STUDIES ON GRINDING CHARACTERISTICS OF CORIANDER (*Coriandrum sativum* L.) SEEDS

M.Tech. (Agril. Engg.) Thesis

by

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ARCHANA BHAGAT

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CERTIFICATE - I

This is to certify that the thesis entitled **"Studies on grinding characteristics of coriander (*Coriandrum sativum* L.) seeds"** submitted in partial fulfillment of the requirements for the degree of "**Master of Technology in Agricultural Engineering**" of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **Archana Bhagat** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

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

Date: 28/08/2021

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CERTIFICATE - II

This is to certify that the thesis entitled "**Studies on grinding characteristics of coriander (*Coriandrum sativum* L.) seeds**" submitted by **Archana Bhagat** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur, in partial fulfillment of the requirements for the degree of **Master of Technology in Agricultural Engineering** in the Department of **Agricultural Processing and Food Engineering** has been approved by the external evaluator and Student's Advisory Committee after oral examination, under the chairmanship of Head of the Department.

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Approved/not approved

Director of Instructions

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ABhagat.

Place: IGKV, Raipur *Archana Bhagat*

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LIST OF ABBRAVIATIONS AND SYMBOLS

Abbreviation and Symbols	**Description**
Agril. Engg.	Agricultural Engineering
IGKV	Indira Gandhi Krishi Vishwavidyalaya
FAE	Faculty of Agricultural Engineering
ICAR	Indian Council of Agricultural Research
M. Tech.	Master of Technology
Fig.	Figure
PM	Ponding machine
P	Pulverizer (hammer type)
BG	Burr Grinder
MG	Mixer grinder
MP	Mortar and pestle
SEC	Specific energy consumption
ha	Hectare
wb	Wet basis (Moisture content)
db	Dry basis (Moisture content)
mm	Millimeter
cm	Centimeter
m	Meter
mg	Milligram
g	Gram
kg	Kilo gram
S	Second
H	Hour
kW	Kilo watt
Wh	Watt hour
^{o}	Degree
^{o}C	Degree Celsius
<	Less than

>	Greater than
%	Per cent
&	And
nm	Nanometer
et al.	And others
No.	Number
G	Grinding methods
M	Moisture content level
etc	Etcetera
viz.	*Videlicet* (namely)
ANOVA	Analysis of variance
CD	Critical difference
SE(m)	Standard error mean
NTFP	Non Timber Forest Produce
MAP	Medicinal and Aromatic Plants
SVCAET & RS	Swami Vivekananda College of Agricultural Engineering and Technology and Research Station
S. No.	Serial number
GAE	Gallic Acid Equivalent
QE	Quercetin Equivalent
TPC	Total Phenolic content
FC	Flavonoid content

THESIS ABSTRACT

Title of the Thesis : Studies on Grinding Characteristics of Coriander (*Coriandrum sativum L.*) Seeds

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Major Subject : Agricultural Processing and Food Engineering

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Date: 28/08/2021

ABSTRACT

Coriander (*Coriandrum sativum* L.) is medicinal herb belongs to the carrot family (*Umbelliferae* or *Apiaceae*) and comes from the mediterranean region. Commercially, this herb is grown in Europe, Asia, and Africa. The fresh coriander seeds after drying are used as spices. Coriander seeds have many medicinal properties and are used as a carminative, aphrodisiac, and a refrigerant. As a result, coriander is a common ingredient in Ayurvedic medicines, as well as a traditional home remedy for a variety of ailments, including dyspeptic, loss of appetite, convulsions, anxiety and insomnia.

India is the world's largest producer of coriander. Dried coriander seeds converted into powder with the help of suitable pulveriser. The aim of grinding is to obtained smaller particle size with good product quality in terms of flavour and

aroma or colour. To find out the effect of moisture content and grinding method/machine during grinding on average particle size, grinding energy, essential oil, oleoresin content, the total phenolic and flavonoid content present study is planned.

For experimental work, the freshly dried coriander seed were taken and evaluated further for its physical properties such as moisture content, length, width, thickness, geometric mean diameter, bulk density, angle of repose, volume, surface area and sphericity. During the experiment five different grinding machines/methods used *i.e.* pulverizer (hammer type), pounding machine, mixer grinder, burr grinder and mortar pestle at different level of moisture content *i.e.* 7.2, 9.1 and 11.2% (wet basis) were selected to produce powder from coriander seed. Grinding characteristics of coriander were analyzed based on the factors such as specific energy consumption, grinding energy and particle size distribution. After grinding, quality of coriander powder was carried out for phytochemical analysis using standard methods.

The initial moisture content of fresh coriander seed was found to be 9.08% (w.b.). The physical properties of coriander seeds *i.e.* length, width, thickness, bulk density, sphericity, volume, surface area, geometric mean diameter and angle of repose were varied between 6.09-6.16 mm, 3.92-3.97 mm, 3.58-3.68 mm, 298.83-291.62 kg/m^3, 72.57-72.85%, 33.05-34.61 mm^3, 61.32-63.24 mm^2, 4.41-4.47 mm and 29.75-32.73^o, respectively with the different level of moisture content. The specific energy consumption, Kick’s constant, Rittinger’s constant, Bond’s work index and average particle size of coriander ranged from 88.14 to 722.13 Wh/kg, 123.74 to 589.72 Wh/kg, 191.25 to 915.82 Wh/kg, 1005.84 to 4807.21 Wh/kg and 0.477 to 0.877 mm, respectively, at moisture level 7.2 to 11.2% wb.

The grinding methods significantly affect the quality of final coriander powder. The value of oleoresin content, total phenolic content, flavonoid content and essential oil of coriander powder ground with different grinding methods varied from 6.828-12.077%, 19.413-33.715 mg GAE/g powder extract, 1.674-3.584 mg QE/g powder extract and 0.09 to 0.32%, respectively at different level of moisture content 7.2-11.2% wb.

After evaluation of all the quality parameters of ground coriander powder in terms of essential oil, oleoresin content, phenolic content, flavonoid

content and rise in temperature the pounding machine produces the best quality coriander powder. On the basis of appearance and particle size the pulverizer (hammer type) produces good quality powder. At the moisture content 7.2% wb the quality of powder is good on the basis of polyphenols. On the basis of grinding energy, the pounding machine consumes less energy to grind the coriander seed. The coriander powder prepared in the pounding machine and mortar pestle (control) have superior quality as compared to other methods.

शोध सारांश

शोध का शीर्षक : धनिया बीज के पीसने की विशेषताओं पर अध्ययन

छात्रा का पूरा नाम : अर्चना भगत

प्रमुख विषय : कृषि प्रसंस्करण और खाद्य अभियांत्रिकी

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छात्रा का हस्ताक्षर

प्रमुख सलाहकार का हस्ताक्षर

दिनांकः 28/06/2021

विभाग के प्रमुख का हस्ताक्षर

सारांश

धनिया एक औषधीय जड़ी बूटी है जो गाजर परिवार (आम्बेलिफेरी) से संबंधित है जो भूमध्य क्षेत्र से आती है। व्यावसायिक रूप से, यह जड़ी बूटी यूरोप, एशिया और अफ्रीका में उगाई जाती है। ताजे बीजों को सुखाने के बाद मसाले के रूप में उपयोग किया जाता है। धनिया के बीज में कई औषधीय गुण होते हैं और इसका उपयोग कार्मिनेटिव, कामोद्दीपक और रेफ्रिजरेंट के रूप में किया जाता है। नतीजतन, धनिया आयुर्वेदिक दवाओं में एक सामान्य घटक है, साथ ही विभिन्न प्रकार की बीमारियों के लिए एक पारंपरिक घरेलू उपचार है, जिसमें अपच, भूख न लगना, आक्षेप, चिंता और अनिद्रा शामिल हैं। भारत दुनिया में धनिया का सबसे बड़ा उत्पादक है। सूखे धनिये के बीज उपयुक्त पल्वराइजर की सहायता से

पाउडर में परिवर्तित हो जाते हैं। पीसने का उद्देश्य स्वाद और सुगंध या रंग के मामले में अच्छी उत्पाद गुणवत्ता के साथ छोटे कण आकार प्राप्त करना है। औसत कण आकार, पीसने की ऊर्जा, एसेंशियल तेल, ओलियोरेसिन सामग्री पर पीसने के दौरान नमी की मात्रा और पीसने की विधि तथा मशीन के प्रभाव का पता लगाने के लिए, वर्तमान अध्यय में कुल फेनोलिक और फ्लेवोनोइड सामग्री की योजना बनाई गई है। प्रायोगिक कार्य के लिए, ताजे सूखे धनिये के बीज को इसके भौतिक गुणों जैसे नमी की मात्रा, लंबाई, चौड़ाई, मोटाई, ज्यामितीय माध्य व्यास, थोक घनत्व, विश्राम कोण, आयतन, सतह क्षेत्र और गोलाकार के लिए आगे मूल्यांकन किया गया। प्रयोग के दौरान पांच अलग–अलग पीसने वाली मशीनों तथा विधियों का उपयोग किया जाता है, जैसे कि पल्वराइजर (हथौड़ा प्रकार का), पांडिंग मशीन, मिक्सर ग्राइंडर, बर ग्राइंडर और मोर्टार मूसल नमी सामग्री के विभिन्न स्तरों पर यानी 7.2, 9.1 और 11.2 प्रतिशत गीले आधार पर धनिया से पाउडर का उत्पादन करने के लिए चुना गया । बीज विशिष्ट ऊर्जा खपत, पीस ऊर्जा और कण आकार वितरण जैसे कारकों के आधार पर धनिया की पीसने की विशेषताओं का विश्लेषण किया गया था। पीसने के बाद, धनिया पाउडर की गुणवत्ता मानक विधियों का उपयोग करके फाइटोकेमिकल विश्लेषण के लिए की गई। ताजे धनिये के बीज में प्रारंभिक नमी की मात्रा 9.08 प्रतिशत पाई गई। धनिये के बीज के भौतिक गुण अर्थात लंबाई, चौड़ाई, मोटाई, थोक घनत्व, गोलाकार, आयतन, सतह क्षेत्र, ज्यामितीय माध्य व्यास और विश्राम कोण 6.09–6.16 मिमी, 3.92–3.97 मिमी, 3.58–3.68 मिमी, 298.83–291.62 किग्रा प्रति घन मीटर, 72.57–72.85 प्रतिशत , 33.05–34.61 घन मिमी, 61.32–63.24 वर्ग मिमी, 4.41–4.47 मिमी और कोण 29.75–32.73, नमी की मात्रा के विभिन्न स्तरों के साथ। विशिष्ट ऊर्जा खपत, किक का स्थिरांक, रिटिंगर का स्थिरांक, बॉन्ड का कार्य सूचकांक और धनिया का औसत कण आकार 88.14 से 722.13 वाट–घंटा प्रति कि.ग्रा., 123.74 से 589.72 वाट–घंटा प्रति कि.ग्रा, 191.25 से 915.82 वाट–घंटा प्रति कि.ग्रा, 1005.84 से 4807.21 वाट–घंटा प्रति कि.ग्रा और नमी स्तर 7.2 से 11.2 प्रतिशत पर क्रमशः 0.477 से 0.877 मिमी था । पीसने के तरीके अंतिम धनिया पाउडर की गुणवत्ता को महत्वपूर्ण रूप से प्रभावित करते हैं। विभिन्न पीसने के तरीकों के साथ ओलियोरेसिन सामग्री, कुल फेनोलिक सामग्री, फ्लेवोनोइड सामग्री और धनिया पाउडर ग्राउंड के एसेंशियल तेल का मूल्य 6.828–12.077 प्रतिशत, 19.413–33.715 मिलीग्राम जीएई प्रति ग्राम पाउडर निकालने, 1.674–3.584 मिलीग्राम क्यूई प्रति ग्राम पाउडर निकालने से भिन्न होता है। 0.09 से 0.32 प्रतिशत, नमी सामग्री के विभिन्न स्तरों पर क्रमशः 7.2–11.2 प्रतिशत था । एसेंशियल तेल, ओलियोरेसिन सामग्री, फेनोलिक सामग्री, फ्लेवोनोइड सामग्री और तापमान में वृद्धि के संदर्भ में जमीन धनिया पाउडर के सभी गुणवत्ता मानकों के मूल्यांकन के बाद पाडिंग मशीन सर्वोत्तम गुणवत्ता वाले धनिया पाउडर का उत्पादन करती है। दिखने और कणों के आकार के आधार पर पल्वराइजर (हथौड़ा प्रकार का) अच्छी गुणवत्ता वाले पाउडर का उत्पादन करता है। नमी की मात्रा 7.2 प्रतिशत पर पॉलीफेनोल्स के आधार पर पाउडर की गुणवत्ता अच्छी होती है। पीसने की ऊर्जा के आधार पर धनिये के बीज को पीसने के लिए पाउंडिंग मशीन कम ऊर्जा की खपत करती है। पाडिंग मशीन में तैयार धनिया पाउडर और मोर्टार मूसल में अन्य तरीकों की तुलना में बेहतर गुणवत्ता होती है।

CHAPTER-I

INTRODUCTION

Coriander (*Coriandrum sativum* L.) is herb belongs to the carrot family (*Umbelliferae* or *Apiaceae*) and comes from the mediterranean region. Commercially, this herb is grown in Europe, Asia, and Africa. It is cultivated for its seeds and leaves. In general fresh coriander leaves are used for garnishing the different preparations and the fresh seeds after drying are used as spices. Coriander is designated as herb from ancient time. The two important constituents present in the seeds are essential oil and fatty oil. It is also a rich source of vitamins, minerals and iron, also a good source of thiamine, zinc and dietary fiber. Coriander seeds have a mild, sweet, slightly pungent, citrus-like flavour. Whole plant *i.e.* root, stem, leaves, and fruits all have a pleasant aromatic odour.

Coriander is an important spice crop having a prime position in flavouring food. The plant is a thin stemmed, small, bushy herb, 25 to 50 cm in height with many branches and umbels. Leaves are alternate, compound. Fruit is globular, 3 to 5 mm diameter, when pressed break into two locules each having one seed. The seeds are pale white to light brown in colour.

Coriander is used to make chutneys and sauces from the whole young plant. The fresh leaf and dried seeds are the most extensively used items in cooking, but all parts of the plant are edible. The leaves are used to season curries and soups from around the world. The fruits are widely used as a seasoning in pickling spices, sausages, and seasonings, as well as in pastry, biscuits, buns, cakes, and liquors, especially gin. India is the world's largest producer of coriander, which is widely used in curry powder products (Blade 1998). The dried seed is used to make steam-distilled essential oil and solvent-extracted oleoresin in the fragrance, perfumery, and flavour industries (Agri-Facts, 1998).

Coriander, like other seed spices, contains varying quantities of proteins, fats, carbohydrates, fibers, minerals, and vitamins. However, since they are used in such limited amounts in foods, their contribution to nutrient requirements is negligible. The most important element in assessing the quality of spices is the essential/volatile oil. Fresh coriander leaves has 87.9% moisture, 3.3 percent protein, 0.6 percent fat, 6.5 percent carbohydrates, and 1.7 percent mineral matter. Dried mature coriander seed contains essential oil (0.3–2.06 percent), fatty oil (13–18 percent), crude protein (11.5–21.3 percent), fat (17.8–19.15 percent), crude fiber (28.4–29.1 percent), and ash (4.9–6.0 percent) (Coskuner and Karababa, 2007).

Coriander is used to treat different disease like diuretic, antipyretic, stomachic, stimulant, laxative, anathematic, and treats biliousness, bronchitis, and vomiting, as well as being a strong aromatic, antiseptic, expectorant, and antispasmodic. Hiccough, suppuration, piles, inflammation, toothache, jaundice, scabies, and gland tuberculosis are all treated with the leaves, which are hypotonic and analgesic (Dash *et al,* 2011). Coriander seeds have many medicinal properties and are used as a carminative, aphrodisiac, and a refrigerant. As a result, coriander is a common ingredient in Ayurvedic medicines, as well as a traditional home remedy for a variety of ailments. Coriander appears to help regulate blood sugar, cholesterol, and free radical production, according to new research. Coriander has diaphoretic, carminative, and stimulant properties, which are used in Indian traditional medicine to treat digestive, respiratory and urinary system disorders. Coriander has been used to treat a variety of ailments, including dyspeptic, loss of appetite, convulsions, anxiety and insomnia (Pathak *et al*, 2011).

India is the world's largest producer of coriander, with 532320 ha under cultivation and an annual output of 709840 MT; in Chhattisgarh, total production is 770 MT from 2850 ha area in year 2017-18 (Anon. 2018). Andhra Pradesh, Rajasthan, Madhya Pradesh, Karnataka, Tamil Nadu, and Uttar Pradesh are the major coriander-growing states in India.

The dried coriander seeds after grinding used to prepare different spices. The size reduction is important unit operation performed in coriander processing. The size reduction have their own importance such as creating a free-flowing material; improving material blending and preventing segregation by making products in different size ranges; increasing the surface area of a material to enhance its reactiveness; easy to handling *etc*. But at the same time grinding have some disadvantages *i.e.* it is an energy-intensive operation; high heat is generated; loss of nutritional/essential components *etc*. Thus, by selecting appropriate grinding method with by controlling the different parameters one can save the cost of grinding and quality of final product.

Dried coriander seeds converted into powder with the help of suitable pulveriser. The aim of grinding is to obtained smaller particle size with good product quality in terms of flavour and aroma or colour. Due to high fat content in spices, in the normal grinding process, heat is generated when energy is used to fracture a particle into a smaller size. This generated heat causes temperature rise in the grinder to the extent of 95ºC which is responsible for a loss of volatile oil in the tune of about 30% and also produces dark coloured powder. Also the grinding is most energy inefficient method where, only 1% of the energy imparted into the material was utilized for loosening the bond between particles, whereas, almost 99% of input energy was dissipated as heat, thus raising the temperature of the ground product. The energy efficiency of the operation was measured by the new surface created by size reduction.

