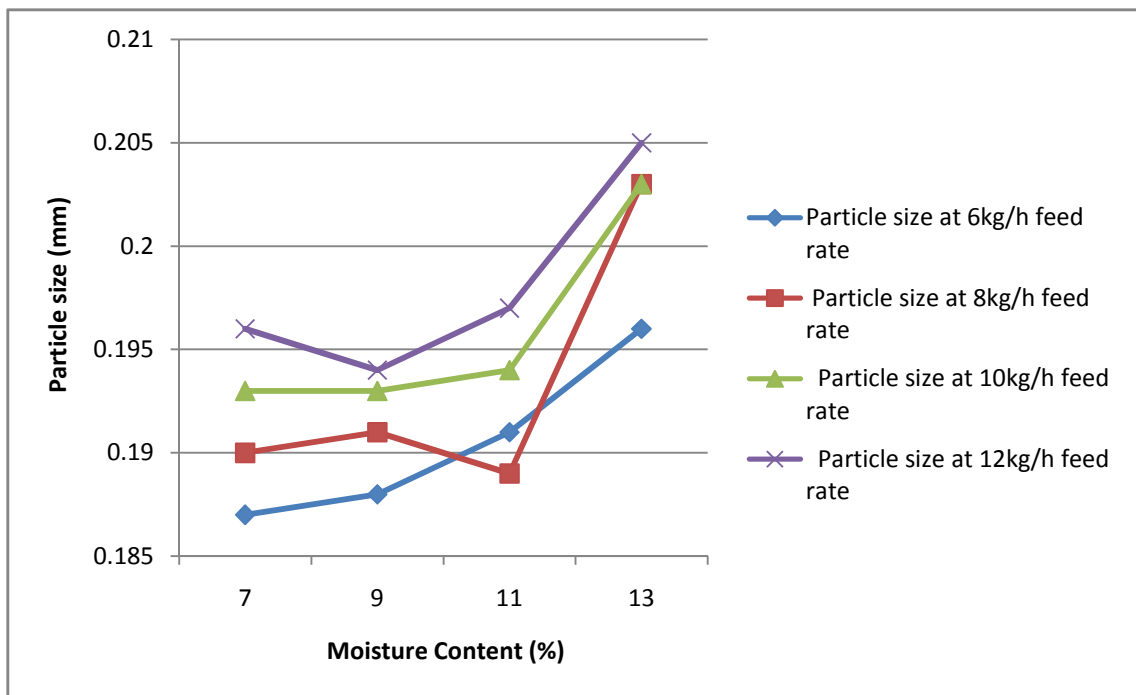
**Fig 4.7 Effect of moisture content and feed rate on particle size (mm) of coriander powder using single stage grinding**

#### **4.2.6 Effect of moisture content and feed rate on Particle size of coriander powder in double stage grinding**

The particle size of ground sample increased with increment in the feed rate and moisture content of the coriander seeds. The maximum value of particle size (0.205) was observed with coriander seed having 13% moisture content (wb) and 12kg/h feed rate. The minimum value of particle size (0.187) was observed with coriander seed having 7% moisture content (wb) and 6 kg/h feed rate (Table 4.7). At a constant feed rate the particle size of the ground sample increased progressively with increment in the moisture content of the sample. e.g. at a constant feed rate of 12 kg/h the fineness modulus increased from 0.194 to 0.196, 0.197 and 0.205 with increment in moisture content from 7 to 9, 11 and 13% m.c., respectively. From Fig.4.8, it was also observed that at a constant m.c. the particle size of the ground coriander powder increased progressively with increment in feed rate. e.g. particle size of the coriander powder obtained from coriander seeds having 9% m.c. were recorded 0.188, 0.191, 0.193 and 0.196 at a feed rate of 6, 8, 10 and 12 kg/h, respectively. The moisture content as well as feed rate has an insignificant effect on the particle size of coriander powder (Appendix B-6)

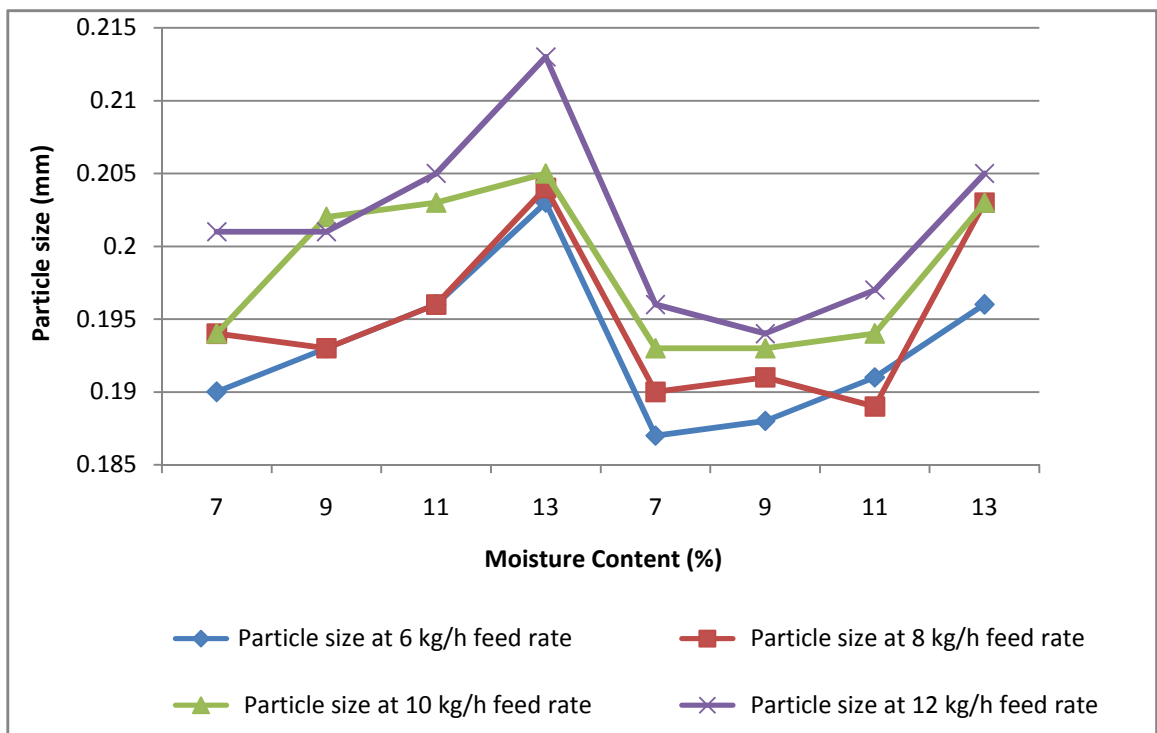
**Table 4.7 Effect of moisture content and feed rate on particle size of coriander powder using Double Stage grinding**

| feed rate<br>(kg/h) | Particle size in double stage grinding at different moisture content (%) |       |       |       |
|---------------------|--|-------|-------|-------|
|                     | 7  | 9     | 11    | 13    |
| 6                   | 0.187  | 0.188 | 0.191 | 0.196 |
| 8                   | 0.190  | 0.191 | 0.189 | 0.203 |
| 10                  | 0.193  | 0.193 | 0.194 | 0.203 |
| 12                  | 0.194  | 0.196 | 0.197 | 0.205 |



**Fig 4.8 Effect of moisture content and feed rate on particle size of coriander powder using Double Stage grinding**

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 0.213 and 0.205 were observed during single stage and double stage grinding of the coriander seeds having 13% moisture content (wb) and fed at a rate of 12 kg/h. However, minimum values of particle size viz 0.190 and 0.187 were observed at 6 kg/h feed rate and 7% moisture content (wb) 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 of coriander powder using Single and Double Stage grinding**

### **4.3 Effect of process variables on volatile oil content of coriander powder during single stage and double stage grinding.**

The essential oil was isolated from the coriander powder (100 g) by using hydrodistillation 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 ( $\text{Na}_2\text{SO}_4$ ), filtered using Millipore filter paper (45  $\mu\text{m}$  pore size) and stored at  $-4^\circ\text{C}$ , until analyzed (ASTM method, 1965).