Thus, looking toward the loss of energy and loss of active compound during grinding process, it is important to identify suitable grinding machine and the process parameters so that the final product should have good quality with less energy consumption. The present research work was entitled **“Studies on Grinding Characteristics of Coriander (*Coriandrum sativum L.*) Seeds”** with the following objectives.

1. To study the physical and bio-chemical properties of dried coriander seeds.
2. To study the grinding characteristics of coriander seeds.
3. To evaluate the quality of ground coriander powder.

CHAPTER-II

REVIEW OF LITERATURE

In this chapter, the previous research work on the methods of determination of physical and bio-chemical properties, the grinding characteristics of coriander seeds and evaluation of quality of the dried coriander powder are briefly enumerated.

The review of literature is divided in the following sub divisions.

2.1 Physical properties of coriander seeds.

2.2 Grinding characteristics of coriander seeds.

2.3 Quality of the ground coriander powder.

2.1 Physical properties of seeds

Rathod *et al.* (2020) tested the fenugreek seeds and plants for certain physical and mechanical properties. Fenugreek seed had an average geometric mean diameter, length, width and thickness, of 2.41 mm, 3.47 mm, 2.53 mm and 1.61 mm, respectively. The length, width, and stalk diameter of the fenugreek plant measured 593.12 mm, 118.16 mm and 2.48 mm, respectively. Sphericity, surface area, volume, thousand seed weight, bulk density, true density, porosity, and angle of repose were found as 0.70 mm, 18.42 mm^2, 5.34 mm^3, 11.93 g, 687.62 kg/m^3, 1360.58 kg/m^3, 49.39 percent, and 37.21 degrees, respectively.

Shirsat *et al.* (2018) studied the physical properties of fresh “Mahim” variety of ginger (Zingiber officinale) rhizomes. The range of moisture content of fresh rhizomes was 76.18 - 78.84 percent. Fresh ginger rhizome had an average length, width, and thickness of 109.94 mm, 71.71 mm, and 25.24 mm, respectively. The geometric mean and sphericity of fresh rhizomes were 57.97 mm and 0.53 mm respectively. Fresh rhizomes had an average mass, length, and surface area of 81.557 g, 77.75 cm^3, and 174.99 cm^2. For fresh rhizomes, the bulk mass, true density, and porosity ranged from 435.60-410.78 kg m^{-3}, 1317.55-951.10 kg m^{-3}, and 66.94-56.81 percent, respectively. The angle of repose ranges from 39.99 to 50.44 degrees. Except for sphericity and bulk density, which decrease as increase in moisture content, all physical properties increase with moisture content.

Beyzi *et al.* (2017) studied the biochemical and bioactive properties of coriander seeds. In addition, the study compared four different Turkish varieties (Arslan, Gamze, Gürbüz, and Erbaa). The Gamze cultivar was found to have the highest crude oil content (COC). Mineral content of seed and seed oil samples showed a large difference. The main fatty acid in all coriander cultivars was petroselinic acid. The Erbaa cultivar had the minimum antiradical activity, while the Arslan cultivar had the maximum amount of total phenolic compounds. This is the first research to look at the bio-chemical and bioactive properties of four Turkish coriander varieties.

Subhashini *et al.* (2015) determined the physical properties of turmeric rhizomes at various moisture contents (8, 12, and 16 percent) such as size, porosity, bulk density and true density. The physical dimensions of the turmeric rhizome were found to increase as the moisture content was increased. At 12 % moisture content, the bulk density and true density of turmeric rhizome were 647.5 kg m^{-3} and 1303.30 kg m^{-3}, respectively. Turmeric rhizomes were found to have a porosity of 67.3 percent.

Sharanagat and Goswami (2014) investigated the physical and mechanical properties of seeds at various moisture levels in order to develop equipment to handle, process, transport and store them. Coriander seed physical properties have been tested as a function of seed moisture content, which ranges from 8-16 percent (wet basis). At the moisture level of 11.2 percent, seeds' major, minor and medium dimensions were 5.062 mm, 3.27 mm and 3.404 mm, respectively. The seeds had a sphericity of 0.757 and surface area of 46.167 mm^2. The bulk density of coriander seeds in 8 to 15% MC (w.b.) ranged from 260 to 245.5 kg m^{-3}. The bulk density of seeds decreased as the moisture content increased. The angle of repose increased gradually from 25.5-30.1 degrees with moisture content increase.

Sharma *et al.* (2014) reported the impact of cryogenic grinding on essential oil, oleoresin, total phenol content, flavonoid content and antioxidant properties of seed extract from two genotypes of cumin (Cuminum cyminum L.). Cryogenic grinding not only preserved the volatiles in both genotypes, but it also improved recovery. In both genotypes, non-cryogenic or conventional grinding at room temperature results in a loss of 18-19% volatile oil. When RZ 209 seeds were ground using cryogenic grinding, the percentage of oleoresin increased significantly (28.28%). In genotype GC 4, however, the increase was less (16.046 percent). The total phenolic and flavonoid content of cryogenically ground seeds of both genotypes was also higher.

Balasubramanian *et al.* (2012) studied the physical properties of the rhizome of the turmeric plant (Curcuma longa)(var. IISR Alleppey Supreme). According to its major dimension, the turmeric rhizome sample was divided in 3 grades (I: 25 to 35 mm, II: 35 to 45 mm, III: 45 to 55 mm). The average values of geometric properties viz., length, width, thickness, arithmetic mean diameter, geometric mean diameter, square mean diameter, sphericity, aspect ratio, unit volume, surface area and shape factor were varied between 30.38–50.60 mm, 9.77–10.64 mm, 5.18–6.44 mm, 15.82–21.91 mm, 12.77–13.76 mm, 24.24–28.58 mm, 0.27–0.42, 0.20–0.35, 1641–2901 mm^3, 771–1265 mm^2, 1.63–1.77, respectively, for grades I, II & III. The gravimetric property viz., bulk density, true density and porosity were 260 to 348 kg/m^3, 1341 to 1354 kg/m^3, 74.53 to 80.93 percent, respectively, and frictional property viz., angle of repose was 37.57 to 38.90 degree.

Coskuner *et al.* (2007) reported the physical properties of coriander seeds. Physical properties were assessed as a function of moisture content of coriander seed, which ranged from 7.10-18.94 percent on dry basis. Seed length decreased gradually from 4.74-4.61 mm as moisture content increased, while width, thickness, geometric mean diameter and arithmetic mean diameter increased from 3.67-3.93 mm, 3.39-3.54 mm, 3.88-3.99 mm and 3.93-4.03 mm, respectively. The sphericity, seed surface area and seed volume increased nonlinearly from 0.82-0.867, 42.09-45.62 mm^2, 24.97-28.52 mm^3, respectively. Moisture content range between 7.10 percent and 18.94 percent dry basis, true density increased nonlinearly from 332-349 kg m^{-3}, while bulk density decreased linearly from 234.1 to 220.2 kg m^{-3}, with increasing moisture content, the angle of repose increased linearly from 24.9-30.7 degrees.

Baumler *et al.* (2006) studied the effect of moisture content on certain physical properties and fracture resistance of safflower seeds commonly grown in Argentina. The oil content of the safflower seeds is 43 ± 3.6 percent (dry basis), the hull content is 37 percent (dry basis), and the initial moisture content of the safflower seed is 6.9 percent (dry basis). The finding shows that changing the moisture content of safflower seed caused minor changes in its size, with the hull thickness being the most affected. The seed volume and weight, as well as the expansion coefficient, equal diameter, and sphericity, all increased in lockstep with seed moisture content. In the range of moisture content considered, true density varied nonlinearly. Simultaneously, an increase in moisture content causes a decrease in bulk density and a linear increase in the porosity of the grain bed.

Murthy and Bhattacharya (1998) investigated physical and uniaxial compression property of black pepper (Piper nigrum L.) seed at various moisture levels (8 to 32 percent on dry basis). The physical properties of the sample were determined, including size, sphericity, roundness, angle of repose, bulk density and flow ability. The roundness and sphericity values were in the range of 1.1 and 95%, showing that the seed was nearly spherical in shape. The angle of repose increased as the moisture content increased.

Singh and Goswami (1996) studied the physical properties of the cumin seeds at different moisture content. 1.77, 5.61, and 1.55 mm were average width, length and thickness, respectively. Founding on dried or rewetted cumin seed showed that bulk density, true density and porosity increased from 477-502 kg m^{-3}, 1047-1134 kg m^{-3}, 54-64 percent, respectively, then bulk density decreased from 502 to 410 kg m^{-3} in the moisture range of 7 to 22 percent on dry basis. The 1000 seed weight and terminal velocity increased linearly from 4.13-4.80 gram and 2.6-4.8 meter per second, respectively. From 36.5-51.3 degrees, the angle of repose increased linearly.

2.2 Grinding characteristics of coriander seeds

Jung *et al.* (2018) Grinding is a popular size-reduction method for producing food powders that are microbiologically and chemically stable and convenient to use as intermediate or end products. The moisture content of food materials prior to grinding is especially important because it defines the physical properties of the materials as well as the powder properties, such as flow ability after grinding. Since the energy expenditure needed to produce new surfaces varies, the moisture content of food materials is generally related to requirement of energy for grinding. Many studies have developed grinding models to analyse and forecast grinding characteristics, including energy. Powder flow properties are also influenced by moisture levels. Since moisture in powders causes inter-particle liquid bridges, the powder flowability is disrupted as the powder cohesiveness increases. Theoretically and experimentally, understanding the grinding characteristics related to different moisture levels is a significant effect in optimising the grinding processes used in the food industry.

Dabbour *et al.* (2015) worked on experiments in order to optimise certain grinding parameters and its effects on corn quality for processing of feed. Different parameters, such as grain moisture content and sieve hole diameter, were used to test the hammer mill. The energy consumption, performance, grinding index, grinding capacity index and ground quality of the grinding process were all studied under various operating conditions. The mill performance, specific energy, energy density, and grinding index were found to be between 0.70 and 6.83 Mg/h, 3.38 and 32.72 kJ/kg, 1.99 and 18.82 MJ/m^3, and 12.35 and 91.28 kJ.mm0.5/kg, respectively. At different sieve hole diameters and moisture content, size reduction, mean weight diameter, grinding effectiveness and bulk density ranged from 2.60 to 5.10 times, 1.47 to 2.89 mm, 8.88 to 14.40 and 524.58 to 621.34 kg m^{-3}, respectively.

Saxena *et al.* (2015) studied the effect of cryogenic grinding on oleoresin content, volatile oil, flavonoid content, total phenolics and antioxidant properties of seed extract from nine genotypes of coriander (Coriandrum sativum L.). In cryogenically ground samples, volatile oil and oleoresin content varied from 0.14 percent in genotype RCr 436 to 0.39 percent in genotype Sindhu, while oleoresin content varied from 13.80 percent in ACr 1 to 19.58 percent in Australia. In cryoground samples of all genotypes, methanol crude seed extract yield was consistently high, and total phenolics were also consistently high. In genotype Sindhu, it ranged from minimal of 32.44 mg in RCr 41 to a maximum of 92.99 mg

Gallic Acid Equivalent (GAE)/g crude seed extract. In all cryogenically ground samples, total flavanoid content increased and ranging from 15.28 mg Quercetin Equivalent (QE)/g crude seed extract in genotype Sindhu to 20.85 mg QE/g crude seed extract in genotype Swati.

Choudhary *et al.* (2014) investigated the effect of cryogenic and traditional grinding on the antioxidant properties of turmeric and coriander. The antioxidant potential of the spices was significantly reduced by conventional grinding, as measured by DPPH radical scavenging ability, reduction in peroxide radical scavenging capacity, and iron chelation. In addition, the conventionally ground spice samples had lower total phenolics, flavonoids, reducing strength, and total antioxidant ability than the cryogenic samples. To conclude, traditional grinding reduces the antioxidant potential of the spice samples, especially coriander, which is a measure of medicinal value.

Barnwal *et al.* (2014) worked on the effect of grinding conditions, such as ambient and cryogenic, at a moisture level of 11.5 percent (dry basis), on quality parameters such as colour, curcumin content, volatile oil, oleoresin content, total phenols and antioxidant activity in DPPH assay, thermal conductivity, specific heat, thermal diffusivity, and glass transition temperature of turmeric powder. The grinding conditions had a significant impact on curcumin, volatile oil, oleoresin, total phenolics, antioxidant activity and b colour value. As compared to ambient grinding, cryogenic ground turmeric powder retained 15% to 25% more curcumin, volatile oil, phenol content, oleoresin and antioxidant activity.

Balasubramanian *et al.* (2013) studied black pepper corn was ground by micro pulverizer at three moisture levels (5.5, 11.4 and 17.6 percent on dry basis) with screen aperture size (0.5, 1.0 and 1.5 mm) and feed rate (8, 16 and 24 kg/h) at constant 3000 rpm rotor speed. It was discovered that as the feed rate was increased, the specific energy consumption decreased (310.71–30.55 kJ kg^{-1}) while the moisture content and screen openings increased. With a 1.0 mm screen aperture size and 11.4 percent moisture content, the maximum specific energy consumption was estimated at feed rate 8 kg/h. With increased moisture content and screen opening, the average particle size increased from 0.21 mm to 0.29 mm. Bond's work index (0.086 to 0.312 kWh/kg) and Kick's constant (0.68 to 20.33 kWh/kg) showed increment with the moisture content, sieve size and feed rate. For different mass fractions of sieve analysis, the loose and compact bulk densities were ranged from 322.8 to 1408 kg m^{-3} and 346.2 to 1760 kg m^{-3}, respectively. Moisture content, but not feed rate, had a significant ($P< 0.05$) effect on Bond's work index and Kick's constants for all screen aperture sizes.

Barnwal *et al.* (2014) investigated the grinding characteristics of fenugreek (cv. AM-1) at ambient and cryogenic conditions. It was discovered that it had an impact on particle size distribution, Rittinger and Kick's energy constants, and specific energy consumption. In the moisture level range of 5 to 15 percent (w.b.) at ambient and cryogenic grinding, the values of average particle size, Rittinger's constant, Kick's constant and specific energy consumption ranged from 0.31-0.80, 0.31-0.57, 0.27-0.77, 0.25-0.41 mm; 16,413 to 34,254 mm^2/g; 5,863 to 111,620 particles per gram, 4.97 to 35.87 kWh/t, 4.76 to 53.59 kWh t^{-1}, and 8.37-50.17 kWh t^{-1}, respectively. According to a report, ambient grinding requires more power and specific energy than cryogenic grinding.

Shashidhar *et al.* (2013) studied the pattern of particle size distribution and its relationship with energy consumption, coriander seeds were ground in an impact style hammer mill and a pin mill. When compared to the Gaudin-Shumann (GS) model and Log-normal function, the Rosin-Rammler-Bennett (RRB) and model with high degree of correlation coefficient better represented the particle size distribution for all samples. The energy consumption of grinding was investigated using Bond's, Rittenger's, and Kick's law, which are all classical grinding laws. Depending on the size reduction ratio, Bond's Work index ranged from 0.5-4.3 kJ/kg. The size reduction ratio had a linear relationship with energy consumption.

Balasubramanian *et al.* (2011) worked on the physical properties of pearl millet, such as arithmetic mean diameter, geometric mean diameter, thousand grain weight, aspect ratio, specific surface area, surface area, and bulk density, were investigated using a hammer mill at different moisture content (6.2, 9.4 and 12.3 percent, dry basis) and feed rates (3, 6 and 9 kg h^{-1}). The rise in moisture content resulted in more medium-sized particles and a lower percent weight retained in the pan, as per sieve analysis. With the decrease in total surface area at higher moisture levels, Bond's work index, Kick's constant, and average particle size all increased. 12.3 percent moisture content required much more energy (2.34 KWh/kg). Moisture content and feed rate also had a major impact on various grinding characteristics, which were measured in terms of Bond's work index, Kick's constant, average particle size, milling effectiveness and bulk density. Milling loss was found to be higher at lower moisture levels and decrease as moisture content and feed rate increased. Across the entire sieve fractions, the loose and compact bulk density ranged from 46.8-199.5 kg m^{-3} and 53.5-254.1 kg m^{-3}, respectively. With the reduction in particle size, the water absorption capacity increased.

Ghorbani *et al.* (2010) studied the energy required to reduce the size of alfalfa may be useful for downstream processes like densification. Alfalfa chops were ground in a hammer mill (1.1 kW) with four screen sizes of 1.68, 2.38, 3.36, and 4.76 mm after passing through sieve sizes of 8mm, 15mm and 12mm. The highest and lowest real energy values were found in alfalfa chops with SS18mm and SS12mm sizes, respectively (30.96 and 5.06 kJ kg^{-1}). With coefficients of determination (R2) values varying from 0.94-0.98, exponential correlations between the basic energy requirement and hammer mill screen sizes were discovered. Bond, Rittinger and Kick models were used to match the relevant energy data. For the three sizes of alfalfa chop, the Rittinger model was the best fitted, with R2 > 0.94. All three models predicted the specific energy values more accurately than a linear model relating the specific energy to the ratio of initial to final screen sizes using the combined data.

Goswami and Singh (2003) reported the effect of feed rate and temperature of cumin on some dependent variables such as rise in temperature and size of ground cumin, real energy consumption, and Bond's work index, an experiment was conducted on cumin seed grinding in a double disc, single spinning, attrition mill. Liquid nitrogen was used to bring down the temperature. The temperature rise gradually, and the size of the ground cumin decreases, but the specific energy consumption and work index decreased first, then increased with an increase in cumin feed rate in the attrition mill. In comparison to feed temperatures of 30 and -40ºC, the effect of cumin feed temperature at -100ºC resulted in relatively low values of temperature increase, real energy consumption, work index, and a high value of reduction ratio. Among feed temperatures of cumin ground at 30 and -40ºC, the dependent variables were not significantly different.

Walde *et al.* (2002) worked on the wheat samples weighed about 20 g were dried in a domestic microwave oven for periods ranging from 15 to 150 seconds, with moisture levels ranging from 0.11-0.23 kg water kg^{-1} dry weight of solids. The samples lost an average of 4.4–10.6 x 10-4 kg of water per kg of dry weight of solids per second. After grinding of dried samples in domestic dry grinder, samples were sieved to determine the average final particle size. The Bond's work index was used to assess the grinding characteristics. In comparison to the control samples, the microwave dried samples for 120 seconds were crisp and used less energy for grinding. Even when the wheat samples were dried in bulk (1 kg of sample with an initial moisture content of 0.11 on dry weight basis) and dried for 15 minutes, the same pattern was observed. Bond's work index for the bulk sample was 2.26 kWh/kg, compared to 2.41 kWh/kg for the control of equal moisture content. Microwave power supply was also studied for its effect on drying and grinding, and it was discovered to have an effect on the latter. All of these studies have found that drying wheat samples in the microwave before grinding reduces power consumption in the wheat milling industry. The overall protein content did not change as a result of microwave drying, although there were some functional changes in the protein, as shown by gluten measurements.

Murthy *et al.* (1999) in this study, at ambient temperatures, black pepper (Piper nigrum L) was ground to various particle sizes, and the ground material temperatures at the mills' outlet were noted. Sieve analysis was used to determine the surface and geometric mean diameter of the black pepper grits. Bond's equation was used to calculate the energy required for size reduction. At 30 minute intervals, the amount of essential oil distilled using Clevenger's method was measured for each particle size. For higher oil concentrations, the effective diffusion coefficient calculated using Fick's second law was constant (1.38 x 10^{-11} m^{2}s^{-1}) whereas it was very low for lower oil concentrations. Gas chromatography analysis was used to assess the essential oil yield in terms of four main compounds. The particle size of about 0.7 mm was discovered to be suitable for essential oil distillation.

Chakkaravarthi *et al.* (1993) studied the grinding characteristics of carrots (*Caucus carota* L.) as grits in a hammer mill. The grits were dried to various moisture content levels before being ground to a powder; the amount of energy needed for grinding was recorded. The constants of Kick's law, Rittinger's law, and Bond's law were discovered when they were applied to the grinding method. The grinding energy increased as the moisture content of the dried grits increased from 10-15 percent, decreased as moisture content raised to 18 percent, and increased again as moisture content rise to higher values. As a result, a moisture content of 18 percent could be recommended for grinding operations because it needs the least amount of grinding energy.

2.3 Quality of the ground coriander powder

Nathenial *et al.* (2019) reported that flavonoids (NaOH Test) were available in high concentration, tannins (Ferric Solution Test), quinines (HCI Test), terpenoids (Salkowaski Test) and cardiovascular glycosides (Killer killiani test) were available in low amount in extract, while alkaloids (Wagner's Test), phenols (FeCl2 Test), phlobatannins (Precipitate Test) and sugars (Molisch's Test) were discovered to be available in least fixations. Nonappearance of oxalates (Ethanoic Acid Glacial Test), saponins (Foam test) and proteins (Ninhydrin Test) was seen in acetone extract. Because of the presence of these optional metabolites, coriander remains as a prospective spice for anticancer, antibacterial, antiviral and antifungal treatment.

Barnwal *et al.* (2018) studied the grinding performance of a cryogenic spice grinding system for coriander seeds. In a pin mill, seeds were ground at temperatures of 10°C and -50°C with screw speeds of 5, 10, and 15 rpm. The volatile oil (0.66 ± 0.01 percent), total phenolics (85.94 ± 0.58 mg GAE/g), flavonoids (24.78 ± 0.88 mg QE/g) and antioxidant (38.56 ± 1.67 BHTE/g) content of coriander seeds ground at -50°C was significantly ($p \leq 0.05$) greater than the corresponding values of the above constituents in ground coriander received at 10°C. The particle size ranged from 0.450 ± 0.038 to 0.529 ± 0.005 mm and temperature and screw speed both had a significant impact ($p \leq 0.05$).

Aniesrani Delfiya (2017) worked on extraction of turmeric oleoresin from ground turmeric powder using organic solvents such as acetone, ethylene dichloride and ethanol. One of the main disadvantages of solvent extraction is the long extraction time, which require more solvent and heat energy. The extraction time can be overcome by heating turmeric powder in the microwave before extracting the solvent. The effect of various microwave exposure times of turmeric powder (0, 1, 2, 3, 4, 5, and 6 minutes) on curcumin recovery, total volatiles, and non-volatiles of turmeric oleoresin was investigated in this report. Dry turmeric powder irradiated for 4 minutes in microwaves yielded higher curcumin (70.54 percent) and oleoresin (0.143 g/g of turmeric powder).

Msaada *et al.* (2017) reported the antioxidant activity of three coriander (Coriandrum sativum L.) varieties (Tunisian, Syrian, and Egyptian) fruit methanolic extracts. Total polyphenols (0.94 ± 0.05– 1.09 ± 0.02 mg GAE g^{-1} DW), total flavonoids (2.03 ± 0.04 to 2.51 ± 0.08 mg EC g^{-1} DW) and total condensed tannins (0.09± 0.01 to 0.17 ± 0.01 mg EC g^{-1} DW) contents were found to differ significantly ($P < 0.05$). The detection of phenolics in coriander fruits was discovered by RP-HPLC research, with chlorogenic and gallic acids as the key compounds in Tunisian, Syrian and Egyptian varieties, respectively. Furthermore, DPPH radical scavenging activity was observed in fruit methanolic extracts, with IC50 values ranging from 27.00 ± 6.57 to 36.00 ± 3.22 lg mL^{-1}. The EC50 values for reducing power activity ranged from 54.20 ± 6.22 to 122.01 ± 13.25 lg mL^{-1}, a differ significant ($P< 0.05$). In the b-carotene bleaching assay, the IC50 values ranged from 160.00 ± 18.63 to 240.00 ± 26.35 lg/mL.

Sharma *et al.* (2016) investigated the impact of cryogenic grinding on the production of volatile oil, fatty oil and constituents in two cumin genotypes (Cuminum cyminum L.). Cryogenic grinding not only preserves the volatiles, but it also improves recovery by 33.9 percent in GC 4 and 43.5 percent in RZ 209. In genotype RZ 209, the oil percentage increased significantly (29.9%) over normal grinding. In genotype GC 4, however, the increase was less (15.4 percent). The essential oils of both genotypes included nineteen major compounds. The dependent variables, essential oil and monoterpenes, were significantly affected by the two grinding techniques. Cuminaldehyde was the most abundant constituent in both genotypes, rising from 48.2-56.1 percent in GC 4 after cryo grinding. Terpine content was found to decrease in cryo ground samples of GC 4, and there was either a decrease or no improvement in RZ 209. Organoleptic tests revealed that cryo ground seeds of both genotypes had a more pleasing fragrance. Cryogenic grinding has resulted in a significant increase in fatty oil yield. On cryogenic grinding, the content of oleic acid increased from 88.1 to 94.9 percent in RZ 209 and from 88.2 to 90.1 percent in GC 4, according to fatty acid methyl ester (FAME) study. Palmitic, palmitoleic, and stearic acids were all common FAMEs. Cryogenic grinding technology has commercial potential for cumin in general and spices in particular for improved flavour and quality retention in spices.

Barnwal *et al.* (2015) worked on the effect of grinding (hammer and pin mills) and moisture content (at 6.4 to 13.6 percent db) on coriander powder quality attributes was explored in this study. These include coriander powder grinding characteristics, essential oil, total phenolic content, and total flavonoid concentration. The geometric properties of coriander seeds, such as major, medium, and minor dimensions, geometric mean diameter, sphericity, surface area, and volume, all increased significantly when moisture (6.4 to 13.6 percent db) rise. The grinding characteristic of average particle size increased significantly with increase in moisture (6.4–13.6 percent db) in coriander powder. Grinding methodss have a significant effect on the total flavonoid content (mg QE/g crude seed extract) of coriander powder. In comparison to the pin mill, the hammer mill produces more fine coriander powder.

Saxena *et al.* (2014) in this study, the seeds of nine coriander genotypes were ground in both a cryogenic grinder and a conventional grinding mill. The impact of cryogenic grinding on volatile oil and its components has been investigated. Both ground cryogenically or non cryogenically, all genotypes showed differences in essential oil content. The content of volatile oil in cryo ground samples was significantly high, ranging from 0.14 percent in genotypes RCr 436 to 0.39 percent in genotype Sindhu. By using gas chromatography, ten major compounds were reported, with percentages ranging from 99.65 to 99.99 percent in cryo ground seeds of various genotypes, and 91.35 to 99.98 percent in non cryo ground seeds.

Surojanametakul *et al.* (2010) studied the impact of extraction solvent on the curcuminoid and total polyphenol content of the turmeric extract. Curcuminoid extract from turmeric was recommended to be prepared in ethanol with a solid:liquid ratio of 1:50 and held at 70°C for 2 hours. The natural turmeric compound "curcuminoid" was entrapped with a polysaccharide, carboxymethyl cellulose, as a complex formation and combined with maltodextrin before drying to produce curcuminoid powder from turmeric extract. The amount of curcuminoid in the powder had an effect on the product's colour, total phenolic compounds, and antioxidant properties. The powder containing an amount of curcuminoid of 411.28µg/g received the highest acceptance score in a sensory assessment of the items in the form of turmeric tea. It also had a high solubility in water (15g/100ml). The product with the highest acceptance score had total phenolic content of 13.27 mg GAE/g and antioxidant capability of 14.46 mg BHAE/g, respectively. The total plate count of yeast and mould in the powder was less than 10 cfu/g, and no pathogenic microorganisms were detected. The curcuminoid content of the powder was only marginally altered after four months of storage in an aluminium foil bag at room temperature, showing the product's high stability. Curcuminoid powder may thus be used as a food ingredient in a variety of health-drink beverages.

Prathapan *et al.* (2009) worked on heat treatment of fresh turmeric rhizome for total phenol content (TPC), colour value (yellow and bright), polyphenol oxidase (PPO) activity and curcuminoid. Heat treatment of fresh turmeric rhizomes at different temperatures (60–100ºC) for different times (10 to 60 minutes) resulted in a reduction in browning, as evidenced by improved yellowishness and brightness. PPO activity was also reduced during heat treatment and PPO was almost inactivated after 30 minutes at 80°C. Heat-treated turmeric has a substantially higher TPC after drying (powder) than fresh turmeric. When samples were heated from 60 to 80 degrees Celsius, TPC values steadily increased. TPC values were nearly identical at 90 and 100 degrees Celsius. When the turmeric was heated above 80ºC, the brightness and yellowishness were at their highest. Curcuminoids in the turmeric powder were quantified using high-performance thin-layer chromatography (HPTLC). The concentration of curcuminoids in the heat-treated samples did not change significantly. Curcuminoid concentration was obtained significantly low in the sun-dried samples.

Shan *et al.* (2005) evaluated the phenolic content and total equivalent antioxidant capacity (TEAC) of twenty six typical spice extracts from twelve botanical families. Reversed-phase high-performance liquid chromatography (RP-HPLC) was used to conduct qualitative and quantitative studies of major phenolic content in spice extracts. Many spices had high levels of phenolic content, which meant they had a lot of antioxidant capacity. The overall phenolic content (0.04 to 14.38 g of gallic acid equivalent/100 g) and TEAC values (0.55 to 168.7 mmol/100 g) varied greatly. The phenolic compounds in the tested spices had significantly effect on their antioxidant potential, as shown by a linear relationship (R^2 = 0.95) between TEAC values and total phenolics. The antioxidant capacity and total and individual phenolics contents of the 26 spice extracts are directly compared in this review.

CHAPTER-III

MATERIALS AND METHODS

This chapter deals with the materials used and procedure adopted to achieve the objectives of the present investigation. This includes the description of experimental set up and methodology used in determination of physical and bio-chemical properties of fresh and powdered coriander seeds, grinding characteristics of coriander seeds, statistical analysis and quality evaluation methods.

The present experimental work was done in the Department of Agricultural Processing and Food Engineering, Swami Vivekananda College of Agricultural Engineering and Technology and Research Station, Faculty of Agricultural Engineering, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh.

3.1 Experiment Plan

For conducting the planed experiment, different variables like dependent, independent and constant are selected. The details of selected variables are as given in the following table (3.1).

S. No	Independent variable		Dependent variable
	Parameters	**Level**	**Measuring parameters**
1	**Grinding method/machine** a) Pulverizer (Hammer type) b) Ponding machine c) Mixer grinder d) Burr grinder e) Mortar pestle	5	**1) Physical properties** i. Length, Width and Thickness ii. GMD, iii. Sphericity iv. Bulk density v. Volume vi. Surface area vii. Angle of repose **2) Grinding characteristics** i. Specific energy consumption ii. Average particle size iii. Grinding energy **3) Quality evaluation** i. Oleoresin content ii. Essential oil iii. Total phenolic content iv. Flavonoid content
2	**Moisture content (% wb)** a) 7.2 b) 9.1 c) 11.2	3	
3	**Feed rate (constant)** -Pulverizer (Hammer type) -Burr grinder	1	

3.2 Raw Material and Sample Preparation

The dried coriander seeds of local variety (*Fal dhaniya*) were purchased from the Raipur local market and were used for this experiment. The procured seeds were first properly cleaned and undesirable portions were removed manually and then the cleaned sample was used for conducting further experiment. The initial moisture content of dried coriander seed was determined by using standard hot air oven method (temperature of oven 105 ± 1°C for 24 h). Initial moisture content of coriander seed was found to be 9.08 % (w.b.).

For conducting grinding experiment, seeds are prepared having varying moisture content with help of standard procedure. To achieve high moisture contents in the seeds, calculated amount of water was sprayed and mixed thoroughly (Fig 3.2). Samples were packed in low density polyethylene (LDPE) pouches and kept in a refrigerator at 5°C for 48 h for uniform distribution of moisture throughout the seed (Barnwal *et al,* 2015). Samples were allowed to reach ambient temperature for measurement of physical properties. Thus, three levels of moisture content (7.2, 9.1 and 11.2 % w.b.) were selected (Balasubramanian *et al.* 2012).

$$Q = \frac{W(M_2 - M_1)}{100 - M_2} \qquad \text{... (3.1)}$$

Where,

Q = Amount of water to be added, L
W = Weight of seed sample at initial moisture content, kg
M_1 = Initial moisture content of seed, % (w.b.)
M_2 = Desired moisture content of seed, % (w.b.)

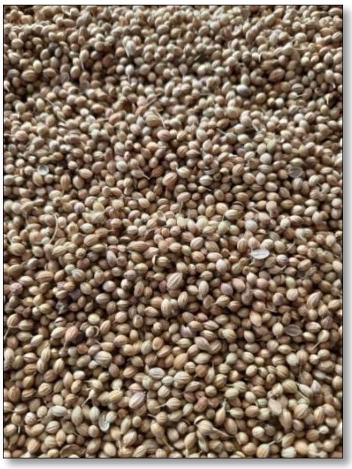

Fig. 3.1 : Coriander seed

Fig. 3.2 : Conditioning of coriander seeds

3.2.1 Equipments / Machines used

For conducting the grinding experiments different types of grinder/ pulverizer/size reduction machines are used *i.e.* Pulverizer (Hammer type), Ponding machine, Burr grinder, Mixer grinder and for analysis work Hot air oven, Vernier caliper, Sieves, Weighing balance, Vacuum evaporator, Sieve shaker *etc*. are used.

Fig. 3.3 : Ponding machine

Fig. 3.4 : Pulverizer (hammer type)

Fig. 3.5 : Mixer grinder

Fig. 3.6 : Burr grinder

Fig. 3.7 : Mortar pestle

Fig. 3.8 : Sieves

Fig. 3.9 : Hot air oven

Fig. 3.10 : Weighing balance

Fig. 3.11 : Gyratory sieve shaker

Fig. 3.12 : Vernier caliper

Fig. 3.13 : Vacuum Evaporator

3.3 Physical Properties of Dried Coriander Seeds

3.3.1 Initial moisture content

The initial moisture content of coriander seed was determined by using hot air oven (Fig 3.9). A pre weighted small sample of seed was kept in a clean and weighed petri dish. The plate was placed in oven at 105 ± 1°C for 24 hours. After 24 hours the petri dish was cooled in desiccators to ambient temperature and then weighed. The moisture content was calculated by taking the difference between the initial weight of sample before drying and final weight after drying and divided by initial weight of sample before drying (AOAC, 1984).

$$\text{Moisture content (\%, wb)} = \frac{W_1\text{-}W_3}{W_1\text{-}W_2} \qquad \text{...(3.2)}$$

$$\text{Moisture content (\%, db)} = \frac{W_1\text{-}W_3}{W_3\text{-}W_2} \qquad \text{...(3.3)}$$

Where,

W_1 = Initial weight of sample with petri dish before drying (g),

W_2 = Weight of petri dish (g),

W_3 = Weight of sample with petri dish after drying (g).