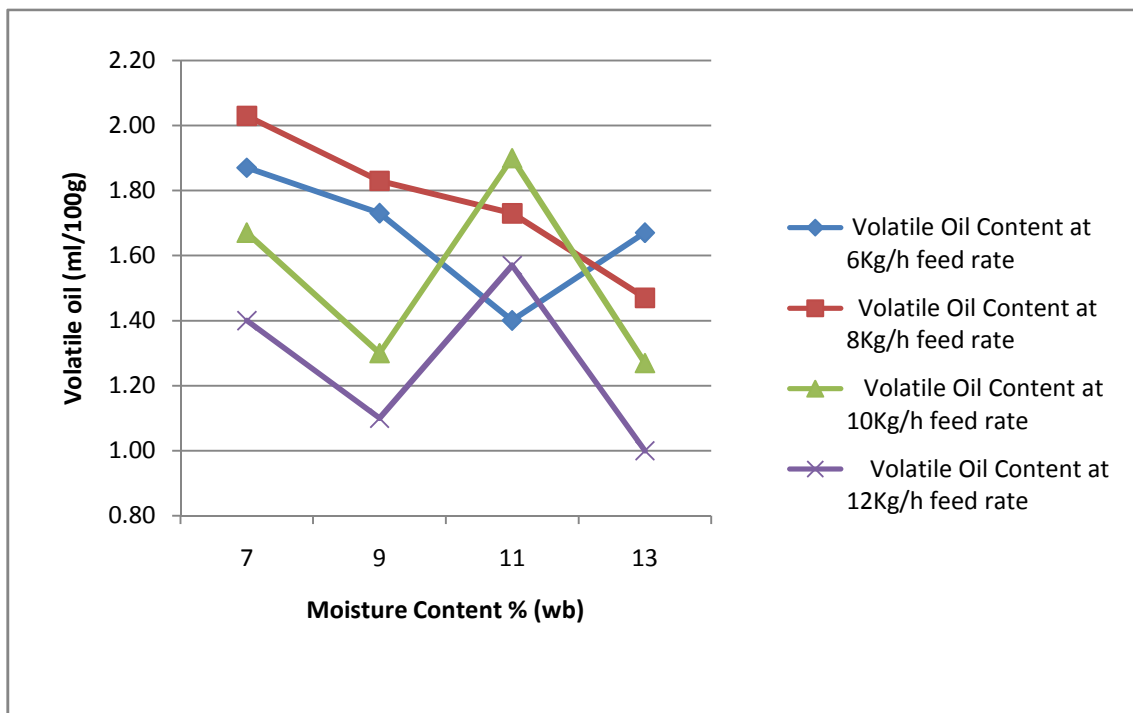
#### **4.3.1 Effect of moisture content and feed rate on volatile oil content of coriander powder in single stage grinding**

In single stage grinding the effect of feed rate and moisture content was observed on the volatile content oil of coriander powder. From Table 4.8, it is clear that as the moisture content of the coriander seeds was increased the volatile oil of the coriander powder decreased. The maximum volatile oil content (2.03ml/100g) was found for the coriander seeds having 7% moisture content (wb) and fed at 8kg/h. The minimum volatile oil (1ml/100g) of the sample were found at 13% (wb) moisture content and 12kg/h feed rate in single stage grinding. The probable reason for the higher recovery of volatile oil at lower m.c. of the coriander seed may be because of the lower temperature rise during the milling process (Table 4.2). At 6 kg/h feed rate and 7% m.c. combination the temperature rise was  $33^\circ\text{C}$  giving 1.87 ml/100g volatile oil. However, the volatile oil content was observed 1 ml/100g at 13% m.c. of coriander seed and 12 kg/h feed rate because of  $50^\circ\text{C}$  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 coriander powder ranged from 1 to 2.03 ml/100g (Fig.4.10).The moisture content as well as feed rate has significant effect on the value of volatile oil of coriander powder Appendix B-7.

Literature revealed that the yield of coriander essential oil differs in relation to the origin and cultivars of seeds as well as due to agroclimatic and geographical variations (Weiss, 2002; Telci et al., 2006; Hussain et al., 2008, Choudhary, 2012).

**Table 4.8 Effect of moisture content and feed rate on volatile oil of coriander powder using single stage grinding**

| Feed rate (kg/h) | Volatile oil (ml/100g) in single stage grinding at different moisture content (%) |      |      |      |
|------------------|---|------|------|------|
|                  | 7   | 9    | 11   | 13   |
| 6                | 1.87  | 1.73 | 1.4  | 1.67 |
| 8                | 2.03  | 1.83 | 1.73 | 1.47 |
| 10               | 1.67  | 1.3  | 1.9  | 1.27 |
| 12               | 1.40  | 1.1  | 1.57 | 1.00 |



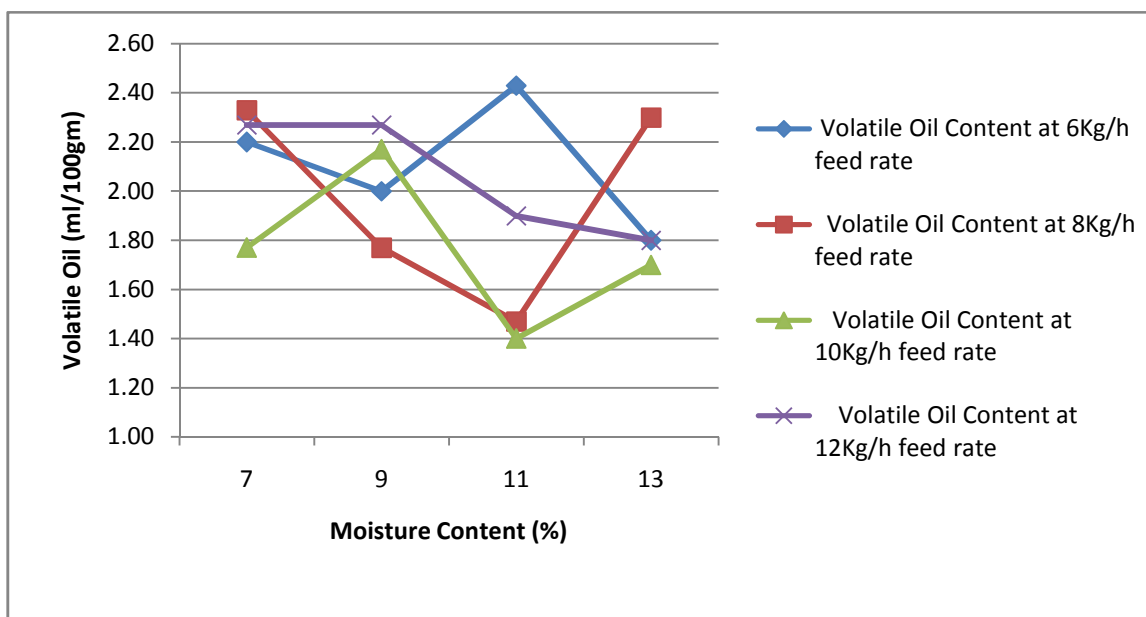
**Fig 4.10 Effect of moisture content and feed rate on volatile oil of coriander powder using single stage grinding**

### 4.3.2 Effect of moisture content and feed rate on volatile oil content of coriander powder in double stage grinding

In double stage grinding the effect of feed rate and moisture content was observed on the volatile content oil of coriander powder. From Table 4.9, it is clear that as the moisture content of the coriander seeds was increased the volatile oil of the coriander powder decreased. The maximum volatile oil content (2.33ml/100g) was found for the coriander seeds having 7% moisture content (wb) and fed at 8kg/h. The minimum volatile oil (1.40ml/100g) of the sample were found at 11% (wb) moisture content and 10kg/h feed rate in double stage grinding. The probable reason for the higher recovery of volatile oil at lower m.c. of the coriander seed may be because of the lower temperature rise during the milling process (Table 4.3). At 6 kg/h feed rate and 7% m.c. combination the temperature rise was 28°C giving 2.20ml/100g volatile oil. However, the volatile oil content was observed 1.8ml/100g at 13% m.c. of coriander seed and 12 kg/h feed rate because of 41.33°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 coriander powder ranged from 1.8 to 2.33ml/100g (Fig 4.11). The moisture content as well as feed rate has significant effect on the value of volatile oil of coriander powder Appendix B-8. These findings are supported by the work of (Landwehr and Pahl, 1986).

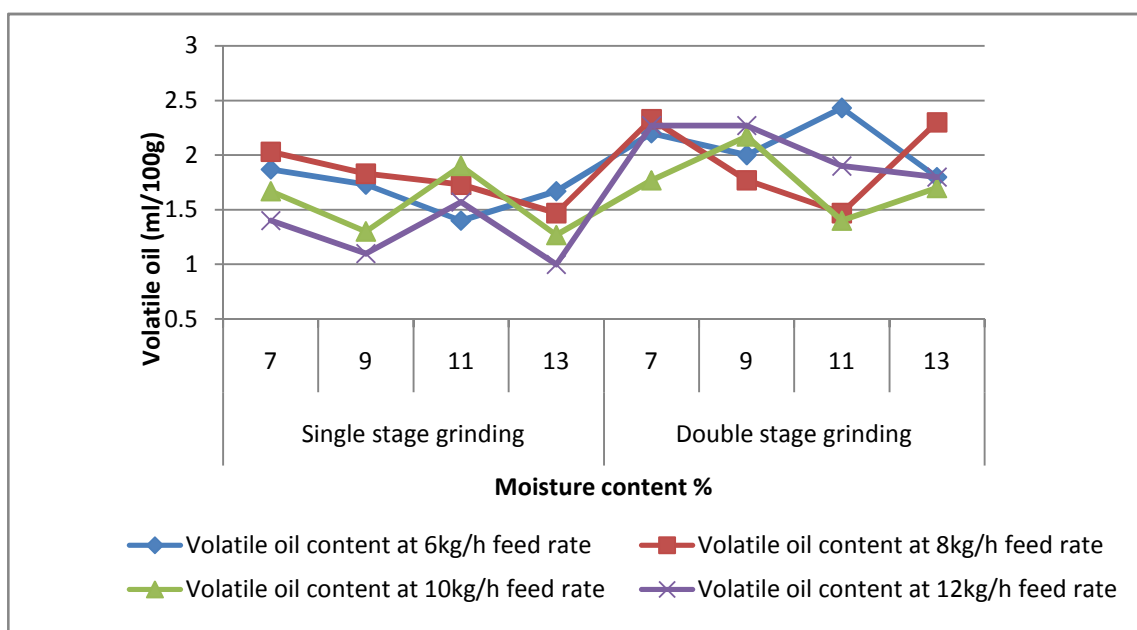
**Table 4.9 Effect of moisture content and feed rate on volatile oil of coriander powder using double stage grinding**

| Feed rate (kg/h) | Volatile oil in double stage grinding at different moisture content (%) |      |      |     |
|------------------|---|------|------|-----|
|                  | 7   | 9    | 11   | 13  |
| 6                | 2.20  | 2    | 2.43 | 1.8 |
| 8                | 2.33  | 1.77 | 1.47 | 2.3 |
| 10               | 1.77  | 2.17 | 1.4  | 1.7 |
| 12               | 2.27  | 2.27 | 1.9  | 1.8 |