3.3.2 Geometric mean diameter

The axial dimensions of a randomly selected 100 coriander seeds was measured using digital Vernier caliper (±0.01 mm, LC) for selected coriander seeds (Fig 3.12). For the determination of geometric mean diameter the experiment was repeated. The geometric mean diameter (GMD) was considered as the size criterion and was expressed as the cube root of three axes of seeds i.e. (a) major dimension, (b) medium and (c) minor dimension. The average geometric mean diameter (mm) was determined by using the following equation (Mohsenin, 1986):

$$\text{GMD} = \sqrt[3]{L \times W \times T} \qquad \text{...(3.4)}$$

Where,

L = Length (major dimension), mm

W = Width (medium dimension), mm

T = Thickness (minor dimension), mm

3.3.3 Sphericity

Sphericity (φ) is defined as the ratio of the surface area of a sphere having the same volume as the seed to the surface area of the seed. The shape of a food material is usually expressed in terms of its sphericity. It is an important property used in fluid flow and heat and mass transfer calculations. Sphericity was determined using the measured geometric dimensions (Mohsenin, 1986).

$$\text{Sphericity } (\varphi) = \frac{\sqrt[3]{L \times W \times T}}{L} \qquad \ldots(3.5)$$

Where,

L = Length (major dimension), mm

W = Width (medium dimension), mm

T = Thickness (minor dimension), mm

3.3.4 Surface area

The surface areas of coriander seed was calculated based on the geometric mean diameter (GMD) in the following equations (Mohsenin, 1986):

$$\text{Surface area (S)} = \pi(\text{GMD})^2 \qquad \ldots(3.6)$$

3.3.5 Volume

Volume of seeds was determined based on three major perpendicular dimensions of the seeds namely length, width and thickness (Coskuner, 2007). The volume of coriander seeds sample was determined by the following equation:

$$\text{Volume} = \frac{\pi B^2 L^2}{6(2L\text{-}B)} \qquad \ldots(3.7)$$

Where B is:

$$B = (WT)^{0.5} \qquad \ldots(3.8)$$

Where,

L = Length (major dimension), mm

W = Width (medium dimension), mm

T = Thickness (minor dimension), mm

3.3.6 Bulk density

The bulk density was determined as the ratio between the mass of seed in a container to its volume. It was determined by filling a 1000 ml measuring cylinder with seeds from a height of about 15 cm, striking the top level and then weighing the contents (Coskuner and Karababa, 2007).

$$\text{Bulk Density} = \frac{\text{Mass of the sample(kg)}}{\text{Volume of the container}(\text{m}^3)} \qquad ...(3.9)$$

3.3.7 Angle of repose

The angle of repose is the angle made by seeds with the horizontal surface when heaped from a known height. 200 gm of seeds were heaped over a horizontal surface of instrument slowly from a height of 10 cm. The slant height of the heap was determined and radius of the heap was calculated from the circumference of the heap. The angle of repose was calculated using the formula (Shirsat, *et al.*, 2019):

$$\theta = \tan^{-1}\left(\frac{2\text{h}}{\text{d}}\right) \qquad ...(3.10)$$

Where, θ is the angle of repose, d is the diameter of the heap, cm; h is the slant height of the heap, cm.

3.4 Grinding Parameters

The dried coriander seed samples were ground in different types of grinder/ pulverizer / size reduction machines *i.e.* Pulverizer (Hammer type), Ponding machine, Burr grinder, Mixer grinder and Mortar and pestle used as control treatment. The grinding characteristics were calculated and compared with the help of specific energy consumption, grinding energy and average particle size. The mixer grinder contains blades made of stainless steel having 18000 to 23000 rpm (Fig 3.5), a pulverizer consists a feed for hopper, grinding unit with hammer type arrangement and outlet (Fig 3.4), the ponding machine consists mortar and pestle like arrangement in which there is two mortar with speed 1440 rpm (Fig 3.3), in burr grinder samples were ground between two revolving abrasive surfaces separated by a distance (Fig 3.6). A known fixed quantity of coriander was fed to the mill at a uniform rate for each experimental run, and the ground material was collected and sieved.

The setup for calculation of specific energy and grinding energy is shown in Fig (3.14). The setup contain an energy meter, current meter and voltmeter connected to the comminuting mill, it record the amount of energy, current and voltage consumed for each run. For grinding, the system provides direct energy, current, and voltage values in kWh, Ampere, and Volt respectively. In this study energy is net energy, which is equal to the gross energy needed for grinding minus the energy consumed under no-load conditions. To compare mechanical grinding to traditional grinding, coriander seed was ground in a mortar pestle.

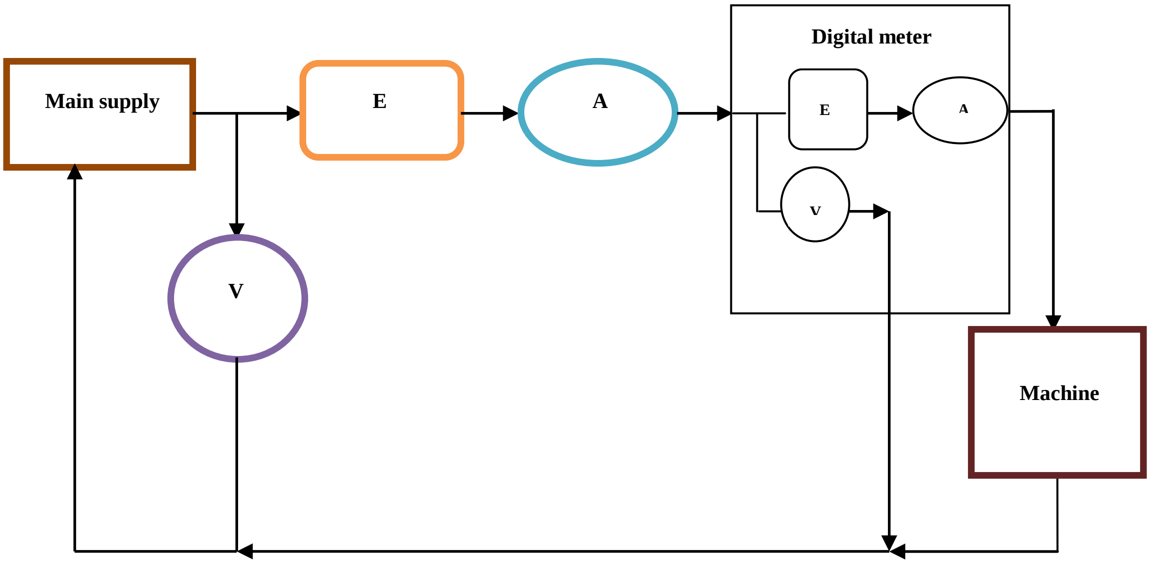

Fig. 3.14 : Setup for calculation of energy consumption

3.4.1 Specific Energy Consumption

Energy consumption during grinding operation (ΔW, Watt) was calculated by following expression

$$\Delta W = (W_{OL} - W_{NL})cos\varphi = V \times (I_{OL} - I_{NL})cos\varphi \qquad \text{... (3.11)}$$

Where, V is operational voltage and I_{OL}, I_{NL}, W_{OL}, and W_{NL} are the current recorded at on load, no load conditions, energy recorded at on load and no load conditions, respectively and cosφ is the power factor (assuming 0.8). Specific energy consumption (ΔE, Wh/kg) was determined by the following expression (Barnwal, *et al.*, 2015):

$$\Delta E = \frac{\Delta W \times 3.6}{f} \qquad \text{... (3.12)}$$

3.4.2 Grinding energy

Based on the particle size (initial and final) and energy required to grind a unit weight of material, Kick's constant (E_K), Rittinger's constant (K_R) and Bond's work index (W_i) was calculated (Sahay & Singh, 2001).

$$E = E_K \, ln \left(\frac{D_1}{D_2}\right) \qquad ...(3.13)$$

$$E = K_R \left(\frac{1}{D_2} - \frac{1}{D_1}\right) \qquad ...(3.14)$$

$$E = 0.3162 \, W_i \left(\frac{1}{\sqrt{D_2}} - \frac{1}{\sqrt{D_1}}\right) \qquad ...(3.15)$$

Where, D_1 and D_2 are the diameter of feed and product at 80% passes from sieve.

3.4.3 Sieve analysis

For sieve analysis, a portion of ground sample was put on top of set of sieves and shaken until it reached equilibrium, then inspected and weighed at 5-minute intervals after a 10 minute sieving period. The mass fractions collected on each sieve were weighed separately using a digital balance (accuracy of 0.001 g) and packed in zip lock polythene bags for further analysis (Balasubramanian, *et al.* 2017). The particle size distribution of coriander ground by different grinding methods was determined in duplicate by using Gyratory sieve shaker shown in Figure (3.11). The fineness modulus was calculated by the total percent of ground coriander retained on the each sieves of the set of sieve shaker and dividing by 100. The average particle size was determined by the following mathematical formula:

$$\text{Average particle size} = [0.135(1.366)^{FM}] \qquad \ldots(3.16)$$

Where,

$$\text{Fineness Modulus (FM)} = \left[\frac{Total\ percent\ material\ retained\ on\ sieves}{100}\right] \qquad \ldots(3.17)$$

3.5 Phytochemical Screening

Phytochemical screening provides general idea about the nature of chemical compounds present in crude drug powder.

3.5.1 Polyphenol extraction

The ground coriander of 3 g was separately extracted by stirring with 10 ml pure methanol for 30 min. The extract were then kept at 4ºC for 24 h, then this supernatant were filtered through filter paper, evaporated under vacuum to dryness and stored at 4ºC until further analysis (Msaada *et al*, 2017).

3.5.2 Test for total Phenol

Ferric chloride test

0.05 gm of extracts was dissolved in 5 ml of distilled water than it was treated with 3-4 drops of 5% ferric chloride solution. Formation of bluish black colour indicates the presence of phenols (Rashmi *et al*, 2019).

3.5.3 Test for Flavonoid

NaOH test

1 ml of sample was mixed with some drops of the 20% sodium hydroxide NaOH solution. On mixing, strong yellow colour appears that becomes colorless when diluted HCl was added to it. It showed the existence of flavonoids (Nathenial *et al*, 2019).

Lead acetate test

Few ml of extract sample was treated with 3 ml of 10% lead acetate solution. A yellow coloured precipitate indicates the presence of flavonoids.

3.6 Quality Evaluation

Food quality is one of the very important parameter in food processing to ensure best quality of finished product. Quality of dried coriander powder was evaluated on the basis of several parameters viz. bio-chemical analysis.

Coriander is mainly exported in the form of powder. The commercial value of coriander is mainly depending upon its characteristics essential oil, polyphenol, flavonoid and oleoresin content. The presence of these contents was affected by the various process parameters such as temperature and duration of process time.

While evaluating the quality of dried product, the effect of these process parameters on oleoresin, essential oil, polyphenol and flavonoid content is essential. Thus, the bio-chemical analysis was carried out to evaluate these components. A bio-chemical analysis includes determination of oleoresin content, phenolic content, flavonoid content and essential oil of dried ground products. These components was analysed by double beam spectrophotometer, clevenger and soxhlet apparatus.

3.6.1 Estimation of oleoresin content

The simplest form of solid-liquid extraction is the treatment of a solid with a solvent. Column extraction apparatus was used for extraction of oleoresin from dried coriander powder. Ethanol was used as solvent for the extraction of coriander oleoresin.

In the present work, oleoresin was quantitatively extracted in column extraction method by using petroleum ether as a solvent. The dried ground coriander were taken at the rate of 2g was loaded in thimble of Soxhlet apparatus (Fig 3.15). Petroleum ether (80 ml) was allowed to percolate down into the glass column and kept in and the contact was maintained for 2h. Soluble extracts were then drained off into a pre-weighed 100 ml beaker. All the extracts were pooled which was then evaporated to near dryness and the final weight noted (Fig 3.16).

Fig. 3.15 : Soxhlet apparatus

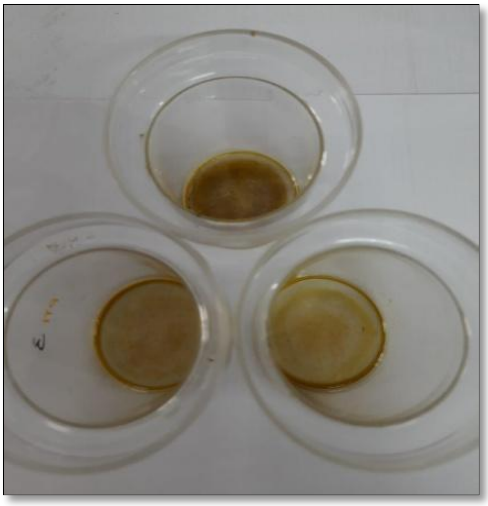

Fig. 3.16 : Oleoresin content

In the present work, percentage of oleoresin present in the final product having different treatment was analyzed. The extracted oleoresin is calculated by using the following formula and expressed as percent (Sahu, *et al,* 2015).

$$\text{Oleoresin content db \%} = \frac{W_3 - W_1}{W_2} \times 100 \qquad \ldots(3.18)$$

Where,

W_1 = Weight of empty beaker,g
W_2 = Weight of sample,g
W_3 = Weight of beaker with coriander oleoresin content,g.

3.6.2 Estimation of essential oil

Five hundred grams of dried powder were separated and hydro-distilled using glass Clevenger apparatus (Fig 3.17). 500 gm of coriander powder sample was taken and transferred into 5000 ml R.B.F. and 2500 ml distilled water was added. Apparatus was set in heating mental for boiling. It was refluxed until the two consecutive reading taken at one hour interval show no change of oil volume in the extraction burette (Sharma *et al.* 2015). The oil volume was measured directly in the extraction burette (Fig 3.18), yield percentage was measured as volume (ml) of essential oils per 100 g of plant dry matter. The distilled essential oils were dried over anhydrous sodium sulphate, filtered, weighed and stored in sealed vials at 4ºC (Ramezani, *et al.* 2009). The oil has a characteristic odour of linalool and a mild, sweet, warm, aromatic flavour.

Calculation

$$\text{Percentage of essential oil (v/w)} = \frac{volume\ of\ oil\ obtained\ (ml)}{weight\ of\ sample\ (g)} \times 100 \qquad \ldots(3.19)$$

Fig. 3.17 : Clevenger apparatus

Fig. 3.18 : Essential oil volume

Fig. 3.19 : Essential oil

3.6.3 Determination of total Phenols

Total phenol content of each ground sample was determined by Folin Ciocalteau's method described by Pradhan and Ojha with slight modifications using gallic acid as a standard. The standard gallic acid solution was prepared by dissolving 10 mg of gallic acid in 100 ml of distilled water. 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1 ml aliquots were taken from stock and placed into the test tubes and volume made up to 3 ml with distilled water. 0.5 ml of Folin Ciocalteu's reagent was added. After 3 minutes, 2 ml of 20% Sodium carbonate solution was mixed thoroughly, placed in boiling water for exactly 1 min, cooled. The phenolic compound reacted with Folin-Ciocalteu reagent and formed blue coloured complex then absorbance was taken at 650 nm against blank by double beam spectrophotometer (Fig 3.20). The calibration curve was constructed by absorbance verses concentration of Gallic acid as standard (µg/ml).

3 gm of the powdered coriander seed was taken in 10 ml of pure methanol. The solution was then continuously stirred for 30 min. The supernatant was kept at 4°C for 24 h, then filtered and evaporated to dryness (Msaada *et al.* 2017). The residue was dissolved in 20 ml of pure methanol. 0.2 ml of sample extracts were performed using reagent. Blank were also performed using same reagent. The data for total phenolic contents of phytoconstituent were expressed as mg of gallic acid equivalent weight (GAE)/ g of dry mass (Rashmi, 2019).

Table 3.2: Protocol for total Phenolic content determination

Standard solution	Gallic acid
Folin Ciocalteau's Reagent	0.5 ml
20% Sodium Carbonate solution	2 ml
Incubation time	90 min
Absorbance taken at	650 nm

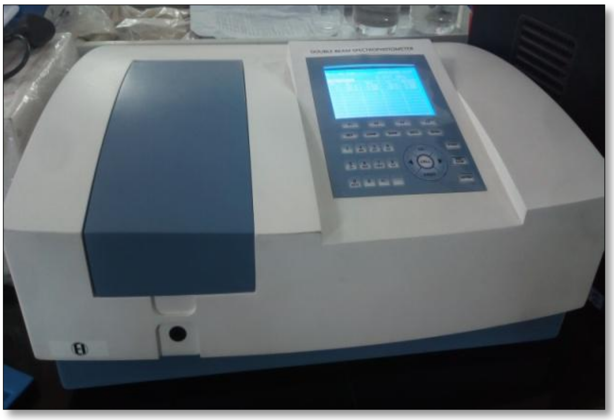

Fig. 3.20 : Double beam spectrophotometer

3.6.4 Determination of Flavonoid content

Total flavonoids were determined by aluminium chloride colorimetric technique, Quercetin was used as a standard. Suitable volume of aliquots were taken from stock and placed into the test tube then mixed with 1.5 ml of 95% ethanol, 0.1 ml of 10% $AlCl_3$, 0.1 ml of potassium acetate and 2.8 ml distilled water. Yellow colour was developed then the tubes were incubated for 30 min at room temperature and absorbance was measured at 415 nm by double beam spectrophotometer (Fig 3.20). The calibration curve was constructed by absorbance versus concentration of qurecetin as standard (µg/ml)(Rashmi, 2019).

Table 3.3: Protocol for Flavonoid content determination

Standard solution	Quercetin
10% Aluminium chloride	0.1 ml
1 M Potassium acetate	0.1 ml
Incubation time	30 min
Absorbance	415 nm

Sample extract was obtained by; the powdered coriander seed (3 gm) was taken in 10 ml of pure methanol. The solution was then continuously stirred for 30 min. The supernatant was kept at 4°C for 24 h, then filtered with filter paper and evaporated to dryness (Msaada *et al.* 2017). The volume was made up to 20 ml with pure methanol. 0.5 ml of filtrate extract was performed with all standard solutions then Blank was also performed using same solutions. The calibration curve was plotted using standard quercetin. The data of total flavonoids of phytoconstituent were expressed as mg of quercetin equivalents (QE)/g of dry mass (Pradhan, *et al.* 2014).

CHAPTER-IV

RESULT AND DISCUSSION

The results of moisture dependant physical properties, grinding characteristics and effect of different grinding methods on quality of grind coriander powder through active ingredients analysis presented in this chapter. This chapter also deals with the quantitative analysis of phytochemicals present in coriander seed. As per the objectives results have been presented under the following sub headings:

4.1 Physical properties of dried coriander seeds.

4.2 Grinding characteristics of dried coriander seeds.

4.3 Quality analysis of ground coriander powder.

4.1 Physical Properties of Dried Coriander Seeds

Seeds of coriander were procured from local market of Raipur Chhattisgarh. Three samples of coriander after cleaning were taken and conditioned to maintain the different moisture levels 7.2, 9.1 and 11.2% w.b. and then the seeds were packed in sealed plastic bags and used to determine the physical properties of coriander seeds. The experimental values of physical parameters such as moisture content, length, width, thickness, geometric mean diameter, sphericity, volume, surface area, bulk density, angle of repose were represented in Table (4.1).

4.1.1 Moisture content

The initial moisture content of coriander seed was measured by hot air oven method at 105 ± 1ºC for 24 hours. After 24 h the sample were kept in desiccator until it reached ambient temperature and then weighed. The moisture content of coriander seed was determined by the ratio of difference between the initial weight of sample before drying and final weight of sample after drying to the initial weight of sample before drying. The mean value of the initial moisture content of dried coriander seed was 9.08 % wet basis.

4.1.2 Geometric mean diameter

A randomly selected coriander seeds were used to measure the dimensions such as length, width and thickness by using vernier caliper. The major, medium and minor dimensions were observed in the range of 6.09-6.16 mm, 3.92-3.97 mm and 3.58-3.68 mm, respectively (Table 4.1). The geometric mean diameter of coriander seed was determined by the formula expressed as the cube root of three axes of rhizome using the major dimension, medium and minor dimension. It was observed that the geometric mean diameter increased linearly from 4.41 to 4.47 mm with the increased in moisture content, it may be due to swelling and stretching in coriander seed surface. Similar results were reported by Coskuner and Karababa (2007) for coriander seed. Balasubramanian *et al.* (2012) reported that the value of medium and minor dimensions and geometric mean diameter of coriander seeds increased from 3.20-3.64 mm, 2.91-3.31 mm and 3.36-3.62 mm respectively with increase in moisture content from 3.5-17.7% (w.b.).

Table 4.1: Effect of moisture content on physical properties of coriander seeds

S.No.	Physical Properties	Moisture content (%)		
		Wet basis / Dry basis		
		7.2/7.7	9.1/10.01	11.2/12.6
1	Length (mm)	6.09	6.12	6.16
2	Width (mm)	3.92	3.94	3.97
3	Thickness (mm)	3.58	3.64	3.68
4	Geometric mean diameter (mm)	4.41	4.43	4.47
5	Bulk density (kg/m^3)	298.83	296.64	291.62
6	Sphericity (%)	72.57	72.72	72.85
7	Volume (mm^3)	33.05	33.83	34.61
8	Surface area (mm^2)	61.32	62.13	63.24
9	Angle of repose (°)	29.75	30.76	32.73

4.1.3 Bulk density

The value of bulk density of the Coriander seeds varied between 298.83 to 291.62 kg/m^3 with the various levels of moisture contents from 7.2 to 11.2% wb. The value of bulk density was decreasing with the increase in moisture content. Similar result was obtained in case of corn where the value of bulk density linearly decreased from 627.4-607.8 kg/m^3 as the moisture content increases from 10.39-19.64% (Probst *et al.* 2013). Sharanagat and Goswami (2014) reported the value of bulk density of Coriander seed varied from 260 to 245.5 kg/m^3 at 8 to 15 % moisture content (w.b.). Singh and Goswami (1996) reported the value of bulk density (502-410 kg/m^3) of Cumin seed decreases with the increase in moisture content (9.5-22%, w.b.).

4.1.4 Sphericity

The values of sphericity of coriander seeds were varied from 72.57-72.85% for different moisture levels 7.2 to 11.2%. It was increased linearly with increase in the moisture content. Similarly result was found by Baumler *et al.* (2006) for Safflower seeds where sphericity increased linearly from 0.58 to 0.62 with the increase in moisture content from 3.7-15.6% (d.b). Coskuner and Karababa, 2007 reported the values of sphericity (0.820 to 0.867) for different moisture levels (7 to 18%).

4.1.5 Surface area

The surface area was determined by the formula given as section 3.2.4. It was observed that the surface areas of the coriander seeds were increased linearly from 61.32 to 63.24 mm^2 with the increase in moisture content range from 7.2-11.2% (w.b.). Similar increasing trends were reported for fenugreek seed 11.35-27.15 mm^2 by Rathod *et al,* 2020. Balasubramanian *et al,* (2012) reported the same increasing trend for surface area in coriander seed from 31.56 to 38.83 mm^2 with the increase in moisture content from 3.5 to 17.7% (db).

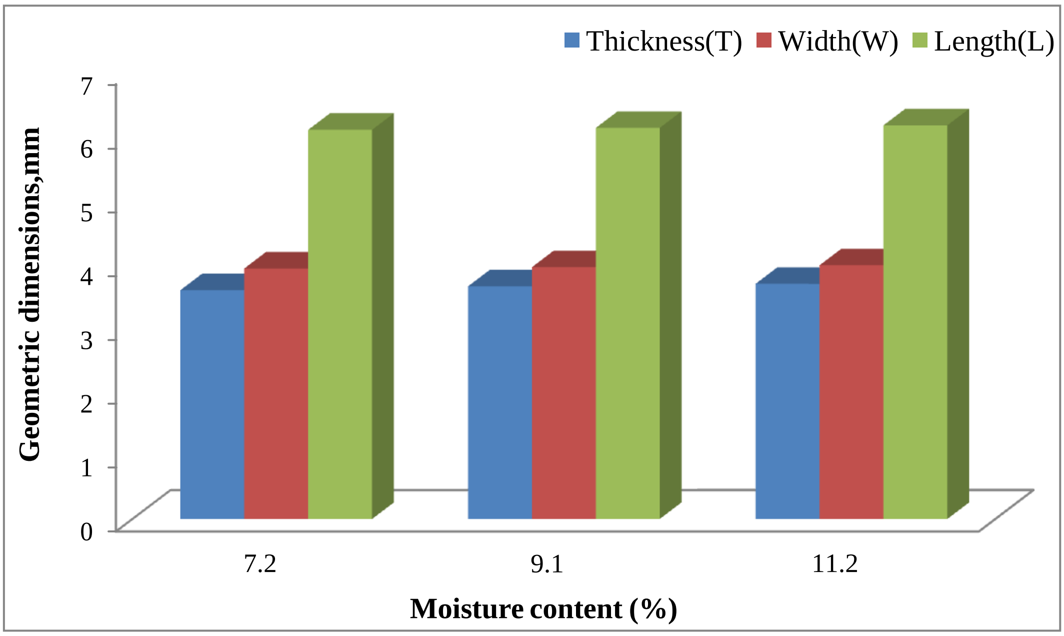

Fig. 4.1 : Effect of moisture content on geometric dimensions

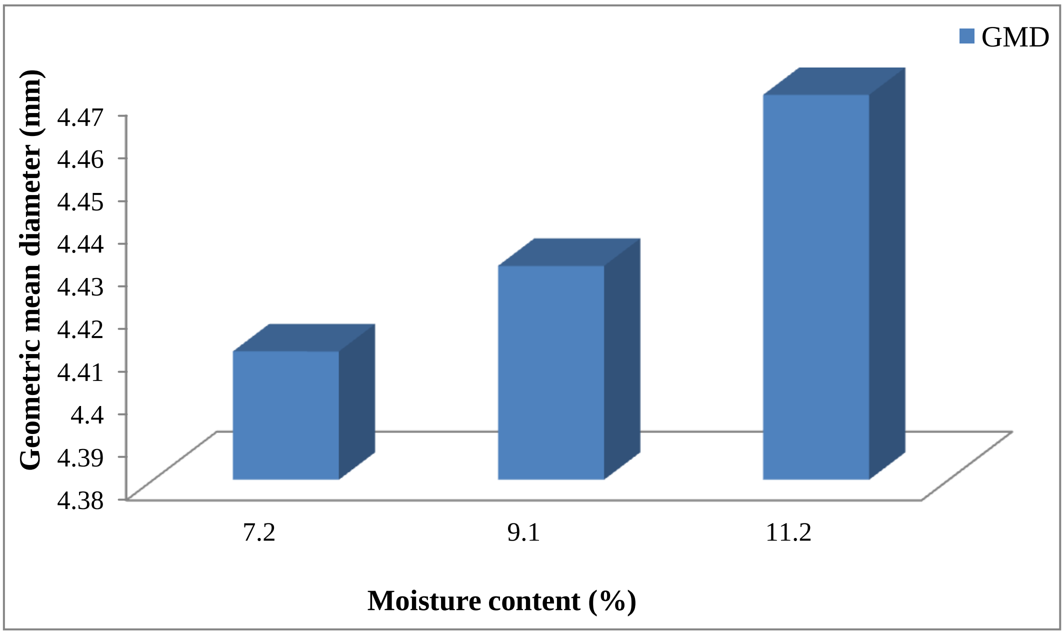

Fig. 4.2 : Effect of moisture content on geometric mean diameter

4.1.6 Volume

The volume of the seeds of coriander varied from 33.05 mm^3 to 34.16 mm^3 as the moisture content increased from 7.2% to 11.2% (w.b.). The volume was determined by the method given in a section 3.2.5. Rathod *et al*, (2020) reported the same increasing trend of surface area from 2.38-9.45 mm^3 with the increase in moisture content for fenugreek seed.

4.1.7 Angle of repose

The angle of repose is the angle made by seeds with the horizontal surface when heaped from a known height. It was varied between 29.75 and 32.73º as the moisture content varied from 7.2 to 11.2% (w.b.). Similar increasing trends in angle of repose for Amaranthus Cruentus seed were found *i.e.* increased in angle of repose from 21.21 to 33.19º with the increase in moisture content from 12.48 to 20.09% db, reported by Ilori and Akinyele (2016). In other study, the angle of repose of coriander seed increased from 24.91º to 30.70º for seed moisture content increases from 7.10 to 18.94% (w.b.) (Coskuner and Karababa, 2007). Sharanagat and Goswami, (2014) also found that the angle of repose of coriander seed increased from 25.5 to 31° with increase in moisture content from 8.5 to 15.89% (w.b.).

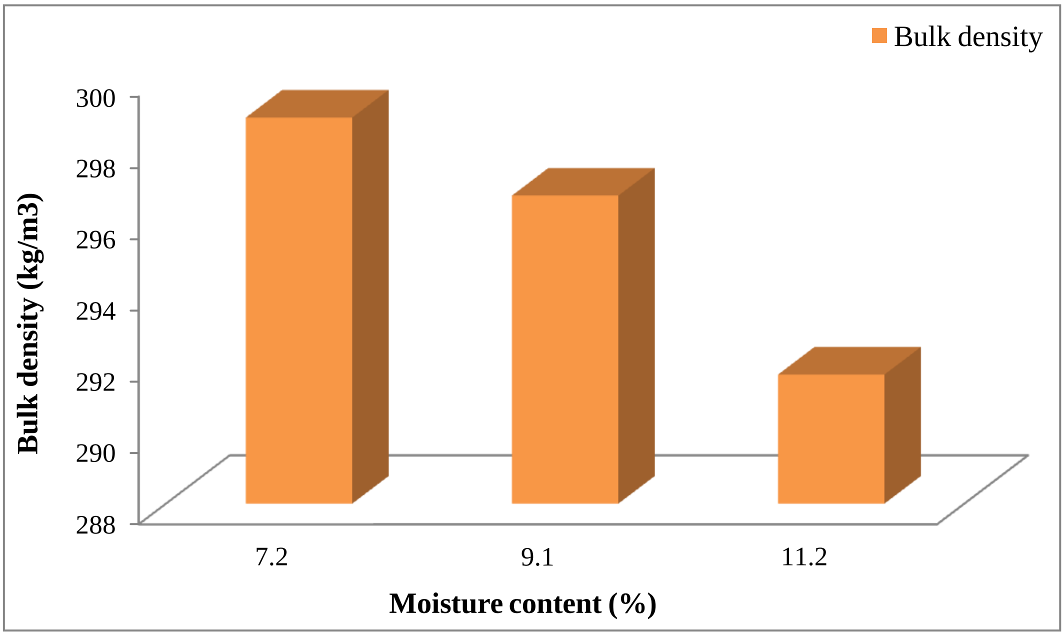

Fig. 4.3 : Effect of moisture content on bulk density

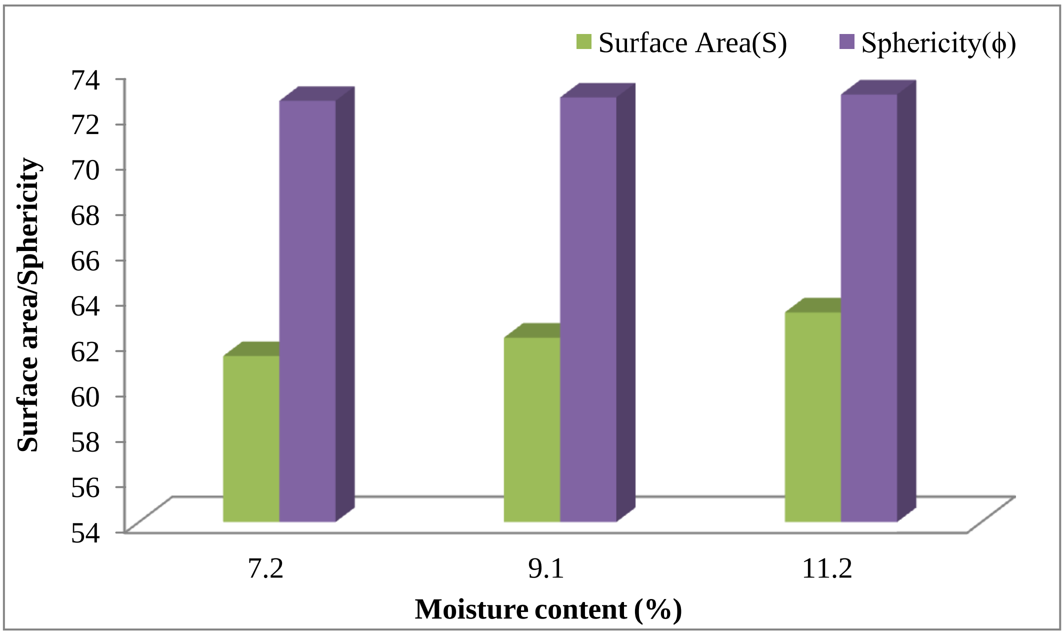

Fig. 4.4 : Effect of moisture content on surface area and sphericity

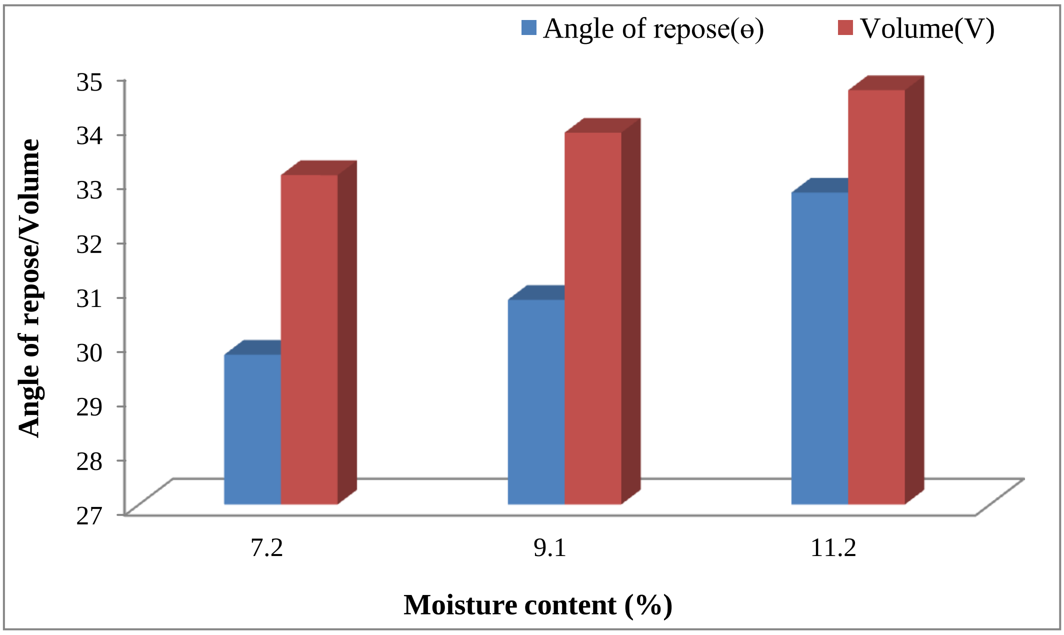

Fig. 4.5 : Effect of moisture content on angle of repose and volume

4.2 Grinding Characteristics of Coriander

4.2.1 Specific energy consumption

The specific energy consumption values for grinding of coriander seeds with different grinding methods are presented in a Table (4.2). The values of specific energy consumption, Rittinger’s constant, Kick’s constant and Bond’s work index was found increased with the increase in moisture content at all different grinding conditions. The value of specific energy consumption (Wh/kg), Rittinger's constant, Kick's constant and Bond's Work index varied between 88.14 to 722.13Wh/kg, 183.35 to 915.82Wh/kg, 118.64 to 589.72Wh/kg and 964.29 to 4807.21Wh/kg at moisture content (7.2-11.2% w.b.) and different grinding conditions, respectively.

In case of pulverizer (hammer type) the required specific energy consumption was higher as compared to mixer grinder and also develops higher temperature (45-90ºC) during grinder and because of this high temperature oil comes out from the cells of coriander seeds and makes the product sticky and viscous in nature. Thus, it leads to high power consumption in pulverizer (hammer type), while in case of burr mill and mixer grinder the temperature rise is low as compared to pulverizer (hammer type) and thus the material gets less sticky and requires less energy for grinding. The lower value of specific energy consumption was found 88.14Wh/kg for 7.2% w.b. moisture content of coriander sample ground in mixer grinder while the higher value of specific energy consumption was found 722.13Wh/kg for 11.2% w.b. moisture content for sample ground in burr grinder (Fig. 4.6 and 4.7).