**Fig 4.11 Effect of moisture content and feed rate on volatile oil of coriander powder using double stage grinding**

The volatile oil contents of the coriander powder decreases with increases in the feed rate and moisture content of the sample in both single and double stage grinding. From Fig. 4.12, 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 2.03ml/100g and 2.33ml/100g were observed during single stage and double stage grinding of the coriander seeds having 7% moisture content (wb) and fed at a rate of 6 kg/h. However, minimum values of volatile oil content viz 1ml/100g and 1.8 were observed at 12 kg/h feed rate and 13% moisture content (wb) 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 4.12 Effect of moisture content and feed rate on volatile oil of coriander powder using Single and Double Stage grinding**

### 4.3.3 Specific gravity and refractive index of volatile oil obtained from coriander powder

The specific gravity and refractive index were taken as physical quality parameters for volatile oil obtained from coriander powder.

#### 4.3.3.1 Specific gravity

Specific gravity of the volatile oil obtained from coriander powder using single stage and double stage grinding was estimated by the method as described in section 3. The specific gravity of volatile oil was 0.865 for single stage grinding and 0.873 for double stage grinding method. The specific gravity values of volatile oil using hydro distillation method differ slightly. The results agree fairly with the literature data. The literature value for specific gravity of coriander is in the range of 0.863 to 0.875. The oil with greater specific gravity is assumed to contain higher amount of aroma resinous compounds that distinguishes coriander oil from the others which is higher in double stage grinding.

### 4.3.3.2 Refractive index

The refractometer is the fastest and reliable technique in quality control assessments. The literature value for refractive index (RI) of volatile oil obtained from coriander is in the range of 1.463 to 1.472.

Refractive index of volatile oil for single stage grinding was 1.465 and 1.470 for double stage grinding method. These results show that all values of RI for laboratory distillation method are within the range of literature values. So coriander oil was found to be of good quality.

## 4.4 Effect of process variables on Colour value of coriander powder

### 4.4.1 Effect of moisture content and feed rate on colour value of coriander powder in single stage grinding

Hunter lab colour apparatus was used to observe the colour of the coriander powder in single stage grinding. The total colour change is given by colour differences ( $E_{ab}^*$ ) in terms of special distance between two colour points interpreted in the colour space (Hunter, 1987)

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

The subscript i and o denote the colour parameters of coriander seed and coriander powder after grinding, respectively. The  $L_i$ ,  $a_i$  and  $b_i$ , values of coriander seed were observed to be 47.56, 8.03 and 22.87 respectively. The  $L_o$ ,  $a_o$  and  $b_o$  values of coriander powder shown in Table 4.10, 4.11 and 4.12, respectively. The higher  $E$  represents greater colour change from the coriander. In single stage grinding the effect of feed rate and moisture content was observed on the colour of ground coriander powder. The value of different attributes viz  $L_o$ ,  $a_o$  and  $b_o$  varied from 50.91 to 52.40, 7.08 to 8.04 and 27.68 to 31.08, 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 decrement in the lightness of coriander powder may be because of the non-enzymatic browning reactions occurring during grinding at higher temperature. The higher  $E$  represents greater colour change from the coriander powder. Colour change

of the sample range in 2.79 to 3.48 (Table 4.13). Results show that increase in colour loss increases with increase in moisture content. The moisture content as well as feed rate has an insignificant effect on the colour value of coriander powder (Appendix B-9) same trend was observed as by Jittant 2010.

**Table 4.10 Effect of moisture content and feed rate on colour change ( $L_o$ ) of coriander powder using single stage grinding**

| Feed rate (kg/h) | Colour Value ( $L_o$ ) in single stage grinding at different moisture content (%) |       |       |       |
|------------------|---|-------|-------|-------|
|                  | 7   | 9     | 11    | 13    |
| 6                | 52.23   | 51.65 | 51.61 | 51.61 |
| 8                | 51.62   | 51.38 | 51.42 | 52.40 |
| 10               | 52.23   | 50.91 | 52.27 | 51.52 |
| 12               | 51.52   | 52.23 | 50.91 | 51.52 |

**Table 4.11 Effect of moisture content and feed rate on colour change ( $a_o$ ) of coriander powder using single stage grinding**

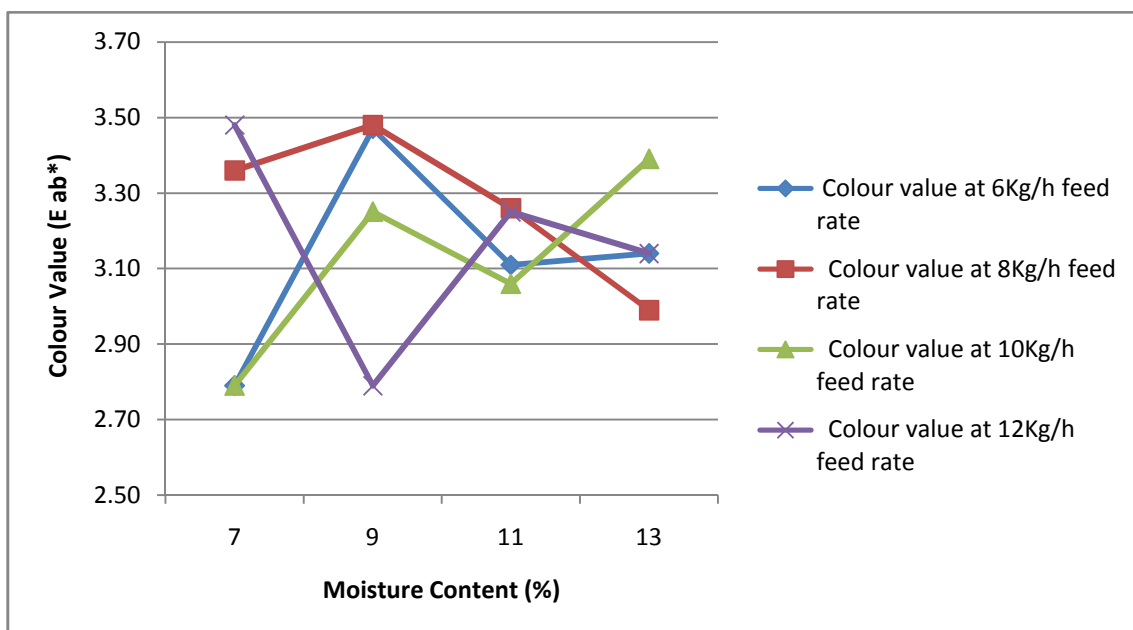
| Feed rate (kg/h) | Colour Value ( $a$ ) in single stage grinding at different moisture content (%) |      |      |      |
|------------------|---|------|------|------|
|                  | 7   | 9    | 11   | 13   |
| 6                | 8.04  | 7.69 | 7.85 | 7.85 |
| 8                | 7.83  | 7.36 | 7.63 | 7.20 |
| 10               | 8.04  | 7.74 | 7.08 | 7.71 |
| 12               | 7.54  | 8.04 | 7.74 | 7.76 |

**Table4.12 Effect of moisture content and feed rate on colour change (b<sub>o</sub>) of coriander powder using single stage grinding**

| Feed rate (kg/h) | Colour Value (b) in single stage grinding at different moisture content (%) |       |       |       |
|------------------|---|-------|-------|-------|
|                  | 7   | 9     | 11    | 13    |
| 6                | 27.68   | 30.78 | 28.73 | 28.57 |
| 8                | 30.03   | 31.08 | 29.50 | 28.02 |
| 10               | 27.68   | 29.94 | 28.75 | 30.24 |
| 12               | 30.74   | 27.68 | 29.94 | 28.55 |

**Table 4.13 Effect of moisture content and feed rate on colour change (E\* ab) of coriander powder using single stage grinding**

| feed rate (kg/h) | Colour Value in single stage grinding at different moisture content (%) |      |      |      |
|------------------|---|------|------|------|
|                  | 7   | 9    | 11   | 13   |
| 6                | 2.79  | 3.47 | 3.11 | 3.14 |
| 8                | 3.36  | 3.48 | 3.26 | 2.99 |
| 10               | 2.79  | 3.25 | 3.06 | 3.39 |
| 12               | 3.48  | 2.79 | 3.25 | 3.14 |



**Fig 4.13 Effect of moisture content and feed rate on colour change ( $E^*_{ab}$ ) of coriander powder using single stage grinding**

#### 4.4.2 Effect of moisture content and feed rate on colour value of coriander powder in double stage grinding

In double stage grinding the effect of feed rate and moisture content was observed on the colour of ground coriander powder.