Table 4.2: Effect of moisture contents and grinding methods on energy consumption and energy parameter

S. No	Grinding Methods	Specific Energy Consumption (Wh/kg)			Rittinger's Constant (Wh/kg)		
		Moisture content (% w.b.)					
		7.2	9.1	11.2	7.2	9.1	11.2
1	Pulverizer (hammer type)	321.98	498.28	619.02	648.65	833.25	915.82
2	Mixer grinder	88.14	107.99	112.46	403.55	487.27	499.39
3	Burr grinder	356.84	507.36	722.13	191.25	229.98	286.14
4	Ponding machine	169.56	301.56	374.94	183.35	247.88	276.92

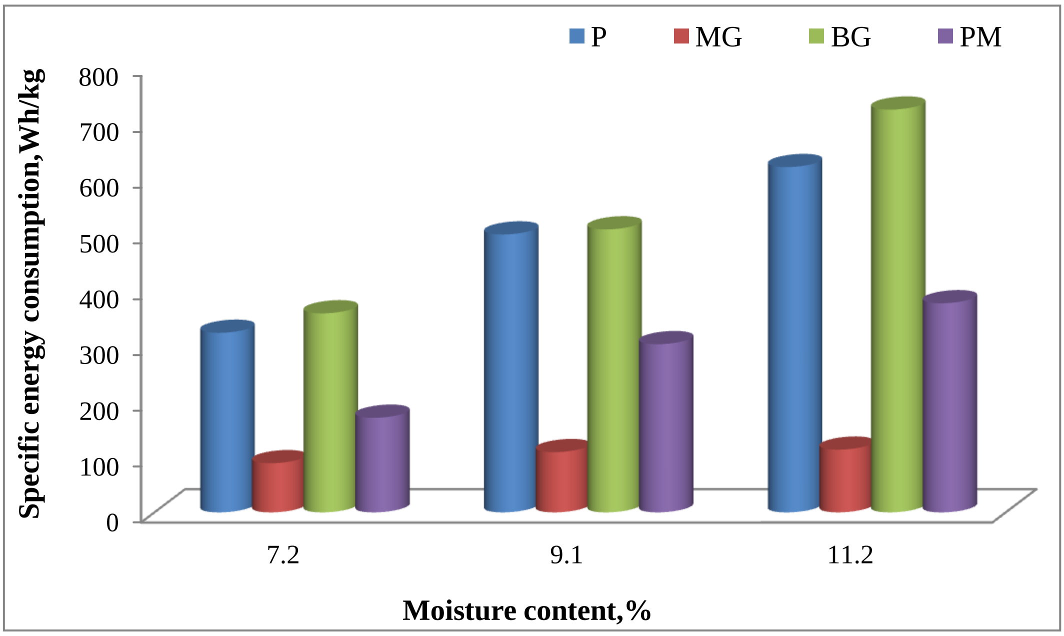

Fig. 4.6 : Specific energy consumption of coriander powder ground at different grinding methods and at different moisture content

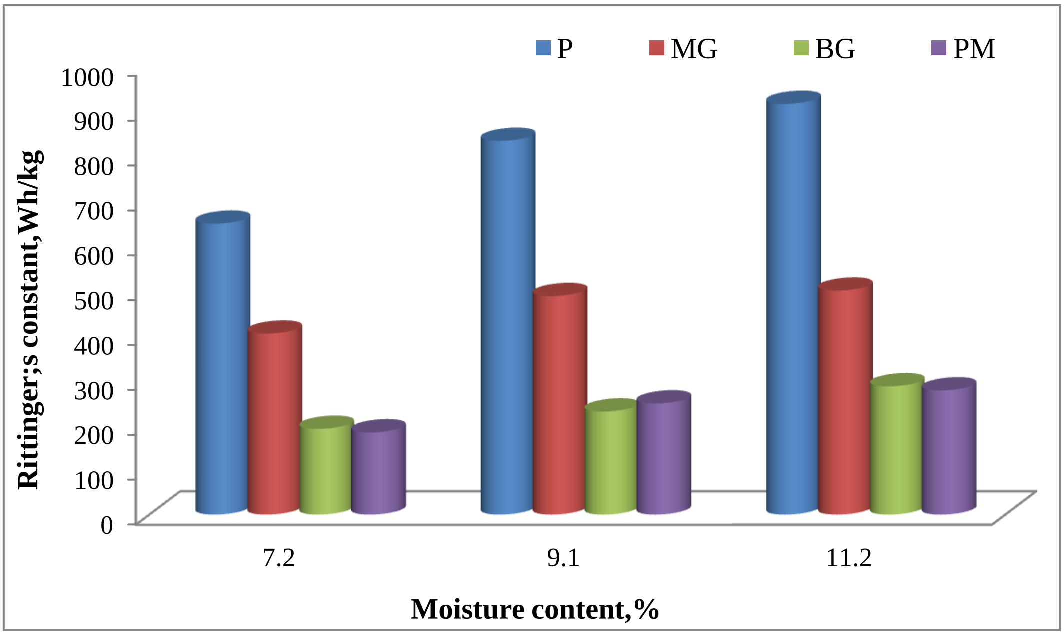

Fig. 4.7 : Rittinger's constant of coriander powder ground at different grinding methods and at different moisture content

4.2.2 Grinding Energy

The grinding energy *i.e.* Rittinger's, Kick's constant and Bond's work index were determined by the method given in a section 3.4.3. It was observed that the Rittinger's constant, Kick's constant and Bond's work index were increase with increase in moisture content (7.2-11.2% w.b.) at different grinding conditions. The energy values Rittinger's constant, Kick's constant and Bond's work index varied from 183.35 to 915.82Wh/kg, 118.64 to 589.72Wh/kg and 964.29 to 4807.21Wh/kg at moisture content (7.2-11.2%) with different grinding conditions, respectively (Table 4.3). Due to low temperature, the mixer grinder requires low power to ground the material as compared to burr and pulverizer (hammer type) and product is non-sticky. Similar result was observed during grinding of carrots where grinding energy was found to be increased with the increase in moisture content as 10-15% (w.b.) (Chakkaravarthi *et al*, 1993). The minimum value of Rittinger's, Kick's and Bond's Constants were found 191.25Wh/kg, 123.74Wh/kg and 1005.84Wh/kg, respectively for moisture content of 7.2% (w.b.) at burr grinding method. The maximum value of Rittinger's, Kick's and Bond's constants were found 915.82Wh/kg, 589.72Wh/kg and 4807.21Wh/kg, respectively, for 11.2% (w.b.) moisture content in pulverizer (hammer type) condition (Fig 4.8 and 4.9). Similar result was found for grinding fenugreek seed where the value of Bond's work index and Kick's constant are increased with the increase in moisture level (Balasubramanian *et al*, 2017).

Table 4.3: Effect of moisture contents on energy parameters with different grinding methods

S. No	Grinding Methods	Kick's Constant (Wh/kg)			Bond's Work Index (Wh/kg)		
		Moisture content (% w.b.)					
		7.2	9.1	11.2	7.2	9.1	11.2
1	Pulverizer (hammer type)	419.68	538.26	589.72	3411.38	4379.43	4807.21
2	Mixer grinder	216.53	261.01	266.59	1914.39	2309.88	2363.98
3	Burr grinder	123.74	148.56	184.25	1005.84	1208.73	1501.97
4	Ponding machine	118.64	160.14	178.31	964.29	1302.88	1453.54

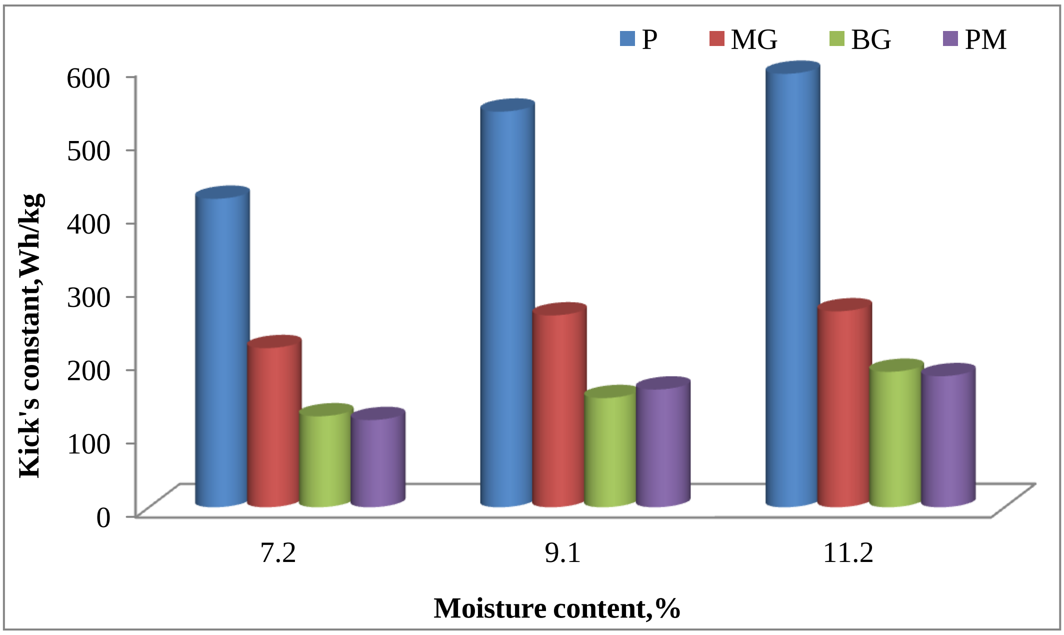

Fig. 4.8 : Kick’s constant of coriander powder ground at different grinding methods and at different moisture content

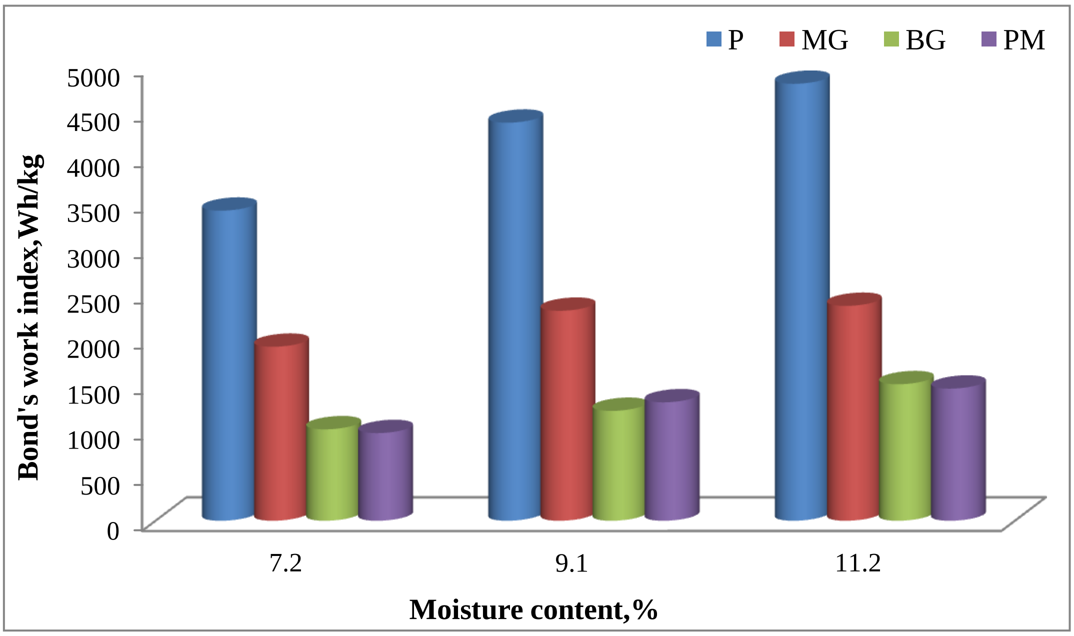

Fig. 4.9 : Bond’s work index of coriander powder ground at different grinding methods and at different moisture content

4.3.3 Particle size distribution

The average particle size of coriander powder was calculated on the basis of mass fractions retained on set of sieves. The details of average particle size of coriander powder ground by different grinding methods were shown in a Table 4.4.

The values of average particle size increases with the increase in moisture level which is may be due to increase in stickiness with increased in moisture content in the seed (Fig 4.10). The values increases with moisture content from 0.277-0.282 mm, 0.646-0.654 mm, 0.587-0.593 mm, 0.392-0.401 mm and 0.663-0.672 mm ground in pulverizer (hammer type), ponding machine, mixer grinder, burr grinder and mortar pestle, respectively. This occurs because moisture sorption is often associated with increased cohesiveness, owing to the formation of inter-particle-liquid bridges. The cohesive strength and arching capacity of bulk materials are thus affected by moisture content. Seed adhesion and cohesion begin to increase as moisture content rises, resulting in coarser grinding at higher moisture levels (Fig. 4.10).

Barnwal *et al.* (2015) found that the same increasing trends of average particle size for fenugreek powder ground at ambient condition varies between 0.31-0.81mm with the moisture level (5-15%) and for coriander powder it was 0.34-0.46 mm with moisture level 6.4-13.6% (d.b.). The maximum value of average particle size 0.672 mm was observed with coriander powder having 11.2% moisture content ground in mortar pestle. The minimum value of average particle size 0.277 mm was observed with coriander powder having 7.2% moisture content ground in pulverizer (hammer type). It was found that the average particle size of ground maize was observed 0.358 to 0.523 mm (Velu *et al.* 2006).

Table 4.4: Effect of different Grinding methods on Particle size of corianderpowder

S. No.	Grinding Methods	**Average particle size (mm)**		
		Moisture content (% w.b.)		
		7.2	9.1	11.2
1	Pulverizer (hammer type)	0.477	0.478	0.482
2	Mixer grinder	0.657	0.671	0.686
3	Burr grinder	0.532	0.539	0.547
4	Ponding machine	0.846	0.851	0.862
5	Mortar pestle	0.863	0.868	0.877

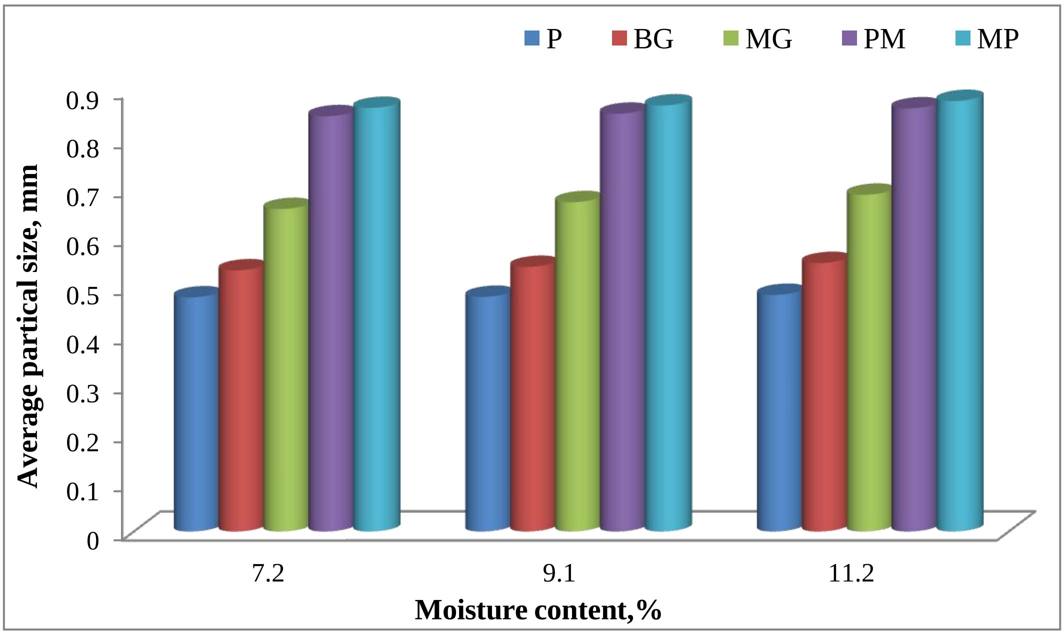

Fig. 4.10 : Effect of different grinding methods on particle size of corianderpowder at different moisture content

4.3 Quality Analysis

In the quality analysis experiment different quality parameters of ground coriander powder was analysed such as oleoresin, essential oil, phenolic and flavonoid content. As per the experiment plan coriander seeds with three different moisture contents (7.2, 9.1 and 11.2% w.b.) was grind in five different grinding methods (pulverizer - hammer type, mixer grinder, burr grinder, ponding machine and mortar pestle) and the received powder was packed in a sealed plastic bags for further quality analysis.

4.3.1 Oleoresin content

The oleoresin content in coriander powder was calculated with the help of standard procedure as explain in the methodology section 3.6.1. Table 4.5 indicate the value of oleoresin contents of coriander powder obtained through various methods of combination. The maximum value of oleoresin i.e. 12.077% was found in the sample ground in pulverizer - hammer type at 11.2 percent moisture content (wet basis) over other grinding methods. In the pulverizer - hammer type, mortar pestle, mixer grinder the oleoresin content increased from 9.627-12.077%, 6.828-8.705%, 8.550-10.434%, respectively, with increase in moisture content 7.2-11.2% (w.b.). The minimum value of oleoresin content was 6.828 percent obtained in mortar pestle method of grinding at 7.2 percent moisture content level (Fig. 4.11). The oleoresin content was found to be higher in pulverizer (hammer type) and ponding machine followed by burr grinder.

Table 4.5 showed that the value of oleoresin content of ground coriander gradually increased with the increase in moisture content. Similar trends of results have been reported by Sigh and Goswami (2000) for ambient grinding of cumin. The oleoresin content of ground coriander varied from 5.39-15.53 percent (Saxena *et al.* 2015). Pisal *et al.* (2015) reported that the oleoresin content decreased with increasing temperature from 50 to 70ºC. This was due to evaporation of volatile oil at higher temperature.