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

The subscript i and o denote the colour parameters of coriander seed and coriander powder after grinding, respectively. The  $L_i$ ,  $a_i$  and  $b_i$ , values of coriander seed were observed to be 43.30, 8.50 and 22.56 respectively. The  $L_o$ ,  $a_o$  and  $b_o$  values of coriander powder shown in Table 4.14, 4.15 and 4.16, respectively. The value of different attributes viz  $L_o$ ,  $a_o$  and  $b_o$  varied from 44.95 to 56.65, 7.20 to 7.64 and 27.10 to 35.34, respectively. From Fig 4.15, 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 3.0 to 4.62 (Table 4.17). Results show that increase in colour loss increases with increase in moisture content. The higher E represents greater colour change from the dried coriander. The moisture content as well as feed rate has significant effect on the colour value of coriander powder (Appendix B-10)

**Table 4.14 Effect of moisture content and feed rate on colour change ( $L_o$ ) of coriander powder using double stage grinding**

| Feed rate (kg/h) | Colour Value (L) in double stage grinding at different moisture content (%) |       |       |       |
|------------------|---|-------|-------|-------|
|                  | 7   | 9     | 11    | 13    |
| 6                | 50.68   | 50.38 | 50.51 | 51.29 |
| 8                | 47.65   | 47.65 | 56.65 | 44.98 |
| 10               | 51.04   | 50.36 | 44.95 | 47.34 |
| 12               | 50.38   | 51.75 | 48.39 | 48.39 |

**Table 4.15 Effect of moisture content and feed rate on colour change ( $a_o$ ) of coriander powder using double stage grinding**

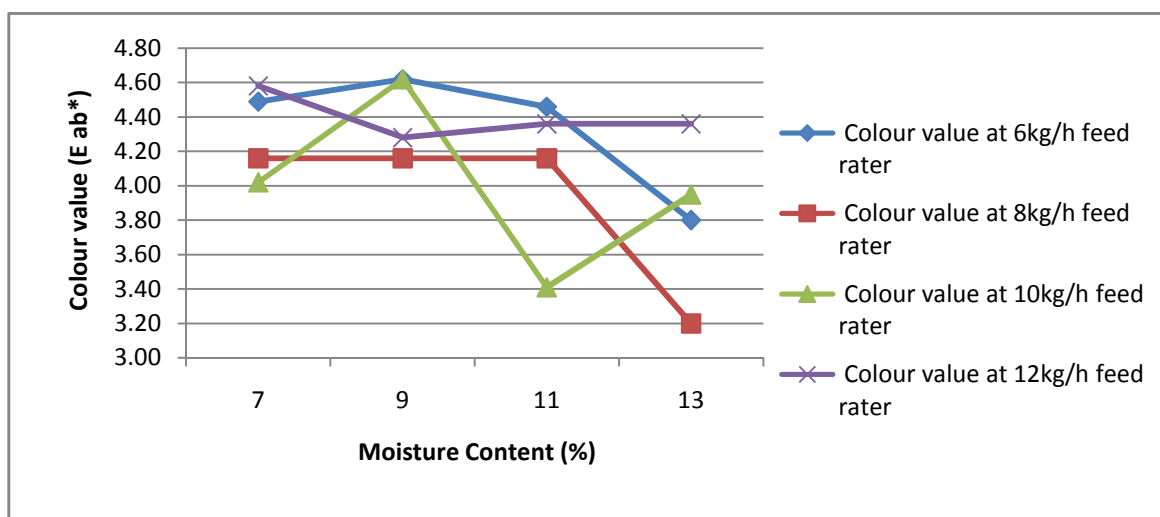
| Feed rate (kg/h) | Colour Value (a) in double stage grinding at different moisture content (%) |      |      |      |
|------------------|---|------|------|------|
|                  | 7   | 9    | 11   | 13   |
| 6                | 7.32  | 7.22 | 7.28 | 7.58 |
| 8                | 7.46  | 7.49 | 7.46 | 7.64 |
| 10               | 7.56  | 7.64 | 7.52 | 7.58 |
| 12               | 7.22  | 7.43 | 7.06 | 7.06 |

**Table 4.16 Effect of moisture content and feed rate on colour change ( $b_o$ ) of coriander powder using double stage grinding**

| Feed rate (kg/h) | Colour Value (b) in double stage grinding at different moisture content (%) |       |       |       |
|------------------|---|-------|-------|-------|
|                  | 7   | 9     | 11    | 13    |
| 6                | 34.21   | 35.34 | 33.16 | 27.10 |
| 8                | 34.79   | 33.49 | 33.79 | 29.68 |
| 10               | 30.15   | 35.30 | 31.05 | 32.42 |
| 12               | 35.46   | 30.94 | 34.09 | 34.09 |

**Table4.17 Effect of moisture content and feed rate on colour change (E\* ab) of coriander powder using double stage grinding**

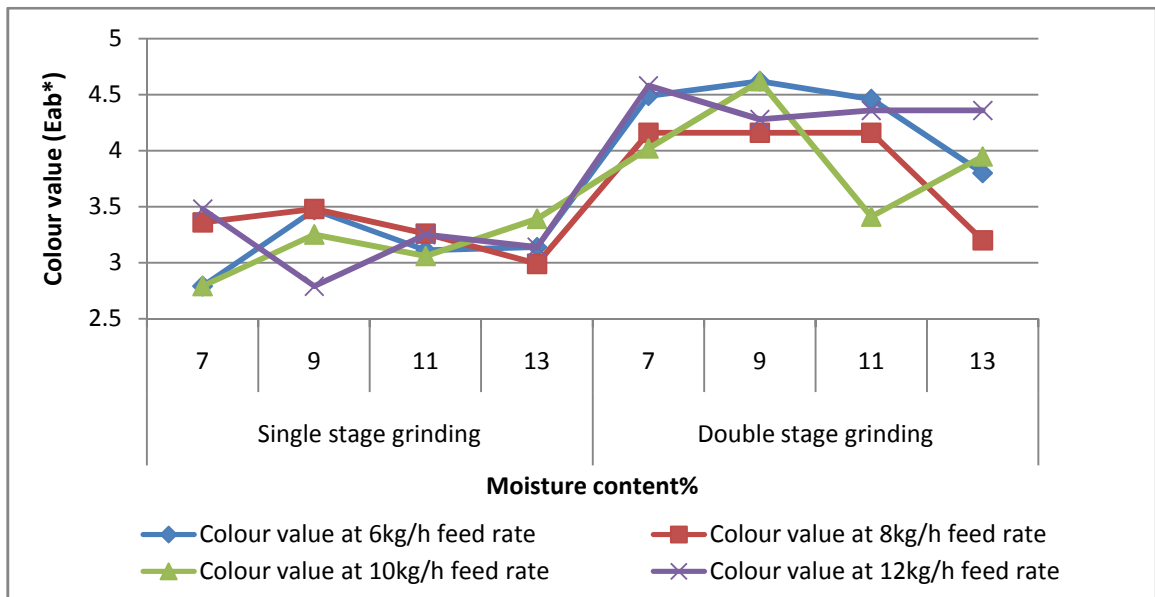
| Feed rate (kg/h) | Colour Value in double stage grinding at different moisture content (%) |      |      |      |
|------------------|---|------|------|------|
|                  | 7   | 9    | 11   | 13   |
| 6                | 4.49  | 4.62 | 4.46 | 3.8  |
| 8                | 4.16  | 4.16 | 4.16 | 3.2  |
| 10               | 4.02  | 4.62 | 3.41 | 3.95 |
| 12               | 4.58  | 4.28 | 4.36 | 4.36 |



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

The colour change value of coriander was measured at different moisture content of sample and different feed rate in both single and double stage grinding. From Fig.4.16, it is evident that the colour change of coriander powder during grinding of single stage hammer mill found to be in the range 2.79 to 3.48. While in double stage hammer mill colour change of coriander powder was found in the range of 3.2 to 4.58. The average hue angle and chroma of coriander powder were 75° 5' and 30.25 in single stage hammer mill. While in double stage hammer mill it was observed that the average hue

angle and chroma of coriander powder were 77° 12', 33.64, 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.