Table 4.5: Effect of grinding methods and moisture on oleoresin content incoriander seed powder

S. No.	Grinding Methods	**Oleoresin content (%)**		
		Moisture content (% w.b.)		
		7.2	9.1	11.2
1	Pulverizer (hammer type)	9.627	11.697	12.077
2	Mixer grinder	8.550	10.328	10.434
3	Burr grinder	9.121	10.569	10.996
4	Ponding machine	10.276	10.321	10.445
5	Mortar pestle	6.828	8.112	8.705

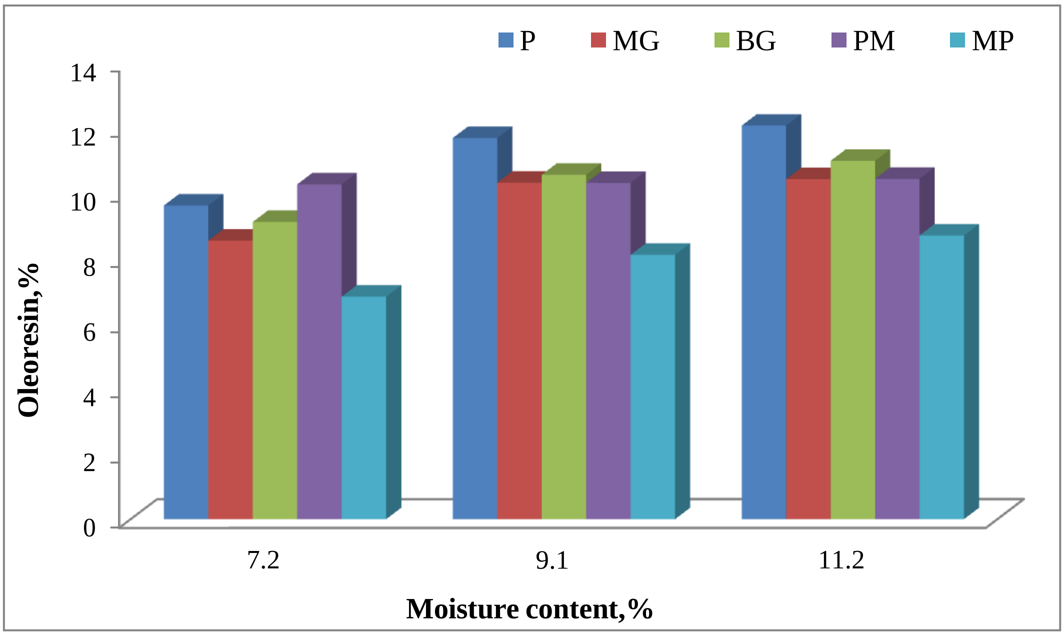

Fig. 4.11 : Effect of grinding methods on oleoresin content of coriander powder

Table 4.6: ANOVA for the effect of grinding methods and moisture contents on oleoresin content of coriander powder

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	SE(m)	CD
G	4	53.644	13.411	5.032*	0.544	1.579
M	2	22.814	11.407	4.280*	0.421	1.223
G × M	8	5.554	0.694	0.260	0.942	
Error	30	79.947	2.665			
Total	44	161.959				

*Significant at $p < 0.05$

The Analysis of variance for the effect of different moisture contents and different grinding methods on oleoresin content of coriander powder is shown in Table 4.6. The grinding method as well as moisture content has significant effect on the value of oleoresin content of coriander powder.

4.3.2 Essential oil

The essential oil was obtained by hydrodistillation method using Clevenger apparatus as described in section 3.6.2. The obtained essential oil was dried over anhydrous sodium sulphate, filtered through filter paper and kept stored at -4°C.

The essential oil extracted from coriander seed powder ground with different grinding methods at different moisture content is presented in the Figure 4.12. The results revealed that the essential oil present in the sample ground in ponding machine and mortar pestle methods were higher as compare to other methods. Also the increased in the moisture content did not have any effect on essential oil content in all the methods of grinding.

The highest value of essential oil content is 0.32 percent found in the sample with the grinding methods *i.e.* ponding machine and mortar pestle at 11.2 percent moisture content (w.b.) and the low level of essential oil was 0.09 percent obtained in the sample ground with pulverizer at 11.2 percent moisture content (w.b.). Table 4.7 indicates that the grinding method significantly influenced the essential oil content present in coriander seed. The temperature rise in grinding process may evaporate some amount of essential oil present in coriander powder thus giving low recovery. The more the temperature rise during coriander seed grinding, the more essential oil might lost. The essential oil of coriander seed ground in pulverizer, ponding machine, mixer grinder, burr grinder and mortar pestle varied between 0.09-0.12%, 0.31-0.32%, 0.17-0.20%, 0.13-0.15% and 0.30-0.32%, respectively. The loss of essential oil was more in pulverizer followed by burr grinder because of temperature rise during grinding. Barnwal *et al.* (2015) concluded the same results *i.e.* essential oil content of coriander seed at different moisture content varied non-significantly.

Table 4.7: Effect of grinding methods and moisture content on essential oil ofcoriander powder

S. No.	Grinding Methods	**Essential oil (%)**		
		Moisture content (% w.b.)		
		7.2	9.1	11.2
1	Pulverizer (hammer type)	0.12	0.11	0.09
2	Ponding machine	0.31	0.31	0.32
3	Mixer grinder	0.17	0.20	0.18
4	Burr grinder	0.14	0.15	0.13
5	Mortar pestle	0.30	0.31	0.32

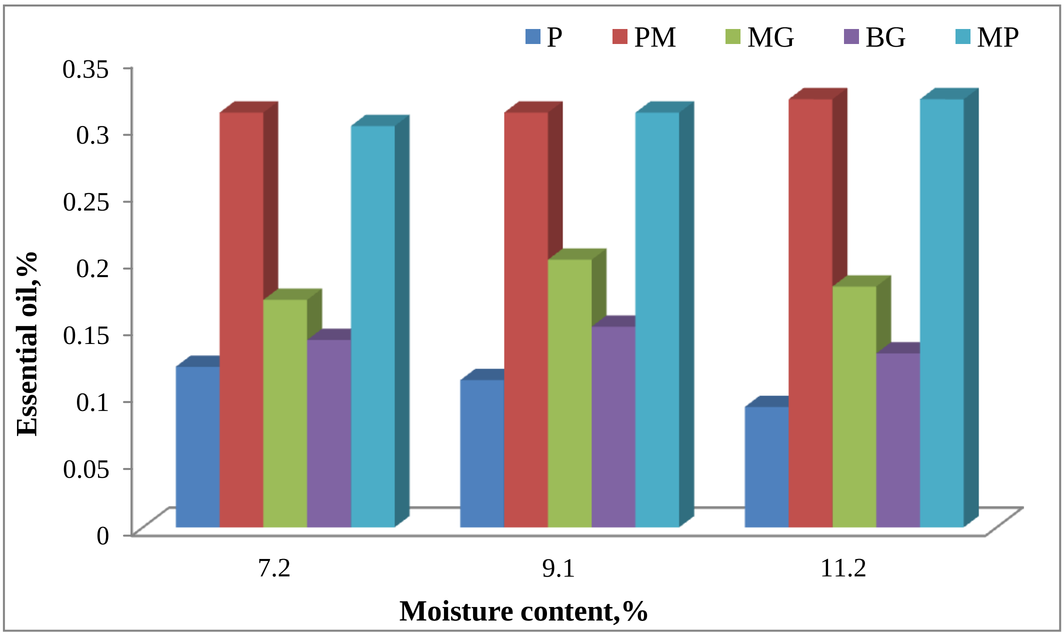

Fig. 4.12 : Effect of grinding methods and moisture content on essential oil of coriander powder

Table 4.8: ANOVA for the effect of grinding methods and moisture contents ontotal essential oil content of coriander powder

Source of Variation	**DF**	**SS**	**MS**	**F**	**SE(m)**	**CD**
G	4	0.212	0.053	168.236*	0.007	0.022
M	2	0.000	0.000	0.169	0.006	
G×M	8	0.003	0.000	1.258	0.013	
Error	15	0.005	0.000			
Total	29	0.220				

*Significant at $p < 0.05$

Table 4.8 indicate the analysis of variance for the effect of different grinding methods and moisture contents on essential oil of coriander powder. The analysis shows that the grinding method has significant effect on essential oil content but the moisture content does not have significant effect.

4.3.3 Total phenolic content

The phenolic compounds are the plant metabolites characterized by the presence of various phenol groups. Some of them are very reactive in nature that has neutralizing effect on free radicals by donating hydrogen atom, chelating metal ions in aqueous solution. A standard curve was prepared using gallic acid as a standard for estimation of total phenol content of various crude extract of coriander. The regression equation obtained between absorbance and the amount of gallic acid was $y = 0.0179x - 0.1205$ ($R^2 = 0.9977$), shows the linear relationship between absorbance and amount of gallic acid (Fig 4.13). The effect of different grinding methods with the variation in moisture level on total phenolic contents of coriander seed are presented in Table 4.6. Data shown in Table are the mean of duplicates.

The total phenolic content was gradually decreased with the moisture content for different grinding methods (Fig 4.14). The total phenolic content (mg GE/g seed extract) of coriander seed ground with different grinding methods varied from 19.413-33.715. The maximum value of phenolic content was observed 33.715 mg GE/g powder extract in 7.2% moisture content (w.b.) ground with mortar pestle. The minimum value of phenolic content was obtained 19.413 mg GE/g coriander extract in 11.2% w.b. moisture content ground with pulverizer (hammer type). The retention of total phenolic content was more in mortar pestle followed by ponding machine and burr grinder. Total phenolic content are heat unstable and reactive compounds and during grinding time there is rise in temperature leads to reduction in phenol contents (Barnwal *et al.* 2014).

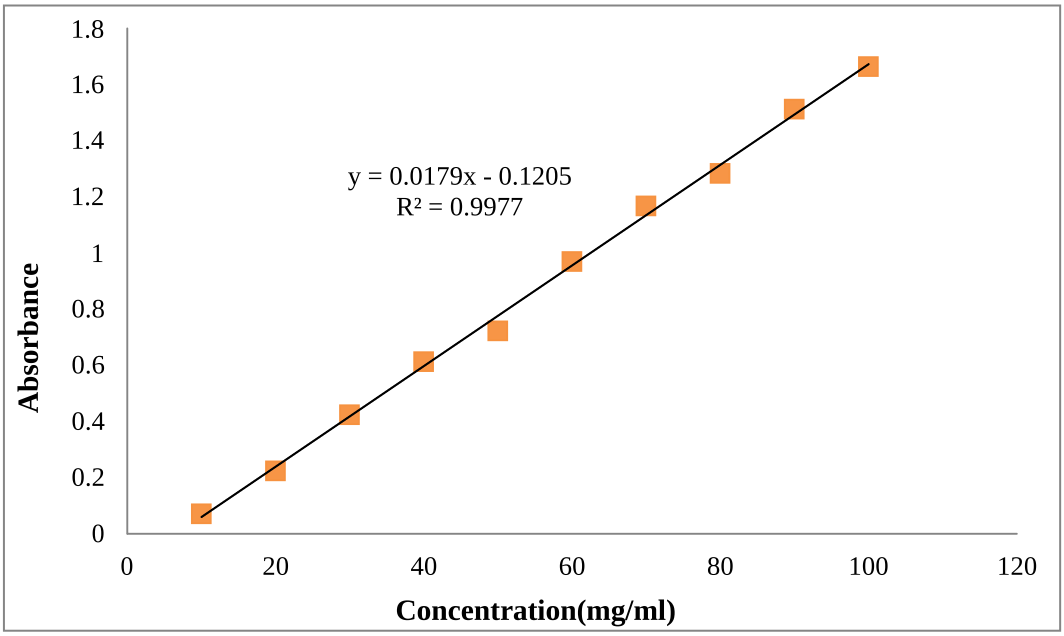

Fig. 4.13 : Standard curve for total phenolic content

Table 4.9: Effect of grinding methods and moisture content on phenolic content of coriander powder

S. No.	Grinding Methods	**Total phenolic content** (mg GAE/g powder extract)		
		Moisture content (% w.b.)		
		7.2	9.1	11.2
1	Pulverizer (hammer type)	28.687	25.223	19.413
2	Ponding machine	33.659	28.911	27.793
3	Mixer grinder	26.341	24.944	21.759
4	Burr grinder	29.413	23.771	19.636
5	Mortar pestle	33.715	28.743	24.497

In one study the total phenol content of coriander crude seed extracts ground in a pin mill was ranging from minimum 19.46 mg GAE/g seed extract to a maximum of 62.39 mg GAE/g seed extract for different varieties of coriander (Saxena *et al.* 2015). In another study by Barnwal *et al.* 2015 concluded that the grinding methods have significant effect on antioxidant activity of coriander seed also the phenolic content of coriander powder was decreased significantly with increase in the moisture content irrespective of grinding methods.

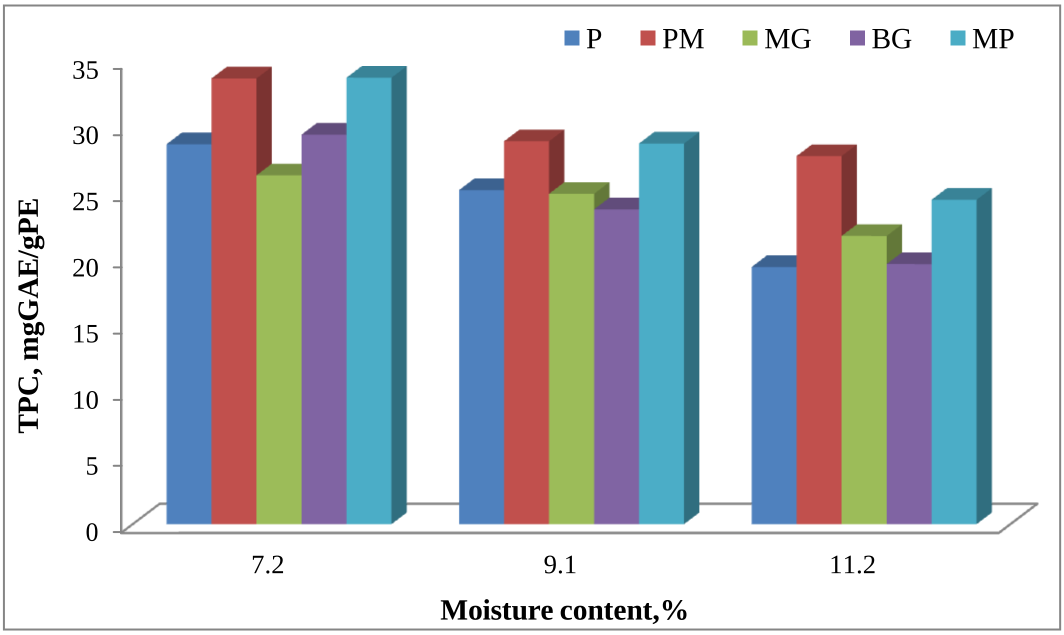

Fig. 4.14 : Effect of grinding methods on total phenolics of coriander powder extract

Table 4.10: ANOVA for the effect of grinding methods and moisture contents on total Phenolic content of coriander powder

Source of Variation	**DF**	**SS**	**MS**	**F**	**SE(m)**	**CD**
G	4	198.552	49.638	45.552*	0.426	1.296
M	2	300.151	150.075	137.723*	0.330	1.004
G×M	8	30.185	3.773	3.463*	0.738	2.245
Error	15	16.345	1.090			
Total	29	545.233				

*Significant at $p < 0.05$

The analysis of variance for the effect of different grinding methods and different moisture contents on total phenolic contents of coriander powder is presented in Table 4.10. The analysis shows that the effect of moisture contents and grinding methods has significant effect on the total phenolic content of coriander powder.

4.3.4 Total flavonoid content

For the estimation of flavonoid contents of coriander powder, a standard curve using quercetin was prepared (Fig 4.15). The equation obtained between absorbance and amount of quercetin was $y = 0.0089x + 0.0291$ ($R^2 = 0.9958$) that shows the linear relation between absorbance and amount of quercetin. The flavonoid content is expressed as mg QE/g seed extract.

The flavonoid contents of different coriander seed extract at different moisture content ground in different grinding methods were presented in a Table (4.11). The result showed the coriander seed ground in mortar pestle and ponding machine revealed higher value of total flavonoid contents than other grinding methods. Coriander seed ground in ponding machine has higher value varied from 3.359-3.584 mg QE/g seed extract at different moisture content level. In case of pulverizer (hammer type) grinder, showed the minimum value of 1.674-1.898 mg QE/g seed extract at different moisture content level (Fig. 4.16). The retention of flavonoid content was more in ponding machine followed by mortar pestle because of lower temperature during grinding.

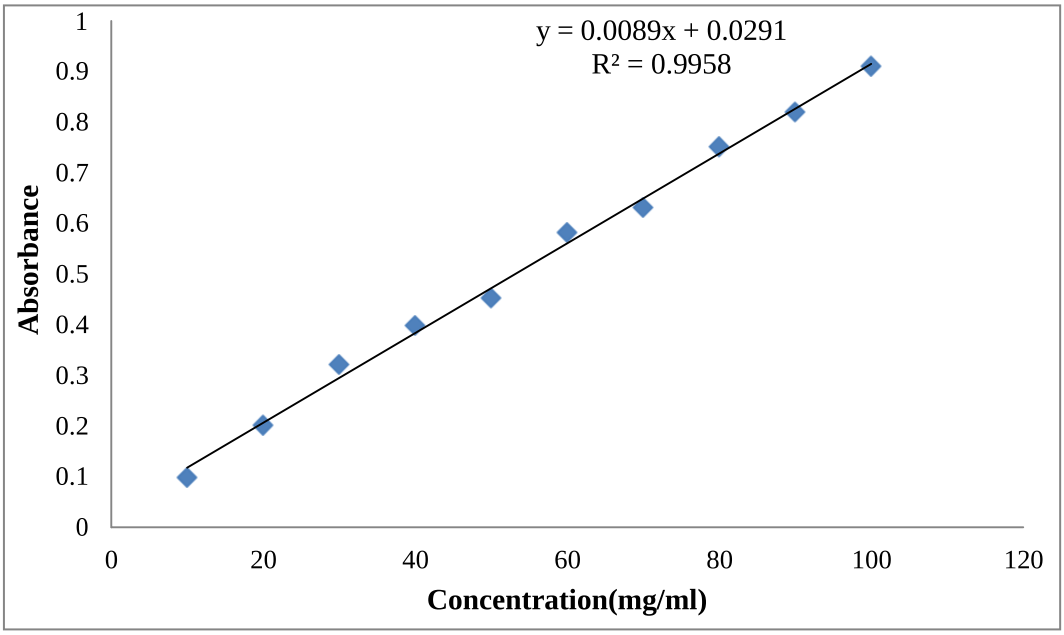

Fig. 4.15 : Standard curve for flavonoid content

Table 4.11: Effect of grinding methods on flavonoid content of coriander powder

S. No.	Grinding Methods	**Total Flavonoid content** (mg QE/g coriander powder) Moisture content (% w.b.)		
		7.2	9.1	11.2
1	Pulverizer (hammer type)	1.898	1.786	1.674
2	Ponding machine	3.584	3.471	3.359
3	Mixer grinder	2.461	2.348	2.236
4	Burr grinder	2.797	2.573	2.461
5	Mortar pestle	3.371	3.247	3.146

It was also observed that with the increased in the moisture content of coriander seeds, flavonoid content exhibits decreasing trend for different grinding methods. The same decreasing trend was observed by Rabhabh *et al.* (2015), the heating may breakdown some phytochemicals which affect cell wall integrity and cause a migration of some flavonoids content. The loss in flavonoid contents were due to breakage or breakdown by chemical reactions includes enzymes, oxygen and light.