**Fig4.15 Effect of moisture content and feed rate on colour value of coriander powder using Single and Double Stage grinding**

## 4.5 Cost economics for coriander powder production

### 4.5.1 Cost analysis for preparing of coriander 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 | 60,000.00        |
| 2     | Digital balance          | 6,000.00         |
| 3     | Miscellaneous            | 1,000.00         |
|       | <b>Total</b>             | <b>67,000.00</b> |

### Total Working Capital (per month)

|            |  | Amount (Rs.)       |
|------------|--|--------------------|
| <b>(A)</b> | <b>Labour</b>                              |                    |
|            | Skilled 2No. @ 5000.00                     | 10,000.00          |
| <b>(B)</b> | <b>Raw material</b>                        |                    |
|            | Coriander 2000kg @Rs. 60/kg                | 1,20,000.00        |
| <b>(C)</b> | Building rent charges                      | 2,000.00           |
| <b>(D)</b> | Electricity (300kWh@Rs.7/kWh)              | 2,100.00           |
| <b>(E)</b> | Repair & maintenance (1% cost of machines) | 670.00             |
| <b>(F)</b> | Transport charges                          | 2,000.00           |
| <b>(G)</b> | Miscellaneous expenses                     | 500.00             |
|            | <b>Total</b>                               | <b>1,37,270.00</b> |

**Total Working capital for 3 month Rs. 4, 11,810.00**

### Total capital investment

|                              |                    |
|------------------------------|--------------------|
| Fixed capital                | 67,000.00          |
| Working capital(for 3 month) | 4,11,810.00        |
| <b>Total</b>                 | <b>4,78,810.00</b> |

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

|   |                     |
|---|---------------------|
| Working capital @300days/year                   | 16,47,270 .00       |
| Depreciation on machines/equipments @ 10% p.a.  | 6700.00             |
| Interest on total capital investment @ 12% p.a. | 57,457.00           |
| <b>Total</b>                                    | <b>17,11,427.00</b> |

### Total Annual Sales

|                  | Quantity (kg) | Sale rate (Rs.) | Amount (Rs.) |
|------------------|---------------|-----------------|--------------|
| Coriander powder | 24000         | 80              | 19,20,000.00 |

### Profitability

Annual profit = (Total sales-Annual cost)

$$= (19, 20,000.00- 17, 11,427.00)$$

$$=2, 08,573.00$$

Monthly profit = Annual profit/12

$$= 2, 08,573.00 /12$$

$$= 17,381.08$$

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

$$= (2, 08,573.00 /19, 20,000.00) \times 100$$

$$= 10.86\%$$

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

$$= (\text{Annual profit} / \text{Total annual cost}) \times 100$$

$$= (2, 08,573.00 / 17, 11,427.00) \times 100$$

$$= 12.18\%$$

## Pay Back Period

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

PEP= fixed cost/profit

$$= 67000.00 / 2,08,573.00$$

$$= 3.85 \text{ years}$$

## 4.5.2 Cost analysis for preparing of coriander 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     | Single stage hammer mill | 80,000.00        |
| 2     | Digital balance          | 6,000.00         |
| 3     | Miscellaneous            | 1,000.00         |
|       | <b>Total</b>             | <b>87,000.00</b> |

**Total Working Capital (per month)**

|   | <b>Amount (Rs.)</b> |
|---|---------------------|
| <b>(A) Labour</b>   |                     |
| Skilled 2No. @ 5000.00                                    | 10,000.00           |
| <b>(B) Raw material</b>                                   |                     |
| Coriander 2000kg @Rs. 60kg                                | 1,20,000.00         |
| <b>(C) Building rent charges</b>                          | 2,000.00            |
| <b>(D) Electricity (500kWh@Rs.7/kWh)</b>                  | 3,500.00            |
| <b>(E) Repair &amp; maintenance (1% cost of machines)</b> | 870.00              |
| <b>(F) Transport charges</b>                              | 2,000.00            |
| <b>(G) Miscellaneous expenses</b>                         | 500.00              |
| <b>Total</b>  | <b>1,38,870.00</b>  |

---

**Total Working capital for 3 month Rs. 4, 16,610.00**

**Total capital investment**

|                              |                    |
|------------------------------|--------------------|
| Fixed capital                | 87,000.00          |
| Working capital(for 3 month) | 4,16,610.00        |
| <b>Total</b>                 | <b>5,03,610.00</b> |

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

|   |                     |
|---|---------------------|
| Working capital @300days/year                   | 16, 66,440 .00      |
| Depreciation on machines/equipments @ 10% p.a.  | 8700.00             |
| Interest on total capital investment @ 12% p.a. | 60,433.00           |
| <b>Total</b>                                    | <b>17,35,573.00</b> |

### Total Annual Sales

|                  | Quantity (kg) | Sale rate (Rs.) | Amount (Rs.) |
|------------------|---------------|-----------------|--------------|
| Coriander powder | 24000         | 90              | 2,160,000.00 |

### Profitability

$$\begin{aligned}\text{Annual profit} &= (\text{Total sales}-\text{Annual cost}) \\ &= (2,160,000.00- 17, 35,573.00) \\ &= 4, 24,427.00\end{aligned}$$

$$\begin{aligned}\text{Monthly profit} &= \text{Annual profit}/12 \\ &= 4, 24,427.00 /12 \\ &= 35,368.91\end{aligned}$$

$$\begin{aligned}\text{Profit on sale} &= \frac{\text{Annual Profit}}{\text{Annual Sale}} \times 100 \\ &= (4, 24,427.00 /2,160,000.00) \times 100 \\ &= 19.64\%\end{aligned}$$

$$\begin{aligned}\text{Return on capital investment} &= \frac{\text{Annual profit}}{\text{Total capital investment}} \times 100 \\ &= (\text{Annual profit} / \text{Total annual cost}) \times 100 \\ &= (4, 24,427.00 / 17, 35,573.00) \times 100 \\ &= 24.45\%\end{aligned}$$

### Pay Back Period

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

$$\text{PEP} = \text{fixed cost}/\text{profit}$$

$$\begin{aligned}&= 87000.00/ 4, 24,427.00 \\ &= 2.45 \text{ year}\end{aligned}$$

## **SUMMARY AND CONCLUSIONS**

### **5.1 Summary**

Grinding characteristic of coriander seed were observed by conducting experiments by using single and double stage grinding process under selected operational condition. In both grinding processes two independent parameters feed rate and moisture content were selected to observe the effect of grinding. Feed rate was kept at four levels (6, 8, 10 and 12 kg/h), the levels of moisture content were (7, 9, 11 and 13% wb). Factorial CRD design was used for the single and double stage grinding method. Different physical characteristics measured are size and shape, bulk density, true density, angle of repose at different moisture content. The quality of ground coriander powder was studied in terms of the observed variables i.e. temperature, fineness modulus, particle size, volatile oil and colour.

### **5.2 Conclusion**

1. The average values length, width, thickness of coriander seeds were 4.25, 3.29 and 3.36 mm, respectively. The on moisture content on bulk density of coriander seeds decreased linearly with the increase in the moisture content. The true density was observed to be more or less constant with the variation in moisture content of coriander. The angle of repose increased linearly with the increase in the moisture content of coriander.
2. In single stage grinding the minimum rise in temperature (33°C) was found at 6 kg/h feed rate and 7% moisture content (wb) and the maximum temperature (50°C) was found at 12 kg/h feed rate & 13% moisture content. While in double stage grinding the minimum rise in temperature (28°C) was found at 6 kg/h feed rate and 9 % moisture content and the maximum temperature (41.33°C) was found at 12 kg/h feed rate & 13% moisture content. It was observed that with increase in moisture content and feed rate the temperature of coriander powder was increased. During double stage grinding temperature rise was less compare to single stage grinding.
3. At 13% moisture content (wb) and fed at a rate of 12 kg/h maximum values of fineness modulus 1.4 and 1.33 were observed during single stage and double stage grinding, respectively. However, minimum

values of fineness modulus viz 1.13 and 1.08 were observed at 6 kg/h feed rate and 7% moisture content (wb) during single stage and double stage grinding, respectively. The values of fineness modulus were higher during single stage grinding compared with the double stage grinding.

4. The average particle size of coriander powder ranged from 0.190 to 0.213 mm in single stage grinding. While double stage grinding particle size of coriander powder ranged from 0.187 to 0.205 mm. Double stage grinding produced finer particles as compared to single stage grinding. It was also observed that in both grinding processes the average particle size of coriander powder increased with increment in moisture content of coriander seeds.
5. The average volatile oil obtained from coriander powder ranged from 1 to 1.87ml/100g in single stage grinding. While in double stage grinding volatile oil of coriander ranged from 1.4 to 2.43ml/100g. It was also observed that as the moisture content and feed rate was increased the temperature of coriander powder also increased resulting in losses of volatile oil. The double stage grinding produces superior product as compared to the single stage grinding.
6. Increase in grinding temperature resulted in increased colour losses. The best colour of coriander powder was found by double stage grinding process.
7. The cost analysis for preparation of coriander powder by using single stage hammer mill indicates a payback period of 3.85 years. The annual profit on sale and return on capital investment comes out to be 10.86% and 12.18%, respectively.
8. The cost analysis for preparation of coriander powder by using double stage hammer mill indicates a payback period of 2.45 month. The annual profit on sale and return on capital investment comes out to be 19.64% and 24.45% respectively.
9. After evaluation of all quality attributes of ground coriander powder in terms of rise in temperature, volatile oil content, fineness modulus, particle size, colour analysis and cost analysis, it was concluded that the best quality product was obtained at 6kg/h feed rate and at 7% moisture content (wb) in double stage grinding. The results showed the superiority of double stage grinding over single stage grinding.

### **5.3 Suggestion for future Work**

Coriander powder is a popular spice in the Indian food system. Its value depends upon the particle size, purity, colour and aroma of the finished product after grinding. It is suggested that further studied should be undertaken to evaluate the product quality when coriander is milled at different rpm, different pretreatments of seed, milling after predetermined storage periods and scale up operations undertaken when the seeds are milled in pilot plants.

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## ABSTRACT

Experiments on grinding of coriander seed were conducted in a single and double stage hammer mill at Department of Post Harvest Processing and Food Engineering, C.A.E., J.N.K.V.V., Jabalpur, (M.P), to find out the effect of feed rate and moisture content on temperature rise during milling, fineness modulus, average particle size, volatile oil content and colour of the coriander powder.

The length, width, thickness, bulk density, true density and angle of repose of coriander seeds were 4.25 mm, 3.29 mm and 3.36 mm, 225 kg/m<sup>3</sup>, 337 kg/m<sup>3</sup> and 26°, respectively. During single stage and double stage grinding there was a gradual increment in temperature and decrement in size of coriander powder, with an increase in feed rate of coriander seeds. The temperature raised gradually from 33°C to 50°C and from 28°C to 41.33°C during single stage and double stage grinding respectively, with an increase in the feed rate from 6 Kg/h to 12 Kg/h and moisture content from 7% to 13% (wb). However the average particle size of the ground coriander powder increased with an increase in the feed rate and moisture content. The average particle size with single stage grinding varied from 0.190 to 0.213 mm while it was 0.187 to 0.205 mm during double stage grinding. Volatile oil content of the coriander powder obtained by double stage grinding was found to be higher compared with single stage grinding. Volatile oil content varied from (1 to 2.03ml/100g) in single stage and (1.4 to 2.20ml/100g) in double stage grinding. The minimum colour losses were observed in double stage grinding as compared to single stage grinding. The colour change value of coriander powder during grinding of single stage hammer mill found was ranged from 2.79 to 3.48, while in double stage hammer mill colour change of coriander powder ranged from 3.2 to 4.58.

The best quality parameters of ground coriander powder were 2.20 ml/100gm of oil content, 1.03 of fineness modulus, 0.187 mm of particle size at 6 kg/h feed rate and 7% moisture content (wb) in double stage grinding. Result of the study showed that the better quality product obtained using double stage grinding.

## APPENDICES-A

**Table A-1: Measurement of length, width, thickness of coriander seeds**

| S No        | Length (mm)   |               |               |               | Width(mm)     |               |               |               | Thickness (mm) |               |               |               |
|-------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|----------------|---------------|---------------|---------------|
|             | 7%            | 9%            | 11%           | 13%           | 7%            | 9%            | 11%           | 13%           | 7%             | 9%            | 11%           | 13%           |
| 1           | 4.97          | 4.43          | 4.57          | 3.39          | 3.61          | 3.54          | 3.02          | 3.29          | 3.49           | 3.26          | 3.18          | 3.4           |
| 2           | 4.57          | 4.89          | 4.39          | 4.57          | 3.55          | 3.29          | 3.05          | 3.26          | 3.44           | 3.49          | 3.44          | 3.27          |
| 3           | 4.24          | 3.98          | 3.97          | 4.27          | 3.36          | 3.31          | 3.16          | 3.31          | 3.34           | 3.65          | 3.34          | 3.2           |
| 4           | 4.47          | 4.61          | 4.52          | 4.24          | 3.29          | 3.35          | 3.13          | 3.39          | 3.26           | 3.45          | 3.26          | 3.02          |
| 5           | 3.91          | 4.9           | 4.12          | 4.16          | 3.26          | 3.65          | 3.21          | 3.35          | 3.18           | 3.21          | 3.49          | 3.12          |
| 6           | 4.28          | 3.92          | 3.68          | 3.39          | 3.31          | 3.28          | 3.41          | 3.29          | 3.28           | 3.26          | 3.28          | 3.17          |
| 7           | 4.57          | 3.39          | 4.55          | 4.89          | 3.39          | 3.32          | 3.05          | 3.34          | 3.35           | 3.54          | 3.35          | 3.37          |
| 8           | 4.61          | 4.57          | 4.89          | 4.75          | 3.35          | 3.08          | 3.01          | 3.66          | 3.29           | 3.69          | 3.29          | 3.22          |
| 9           | 4.27          | 4.27          | 4.75          | 4.28          | 3.29          | 3.17          | 3.16          | 3.16          | 3.26           | 3.58          | 3.26          | 3.27          |
| 10          | 3.92          | 4.24          | 4.28          | 4.16          | 3.34          | 3.17          | 3.13          | 3.13          | 3.25           | 3.57          | 3.25          | 3.37          |
| 11          | 4.9           | 4.16          | 4.16          | 4.23          | 3.66          | 3.42          | 3.14          | 3.14          | 3.6            | 3.68          | 3.6           | 3.17          |
| 12          | 4.33          | 3.39          | 4.23          | 3.68          | 3.7           | 3.21          | 3.11          | 3.11          | 3.65           | 3.25          | 3.65          | 3.62          |
| 13          | 4.75          | 4.89          | 3.87          | 4.56          | 3.4           | 3.15          | 3.37          | 3.37          | 3.38           | 3.21          | 3.38          | 3.65          |
| 14          | 4.23          | 4.25          | 3.68          | 4.38          | 3.61          | 3.42          | 3.25          | 3.61          | 3.59           | 3.36          | 3.59          | 3.12          |
| 15          | 3.92          | 3.39          | 4.56          | 4.85          | 3.29          | 3.24          | 3.24          | 3.29          | 3.27           | 3.26          | 3.27          | 3.42          |
| 16          | 3.39          | 4.16          | 4.38          | 3.39          | 3.17          | 3.26          | 3.42          | 3.17          | 3.15           | 3.25          | 3.15          | 3.58          |
| 17          | 4.27          | 4.58          | 4.85          | 4.27          | 3.32          | 3.28          | 3.21          | 3.32          | 3.25           | 3.68          | 3.29          | 3.51          |
| 18          | 4.16          | 4.21          | 4.55          | 4.16          | 3.08          | 3.1           | 3.15          | 3.08          | 3.06           | 3.69          | 3.06          | 3.49          |
| 19          | 4.28          | 3.68          | 3.78          | 4.28          | 3.04          | 3.25          | 3.1           | 3.04          | 3.01           | 3.57          | 3.01          | 3.24          |
| 20          | 3.98          | 3.98          | 3.95          | 4.16          | 3.81          | 3.32          | 3.81          | 3.81          | 3.79           | 3.98          | 3.79          | 3.21          |
| 21          | 3.65          | 4.28          | 4.86          | 4.58          | 3.6           | 3.31          | 3.6           | 3.61          | 3.6            | 3.25          | 3.18          | 3.33          |
| 22          | 4.45          | 3.85          | 4.52          | 4.21          | 3.5           | 3.15          | 3.5           | 3.29          | 3.2            | 3.68          | 3.28          | 3.43          |
| 23          | 4.56          | 4.24          | 3.98          | 3.68          | 3.2           | 3.25          | 3.4           | 3.17          | 3.6            | 3.96          | 3.25          | 3.41          |
| 24          | 4.18          | 4.18          | 4.25          | 4.16          | 3.3           | 3.4           | 3.07          | 3.32          | 3.2            | 3.28          | 3.26          | 3.02          |
| 25          | 3.98          | 4.24          | 4.78          | 4.58          | 3.1           | 3.07          | 3.08          | 3.08          | 3.4            | 3.35          | 3.27          | 3.03          |
| 26          | 3.48          | 4.15          | 4.63          | 4.21          | 3.8           | 3.08          | 3.2           | 3.04          | 3.5            | 3.39          | 3.34          | 3.08          |
| 27          | 4.42          | 4.25          | 4.29          | 3.68          | 3.2           | 3.2           | 3.32          | 3.81          | 3.3            | 3.25          | 3.44          | 3.19          |
| 28          | 4.12          | 3.39          | 4.58          | 3.39          | 3.5           | 3.32          | 3.14          | 3.21          | 3.1            | 3.95          | 3.06          | 3.28          |
| 29          | 4.89          | 4.25          | 4.78          | 4.25          | 3.6           | 3.14          | 3.21          | 3.01          | 3.2            | 3.75          | 3.01          | 3.35          |
| 30          | 4.44          | 4.89          | 4.56          | 4.89          | 3.4           | 3.07          | 3.54          | 3.14          | 3.6            | 3.68          | 3.17          | 3.05          |
| <b>Mean</b> | <b>4.27</b>   | <b>4.19</b>   | <b>4.36</b>   | <b>4.19</b>   | <b>3.40</b>   | <b>3.26</b>   | <b>3.23</b>   | <b>3.29</b>   | <b>3.35</b>    | <b>3.51</b>   | <b>3.31</b>   | <b>3.29</b>   |
| <b>SD</b>   | <b>0.3900</b> | <b>0.4409</b> | <b>0.3595</b> | <b>0.4446</b> | <b>0.2067</b> | <b>0.1378</b> | <b>0.1909</b> | <b>0.2161</b> | <b>0.19448</b> | <b>0.2381</b> | <b>0.1845</b> | <b>0.1787</b> |

**Table A-2: Measurement of physical properties of coriander seed**

| S No        | Bulk Density(kg/m <sup>3</sup> ) |                |               |               | True Density (kg/m <sup>3</sup> ) |               |               |               | Dynamic angle of repose (Ø) |               |               |               |
|-------------|----------------------------------|----------------|---------------|---------------|-----------------------------------|---------------|---------------|---------------|-----------------------------|---------------|---------------|---------------|
|             | 7%                               | 9%             | 11%           | 13%           | 7%                                | 9%            | 11%           | 13%           | 7%                          | 9%            | 11%           | 13%           |
| 1           | 234                              | 223            | 221           | 222           | 332                               | 341           | 345           | 340           | 24                          | 27            | 28            | 29            |
| 2           | 233                              | 224            | 223           | 225           | 335                               | 334           | 342           | 339           | 26                          | 25            | 27            | 27            |
| 3           | 231                              | 229            | 225           | 227           | 336                               | 337           | 340           | 338           | 28                          | 26            | 25            | 30            |
| 4           | 230                              | 227            | 228           | 230           | 334                               | 334           | 339           | 336           | 27                          | 27            | 28            | 27            |
| 5           | 232                              | 224            | 221           | 224           | 339                               | 335           | 392           | 334           | 25                          | 25            | 27            | 28            |
| 6           | 221                              | 221            | 223           | 222           | 332                               | 341           | 338           | 335           | 24                          | 24            | 26            | 30            |
| 7           | 223                              | 223            | 231           | 221           | 340                               | 334           | 336           | 332           | 26                          | 26            | 27            | 29            |
| 8           | 231                              | 231            | 222           | 224           | 341                               | 337           | 338           | 336           | 27                          | 27            | 28            | 28            |
| 9           | 222                              | 222            | 225           | 225           | 334                               | 334           | 341           | 343           | 25                          | 26            | 29            | 30            |
| 10          | 225                              | 225            | 227           | 226           | 337                               | 335           | 343           | 332           | 24                          | 28            | 27            | 28            |
| 11          | 227                              | 227            | 230           | 231           | 334                               | 334           | 332           | 336           | 26                          | 24            | 26            | 27            |
| 12          | 230                              | 230            | 231           | 222           | 335                               | 340           | 336           | 338           | 25                          | 25            | 27            | 30            |
| 13          | 224                              | 220            | 226           | 225           | 339                               | 339           | 338           | 335           | 24                          | 26            | 27            | 29            |
| 14          | 227                              | 230            | 220           | 227           | 342                               | 338           | 335           | 337           | 25                          | 27            | 28            | 29            |
| 15          | 226                              | 231            | 221           | 230           | 337                               | 336           | 337           | 340           | 24                          | 27            | 26            | 27            |
| 16          | 220                              | 226            | 224           | 224           | 334                               | 334           | 342           | 342           | 26                          | 26            | 27            | 28            |
| 17          | 230                              | 220            | 225           | 221           | 336                               | 335           | 340           | 339           | 27                          | 25            | 28            | 30            |
| 18          | 231                              | 221            | 226           | 223           | 338                               | 332           | 336           | 340           | 24                          | 27            | 27            | 29            |
| 19          | 234                              | 224            | 227           | 231           | 336                               | 336           | 338           | 339           | 26                          | 26            | 29            | 28            |
| 20          | 224                              | 225            | 224           | 222           | 332                               | 338           | 336           | 338           | 25                          | 24            | 28            | 26            |
| 21          | 229                              | 222            | 221           | 225           | 334                               | 335           | 332           | 334           | 28                          | 25            | 26            | 30            |
| 22          | 228                              | 225            | 223           | 227           | 335                               | 337           | 334           | 338           | 26                          | 26            | 27            | 29            |
| 23          | 224                              | 227            | 231           | 230           | 339                               | 342           | 335           | 336           | 24                          | 24            | 26            | 28            |
| 24          | 223                              | 230            | 222           | 222           | 338                               | 340           | 338           | 335           | 24                          | 25            | 29            | 27            |
| 25          | 221                              | 222            | 225           | 227           | 334                               | 343           | 340           | 336           | 28                          | 26            | 28            | 30            |
| 26          | 222                              | 220            | 227           | 230           | 333                               | 337           | 339           | 332           | 26                          | 24            | 29            | 26            |
| 27          | 224                              | 227            | 230           | 222           | 337                               | 332           | 338           | 334           | 24                          | 29            | 28            | 29            |
| 28          | 234                              | 229            | 222           | 220           | 336                               | 334           | 336           | 335           | 25                          | 25            | 27            | 28            |
| 29          | 232                              | 223            | 224           | 221           | 334                               | 335           | 334           | 343           | 27                          | 26            | 28            | 29            |
| 30          | 230                              | 225            | 234           | 223           | 332                               | 337           | 335           | 341           | 25                          | 27            | 29            | 30            |
| <b>Mean</b> | <b>227.4</b>                     | <b>225.1</b>   | <b>225.3</b>  | <b>224.97</b> | <b>335.83</b>                     | <b>336.53</b> | <b>339.31</b> | <b>337.1</b>  | <b>25.5</b>                 | <b>25.833</b> | <b>27.542</b> | <b>28.5</b>   |
| <b>SD</b>   | <b>4.3991</b>                    | <b>3.44764</b> | <b>3.6686</b> | <b>3.3578</b> | <b>2.7428</b>                     | <b>2.9094</b> | <b>3.201</b>  | <b>3.1001</b> | <b>1.3326</b>               | <b>1.2617</b> | <b>1.07</b>   | <b>1.2526</b> |

## APPENDICES-B

**Table B-1 Temperature in single stage grinding for feed rate and moisture content.**

|                  |   |          |         |
|------------------|---|----------|---------|
| Moisture content | 4 | G.Mean = | 39.2500 |
| feed rate        | 4 | SD=      | 4.7288  |
| Replication=     | 3 | CV%=     | 8.3002  |

### ANOVA

| <i>Source</i> | <i>DF</i> | <i>SS</i> | <i>MSS</i> | <i>Fcal</i> | <i>Ftab 5%</i> |
|---------------|-----------|-----------|------------|-------------|----------------|
| M             | 3         | 370.17    | 123.39     | 28.612      | 2.901          |
| F             | 3         | 475.50    | 158.50     | 36.754      | 2.901          |
| MXF           | 9         | 67.33     | 7.48       | 1.735       | 2.189          |
| Error         | 32        | 138.00    | 4.31       |             |                |
| Total         | 47        | 1051.00   |            |             |                |

|     | <b>SE M</b> | <b>SE D</b> | <b>CD</b> |
|-----|-------------|-------------|-----------|
| M   | 0.5995      | 0.8478      | 1.7269    |
| F   | 0.5995      | 0.8478      | 1.7269    |
| MXF | 1.1990      | 1.6956      | 3.4537    |

**Table B-2 Temperature in Double stage grinding for feed rate and moisture content.**

|                   |   |          |         |
|-------------------|---|----------|---------|
| Moisture content= | 4 | G.Mean = | 33.9375 |
| feed rate=        | 4 | SD=      | 4.0707  |
| Replication=      | 3 | CV%=     | 8.3370  |

### ANOVA

| <i>Source</i> | <i>DF</i> | <i>SS</i> | <i>MSS</i> | <i>Fcal</i> | <i>Ftab 5%</i> |
|---------------|-----------|-----------|------------|-------------|----------------|
| M             | 3         | 191.73    | 63.91      | 16.855      | 2.901          |
| F             | 3         | 397.40    | 132.47     | 34.936      | 2.901          |
| MXF           | 9         | 68.35     | 7.59       | 2.003       | 2.189          |
| Error         | 32        | 121.33    | 3.79       |             |                |
| Total         | 47        | 778.81    |            |             |                |

|     | <b>SE M</b> | <b>SE D</b> | <b>CD</b> |
|-----|-------------|-------------|-----------|
| M   | 0.5621      | 0.7949      | 1.6192    |
| F   | 0.5621      | 0.7949      | 1.6192    |
| MXF | 1.1242      | 1.5899      | 3.2385    |

**Table B-3 Fineness Modulus in single stage grinding for feed rate and moisture content.**

|                   |   |          |        |
|-------------------|---|----------|--------|
| Moisture content= | 4 | G.Mean = | 1.2450 |
| feed rate=        | 4 | SD=      | 0.0833 |
| Replication=      | 3 | CV%=     | 14.948 |
|                   |   |          | 9      |

**ANOVA**

| <b>Source</b> | <b>DF</b> | <b>SS</b> | <b>MSS</b> | <b>Fcal</b> | <b>Ftab 5%</b> |
|---------------|-----------|-----------|------------|-------------|----------------|
| M             | 3         | 0.23      | 0.08       | 214.397     | 2.901          |
| F             | 3         | 0.03      | 0.01       | 32.048      | 2.901          |
| MXF           | 9         | 0.06      | 0.01       | 17.788      | 2.189          |
| Error         | 32        | 0.01      | 0.00       |             |                |
| Total         | 47        | 0.33      |            |             |                |

|     | <b>SE M</b> | <b>SE D</b> | <b>CD</b> |
|-----|-------------|-------------|-----------|
| M   | 0.0054      | 0.0076      | 0.0156    |
| F   | 0.0054      | 0.0076      | 0.0156    |
| MXF | 0.0108      | 0.0153      | 0.0311    |

**Table B-4 Fineness Modulus in double stage grinding for feed rate and moisture content.**

|                   |   |          |         |
|-------------------|---|----------|---------|
| Moisture content= | 4 | G.Mean = | 1.1856  |
| feed rate=        | 4 | SD=      | 0.0693  |
| Replication=      | 3 | CV%=     | 17.1062 |

**ANOVA**

| <b>Source</b> | <b>DF</b> | <b>SS</b> | <b>MSS</b> | <b>Fcal</b> | <b>Ftab 5%</b> |
|---------------|-----------|-----------|------------|-------------|----------------|
| M             | 3         | 0.14      | 0.05       | 109.652     | 2.901          |
| F             | 3         | 0.07      | 0.02       | 52.606      | 2.901          |
| MXF           | 9         | 0.01      | 0.00       | 1.386       | 2.189          |
| Error         | 32        | 0.01      | 0.00       |             |                |
| Total         | 47        | 0.23      |            |             |                |

|     | <b>SE M</b> | <b>SE D</b> | <b>CD</b> |
|-----|-------------|-------------|-----------|
| M   | 0.0060      | 0.0084      | 0.0171    |
| F   | 0.0060      | 0.0084      | 0.0171    |
| MXF | 0.0119      | 0.0168      | 0.0343    |

**Table B-5 Particle size in single stage grinding for feed rate and moisture content.**

Moisture content= 4 G.Mean = 0.1999  
 feed rate= 4 SD= 0.0060  
 Replication= 3 CV%= 33.4526

**ANOVA**

| <b>Source</b> | <b>DF</b> | <b>SS</b> | <b>MSS</b> | <b>Fcal</b> | <b>Ftab 5%</b> |
|---------------|-----------|-----------|------------|-------------|----------------|
| M             | 3         | 0.01      | 0.00       | 2.110       | 2.901          |
| F             | 3         | 0.00      | 0.00       | 1.662       | 2.901          |
| MXF           | 9         | 0.01      | 0.00       | 0.910       | 2.189          |
| Error         | 32        | 0.03      | 0.00       |             |                |
| Total         | 47        | 0.04      |            |             |                |

|     | <b>SE M</b> | <b>SE D</b> | <b>CD</b> |
|-----|-------------|-------------|-----------|
| M   | 0.0081      | 0.0115      | 0.0234    |
| F   | 0.0081      | 0.0115      | 0.0234    |
| MXF | 0.0162      | 0.0230      | 0.0468    |

**Table B-6 Particle size in single stage grinding for feed rate and moisture content.**

Moisture content= 4 G.Mean = 0.1947  
 feed rate= 4 SD= 0.0055  
 Replication= 3 CV%= 35.1197

**ANOVA**

| <b>Source</b> | <b>DF</b> | <b>SS</b> | <b>MSS</b> | <b>Fcal</b> | <b>Ftab 5%</b> |
|---------------|-----------|-----------|------------|-------------|----------------|
| M             | 3         | 0.00      | 0.00       | 1.618       | 2.901          |
| F             | 3         | 0.00      | 0.00       | 1.793       | 2.901          |
| MXF           | 9         | 0.01      | 0.00       | 0.887       | 2.189          |
| Error         | 32        | 0.02      | 0.00       |             |                |
| Total         | 47        | 0.04      |            |             |                |

|     | <b>SE M</b> | <b>SE D</b> | <b>CD</b> |
|-----|-------------|-------------|-----------|
| M   | 0.0080      | 0.0113      | 0.0230    |
| F   | 0.0080      | 0.0113      | 0.0230    |
| MXF | 0.0160      | 0.0226      | 0.0461    |

**Table B-7 Volatile oil content in single stage grinding for feed rate and moisture content.**

|                   |   |          |        |
|-------------------|---|----------|--------|
| Moisture content= | 4 | G.Mean = | 1.5583 |
| feed rate=        | 4 | SD=      | 0.3293 |
| Replication=      | 3 | CV%=     | 4.7322 |

**ANOVA**

| <b>Source</b> | <b>DF</b> | <b>SS</b> | <b>MSS</b> | <b>Fcal</b> | <b>Ftab 5%</b> |
|---------------|-----------|-----------|------------|-------------|----------------|
| M             | 3         | 1.08      | 0.36       | 10.394      | 2.901          |
| F             | 3         | 1.69      | 0.56       | 16.289      | 2.901          |
| MXF           | 9         | 1.22      | 0.14       | 3.925       | 2.189          |
| Error         | 32        | 1.11      | 0.03       |             |                |
| Total         | 47        | 5.10      |            |             |                |

|     | <b>SE M</b> | <b>SE D</b> | <b>CD</b> |
|-----|-------------|-------------|-----------|
| M   | 0.0537      | 0.0759      | 0.1546    |
| F   | 0.0537      | 0.0759      | 0.1546    |
| MXF | 0.1074      | 0.1518      | 0.3093    |

**Table B- 8 Volatile oil content in double stage grinding for feed rate and moisture content.**

|                  |   |          |        |
|------------------|---|----------|--------|
| Moisture content | 4 | G.Mean = | 1.9729 |
| feed rate        | 4 | SD=      | 0.3413 |
| Replication=     | 3 | CV%=     | 5.7806 |

**ANOVA**

| <b>Source</b> | <b>DF</b> | <b>SS</b> | <b>MSS</b> | <b>Fcal</b> | <b>Ftab 5%</b> |
|---------------|-----------|-----------|------------|-------------|----------------|
| M             | 3         | 0.84      | 0.28       | 9.759       | 2.901          |
| F             | 3         | 0.86      | 0.29       | 10.051      | 2.901          |
| MXF           | 9         | 2.87      | 0.32       | 11.154      | 2.189          |
| Error         | 32        | 0.91      | 0.03       |             |                |
| Total         | 47        | 5.47      |            |             |                |

|     | <b>SE M</b> | <b>SE D</b> | <b>CD</b> |
|-----|-------------|-------------|-----------|
| M   | 0.0488      | 0.0690      | 0.1405    |
| F   | 0.0488      | 0.0690      | 0.1405    |
| MXF | 0.0975      | 0.1379      | 0.2810    |

**Table B-9 Colour value in single stage grinding for feed rate and moisture content**

Moisture content= 4 G.Mean = 3.1721  
 feed rate= 4 SD= 0.4907  
 Replication= 3 CV%= 6.4638

**ANOVA**

| <i>Source</i> | <i>DF</i> | <i>SS</i> | <i>MSS</i> | <i>Fcal</i> | <i>Ftab 5%</i> |
|---------------|-----------|-----------|------------|-------------|----------------|
| M             | 3         | 0.13      | 0.04       | 0.158       | 2.901          |
| F             | 3         | 0.18      | 0.06       | 0.217       | 2.901          |
| MXF           | 9         | 2.34      | 0.26       | 0.961       | 2.189          |
| Error         | 32        | 8.67      | 0.27       |             |                |
| Total         | 47        | 11.32     |            |             |                |

|     | <b>SE M</b> | <b>SE D</b> | <b>CD</b> |
|-----|-------------|-------------|-----------|
| M   | 0.1503      | 0.2125      | 0.4328    |
| F   | 0.1503      | 0.2125      | 0.4328    |
| MXF | 0.3005      | 0.4250      | 0.8657    |

**Table B-10 Colour value in double stage grinding for feed rate and moisture content**

Moisture content= 4 G.Mean = 4.1642  
 feed rate= 4 SD= 0.5103  
 Replication= 3 CV%= 8.1595

**ANOVA**

| <i>Source</i> | <i>DF</i> | <i>SS</i> | <i>MSS</i> | <i>Fcal</i> | <i>Ftab 5%</i> |
|---------------|-----------|-----------|------------|-------------|----------------|
| M             | 3         | 2.44      | 0.81       | 5.722       | 2.901          |
| F             | 3         | 2.07      | 0.69       | 4.867       | 2.901          |
| MXF           | 9         | 3.18      | 0.35       | 2.489       | 2.189          |
| Error         | 32        | 4.55      | 0.14       |             |                |
| Total         | 47        | 12.24     |            |             |                |

|     | <b>SE M</b> | <b>SE D</b> | <b>CD</b> |
|-----|-------------|-------------|-----------|
| M   | 0.1088      | 0.1539      | 0.3134    |
| F   | 0.1088      | 0.1539      | 0.3134    |
| MXF | 0.2176      | 0.3078      | 0.6269    |

## VITA



**Madhuri Gajabe**  
**Candidate for the award of degree of Master of Technology**

- Title of Thesis :** “**Studies on the Effect of Single Stage and Double Stage Grinding on the Quality Attributes of Coriander Powder**”
- Major Field :** Post Harvest Process and Food Engineering
- Biographical :** Born on 26<sup>th</sup> August, 1989 at Yeoda, Maharashtra.

The author of this thesis, Miss Madhuri Gajabe graduated from College of Agricultural Engineering, Dr.P.D.K.V Akola (M.S) in the year 2011 and received the degree of Bachelor of Technology (Agricultural Engineering) with 7.74 in 10 point scale. She joined Master of Technology programme in Agricultural Engineering with specialization in Post Harvest Process and Food Engineering at, CAE, JNKVV, and Jabalpur.

- Permanent Address :** Madhuri Gajabe D/O Shri H. D. Gajabe  
At Post - Yoda (Ramnagar)  
Taluka - Daryapur  
District - Amravati  
(M.S.) Pin- 444706
- E-mail ID :** madhurigajabe@gmail.com
- Contact no. :** +91- 7415059947, +91-9960818494