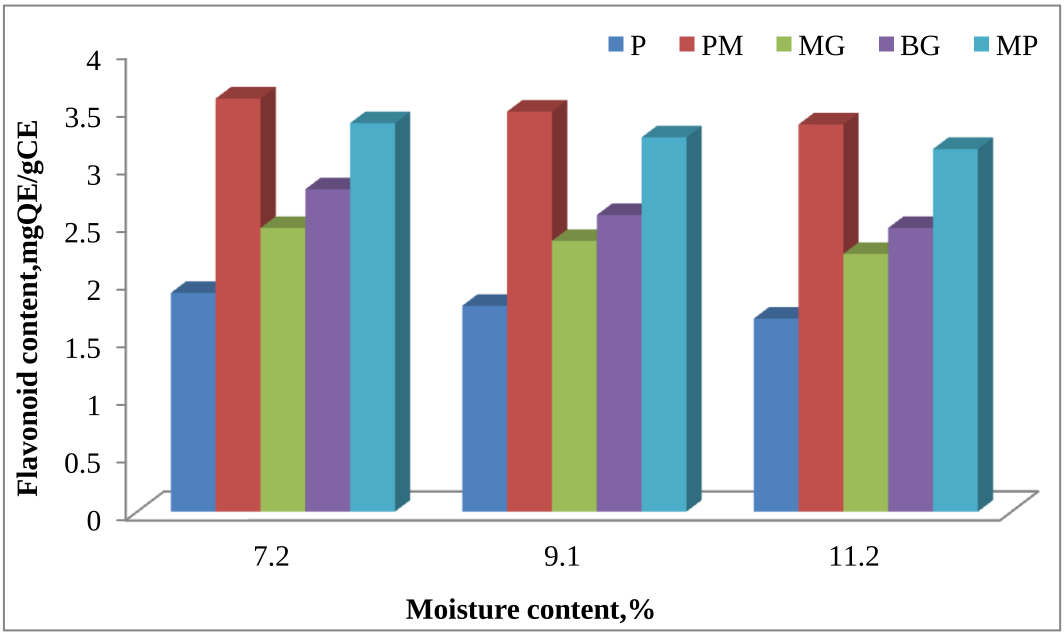

Fig. 4.16 : Effect of grinding methods on flavonoid content of coriander powder extract

In one study by Rashmi *et al.* (2019), flavonoid content of giloy stem followed decreasing trend with increasing drying temperature. In other study by Saxena *et al.* (2015), total flavonoid content in methanol seed extract showed significant genotype variation. Total flavonoid content was ranging from a minimum of 5.81 mg QE/g in crude seed extract to a maximum of 16.92 mg QE/g seed extract.

Table 4.12: ANOVA for the effect of grinding methods and moisture contents on flavonoid content of coriander powder

Source of Variation	**DF**	**SS**	**MS**	**F**	**SE(m)**	**CD**
G	4	11.218	2.805	180.260*	0.051	0.155
M	2	0.306	0.153	9.846*	0.039	0.120
G×M	8	0.013	0.002	0.105	0.088	
Error	15	0.233	0.016			
Total	29	11.771				

*Significant at $p < 0.05$

The analysis of variance for the effect of different grinding methods and different moisture contents on flavonoid contents of coriander powder is presented in Table 4.12. It was observed that the flavonoid content varied with different grinding methods and moisture contents at $p < 0.05$.

P ground coriander powder

PM ground coriander powder

BG ground coriander powder

MG ground coriander powder

MP ground coriander powder

Fig. 4.17 : Coriander powder ground by different grinding machine/methods

CHAPTER-V

SUMMARY AND CONCLUSION

Coriander is an annual herb that belongs to the carrot family (*Umbelliferae* or *Apiaceae*) and comes from the mediterranean region. Commercially, this herb is grown in Europe, Asia, and Africa. It is cultivated primarily for its seed and secondly for its green leaf. Coriander seeds have a mild, sweet, slightly pungent, citrus-like flavour with a hint of sage. It is a miracle herb that can be used as a seasoning as well as a natural remedy. Coriander seed have medicinal properties like diuretic, antipyretic, stomachic, stimulant, laxative, anathematic, and treats biliousness, bronchitis, and vomiting, as well as being a strong aromatic, antiseptic, expectorant, and antispasmodic. Hiccough, suppuration, piles, inflammation, toothache, jaundice, scabies, and gland tuberculosis are all treated with the leaves, which are hypotonic and analgesic.

The present work on Studies on Grinding Characteristics of Coriander (*Coriandrum sativum L*) Seeds was carried out at Department of Agricultural Processing and Food Engineering, SVCAET & RS, IGKV, Raipur with set of objectives of grinding characteristics of Coriander seeds under different grinding methods and its effect on phytochemicals content in coriander powder.

India is the world's largest producer of coriander, which is widely used in curry powder products. Coriander is used to make chutneys and sauces from the whole young plant. The fresh leaf and dried seeds are the most extensively used items in cooking, but all parts of the plant are edible. The dried seed is used to make steam-distilled essential oil and solvent-extracted oleoresin in the fragrance, perfumery, and flavour industries. Coriander seed contains varying quantities of proteins, fats, carbohydrates, fibers, minerals, and vitamins. The most important element in assessing the quality of spices is the essential/volatile oil.

Grinding is one of the most essential unit operations in the post-harvest processing of spices, and it requires special attention due to the additional issues of volatility and aroma loss. The essential oils, which are the main ingredient in spices, give most spices their unique aroma, and hence their true meaning as spice. These oils are hidden away in oil cells or matrix, which can only be obtained after grinding. Coriander is a good source of polyphenols and phytochemicals because of its high antioxidant activity. Phytochemicals are natural chemical compounds found in plants.

The fresh and dried coriander seed were taken and evaluated further for its physical properties such as moisture content, length, width, thickness, geometric mean diameter, bulk density, angle of repose, volume, surface area and sphericity. During the experiment five grinding machines/methods used *i.e.* pulverizer (hammer type), ponding machine, mixer grinder, burr grinder and mortar pestle at different level of moisture content *i.e.* 7.2, 9.1 and 11.2% wet basis were selected to produce powder from coriander seed. Grinding characteristics of coriander were analyzed based on the factors such as specific energy consumption, grinding energy and particle size distribution. After grinding, quality of coriander powder was carried out for phytochemical analysis using standard methods.

Based on the experimental observations, the following results were obtained.

- The initial moisture content of fresh coriander seed was found to be 9.08% (w.b.) and after conditioning the moisture contents maintained in coriander seed was 7.2, 9.1 and 11.2% (w.b.).
- The length, width and thickness were measured by vernier calliper to determine the size of coriander seeds. The average length, width and thickness of coriander seed were varied between 6.09-6.16, 3.92-3.97 and 3.58-3.68 mm respectively, at 7.2-11.2% moisture content on wet basis. The length, width and thickness of the coriander seeds increased linearly with increase in moisture content.
- Geometric mean diameter, sphericity, bulk density, angle of repose, volume and the surface area of coriander seed was varied with the variation in moisture content from 7.2-11.2% (wet basis), the values were 4.41-4.47 mm, 72.57-72.85%, 298.83-291.62 kg/m^3, 29.75-32.73º, 33.05-34.61 mm^3 and 61.32-63.24 mm^2 respectively. Geometric mean diameter, sphericity, angle of repose, volume and surface area of coriander seed increased gradually with increase in the coriander moisture level. The bulk density was observed to follow decreasing trend with increase in moisture content of coriander.

- There was five different types of grinding machine/methods used for experiment, pulverizer (hammer type), chilli ponding machine, mixer grinder, burr grinder and one traditional method mortar and pestle.
- The specific energy consumption, Kick’s constant, Rittinger’s constant, Bond’s work index and average particle size of coriander ranged from 88.14 to 722.13Wh/kg, 123.74 to 589.72Wh/kg, 191.25 to 915.82Wh/kg, 1005.84 to 4807.21Wh/kg and 0.477 to 0.877mm, respectively, at moisture level 7.2 to 11.2% wb. The pulverizer (hammer type) unit produces more fine particles as compared to the other grinding methods/machines. It was also observed that in all grinding methods the specific energy consumption, Kick’s, Rittinger’s constants, Bond’s work index and particle size of coriander increased with the increment in moisture content.
- The grinding methods significantly affect the quality of final coriander powder. The value of oleoresin content of coriander powder ground with different grinding methods varied from 6.828-12.077% at different moisture content level 7.2-11.2% wb. The value of oleoresin content is higher in the sample ground with pulverizer (hammer type) method at 11.2% (w.b.) moisture content.
- In methanolic extract the phenolic and flavonoid contents are present. The total phenolic content of methanolic extract of coriander powder ground with different grinding methods was varied between 19.413-33.715 mg GAE/g powder extract at moisture content 7.2-11.2% wb. The mortar pestle and ponding machine produces high quantity of total phenolic contents. The Flavonoid content of coriander seed ground with different grinding methods was varied from 1.674-3.584 mg QE/g powder extract at moisture content 7.2-11.2% (w.b). The higher value of flavonoid content was observed in ponding machine and in mortar pestle method of grinding. It was also observed that, if the moisture content was increased then the total phenolic and flavonoid contents of coriander powder were decreased in all grinding methods.
- The essential oil content of coriander ground with different grinding methods was ranged from 0.09 to 0.32% at different moisture level. It was observed

that with the increased in moisture content there was decrease in the essential oil of the coriander ground with pulverizer (hammer type), burr mill and mixer grinder method of grinding.

- After evaluation of all the quality parameters of ground coriander powder in terms of essential oil, oleoresin content, phenolic content, flavonoid content and rise in temperature the ponding machine and mortar pestle produces the best quality coriander powder. On the basis of appearance and particle size the pulverizer (hammer type) produces good quality powder. At the moisture content 7.2% wb the quality of powder is good on the basis of polyphenols. On the basis of grinding energy, the ponding machine consumes less energy to grind the coriander seed.

SUGGESTION FOR FUTURE WORK

1. GC analysis of active components of coriander essential oil can be analyzed.
2. Cryogenic grinding of coriander can be considered for future work.
3. Different solvent can be used to make extract for phytochemical screening.

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APPENDIX

APPENDIX - A

Table A.1 Physical properties of Coriander seeds at 7.2% wb moisture content

S.No.	Length	Width	Thickness	Geometric Mean Diameter	Sphericity (ϕ)	Volume(V)	Surface area
1	7.08	4.26	3.96	4.924	0.695	44.063	76.201
2	5.63	3.7	3.3	4.096	0.727	26.106	52.725
3	6.16	3.81	3.51	4.351	0.706	30.684	59.485
4	5.61	3.79	3.61	4.249	0.757	29.990	56.747
5	5.15	3.58	3.04	3.826	0.743	21.597	46.016
6	6.02	3.47	3.12	4.024	0.668	23.489	50.885
7	5.67	3.67	3.45	4.156	0.733	27.401	54.273
8	6.42	3.87	3.6	4.472	0.696	33.027	62.840
9	6.3	4.22	3.47	4.518	0.717	34.701	64.149
10	7.28	4.58	4.1	5.151	0.707	50.976	83.379
11	5.57	3.52	3.49	4.090	0.734	26.149	52.563
12	6.39	4.05	3.8	4.615	0.722	37.166	66.942
13	6.16	4.13	3.8	4.589	0.745	37.321	66.183
14	6.11	4.19	3.88	4.631	0.757	38.827	67.390
15	6.68	4	3.17	4.391	0.657	30.246	60.599
16	6.77	3.81	3.54	4.503	0.665	32.816	63.711
17	5.83	3.89	3.3	4.214	0.722	28.296	55.799
18	6.24	3.9	3.71	4.486	0.718	34.015	63.234
19	6.91	4.68	4.69	5.332	0.771	60.097	89.358
20	5.94	3.82	3.59	4.334	0.729	30.998	59.043
21	5.51	3.51	3.25	3.976	0.721	23.738	49.670
22	5.41	3.32	3.24	3.875	0.716	21.871	47.183
23	5.73	3.61	3.4	4.127	0.720	26.531	53.534
24	6.1	3.71	3.25	4.189	0.686	26.928	55.156
25	5.97	4.19	3.82	4.571	0.765	37.639	65.671
26	6.25	4.17	3.65	4.564	0.730	36.220	65.475
27	4.25	3.98	3.38	3.852	0.906	26.340	46.629
28	6.97	4.18	3.81	4.805	0.689	40.735	72.570
29	6.84	4.12	4.04	4.846	0.708	42.491	73.806
30	5.76	3.81	3.64	4.306	0.747	30.916	58.278
Total	**182.71**	**117.54**	**107.61**	**132.078**	**21.772**	**991.389**	**1763.308**
Mean	**6.09033**	**3.918**	**3.587**	**4.402**	**0.725**	**33.046**	**60.803**

Table A.2 Physical properties of Coriander seeds at 9.1% wb moisture content

S.No.	**Length**	**Width**	**Thickness**	**Geometric Mean Diameter**	**Sphericity (ϕ)**	**Volume(V)**	**Surface area**
1	6.25	4.62	3.64	4.719	0.755	40.969	69.976
2	5.88	4.2	3.58	4.454	0.757	34.548	62.356
3	6.32	4.08	3.92	4.658	0.737	38.727	68.178
4	7.25	4.23	3.91	4.931	0.680	43.648	76.402
5	6.26	4.61	3.96	4.852	0.775	45.438	73.992
6	6.46	4.31	4.02	4.819	0.746	43.249	72.973
7	6.17	4.11	4.03	4.675	0.757	39.938	68.679
8	6.55	3.88	3.56	4.489	0.685	33.082	63.322
9	5.64	3.65	2.91	3.912	0.693	22.065	48.104
10	6.75	3.83	3.47	4.476	0.663	32.188	62.964
11	5.31	3.61	2.9	3.816	0.718	20.939	45.765
12	4.9	3.71	3.4	3.953	0.806	25.390	49.117
13	5.9	3.82	3.19	4.158	0.704	26.741	54.326
14	6.69	4.3	4.04	4.880	0.729	44.211	74.826
15	6.76	4.29	3.76	4.777	0.706	40.629	71.713
16	5.66	3.76	3.43	4.179	0.738	28.002	54.878
17	5.6	3.65	3	3.943	0.704	22.795	48.858
18	5.64	4.21	3.33	4.292	0.761	30.999	57.881
19	6.49	3.17	3.36	4.104	0.632	24.186	52.921
20	5.2	3.24	2.71	3.574	0.687	16.723	40.137
21	7.51	4.4	4.14	5.152	0.686	50.053	83.419
22	5.79	3.77	3.54	4.259	0.735	29.566	57.001
23	5.56	3.46	4.39	4.387	0.789	34.055	60.480
24	5.11	3.54	4.76	4.415	0.864	37.691	61.267
25	6.85	3.59	3.35	4.351	0.635	28.890	59.487
26	5.78	3.77	3.47	4.228	0.731	28.822	56.183
27	6.83	3.9	3.89	4.696	0.687	37.964	69.315
28	6.03	4.23	3.83	4.605	0.763	38.404	66.646
29	6.03	4.26	4.04	4.699	0.779	41.434	69.387
30	6.4	3.89	3.64	4.491	0.701	33.618	63.390
Total	**183.57**	**118.09**	**109.17**	**132.956**	**21.815**	**1014.978**	**1863.958**
Mean	**6.119**	**3.93633**	**3.639**	**4.431**	**0.727**	**33.832**	**62.131**

Table A.3 Physical properties of Coriander seeds at 11.2% wb moisture content

S. No.	Length	Width	Thickness	Geometric Mean Diameter	Sphericity (ϕ)	Volume(V)	Surface area
1	6.35	4.13	3.07	4.318	0.680	29.303	58.584
2	5.64	3.84	3.56	4.256	0.754	30.040	56.917
3	5.98	3.94	3.66	4.418	0.738	33.093	61.327
4	7.63	5.06	3.7	5.227	0.685	52.221	85.859
5	5.42	4	4.05	4.444	0.820	36.579	62.070
6	6.62	4.26	3.76	4.733	0.714	39.805	70.389
7	6.31	4.26	3.71	4.637	0.734	38.132	67.569
8	5.7	3.46	3.18	3.973	0.697	23.167	49.597
9	4.98	3.2	3.42	3.791	0.761	21.374	45.165
10	6.47	4.02	3.69	4.578	0.707	35.789	65.863
11	6.12	3.92	3.74	4.476	0.731	34.198	62.971
12	6.56	3.91	4.55	4.886	0.744	45.050	75.035
13	5.69	4.1	3.54	4.354	0.765	32.515	59.585
14	5.64	3.24	2.85	3.734	0.662	18.670	43.817
15	5.92	4.25	3.86	4.596	0.776	38.662	66.385
16	6.88	4.16	4.07	4.883	0.709	43.525	74.941
17	6.64	4.17	3.72	4.687	0.705	38.352	69.040
18	5.36	3.36	4.26	4.249	0.792	31.054	56.730
19	6.46	4.06	3.42	4.476	0.692	33.015	62.959
20	6.06	3.63	3.66	4.318	0.712	30.156	58.584
21	6.17	4.42	4.1	4.817	0.780	44.709	72.923
22	6.09	3.91	3.63	4.421	0.726	32.777	61.424
23	6.22	3.93	3.88	4.560	0.733	36.206	65.345
24	6.52	3.97	3.7	4.575	0.701	35.525	65.770
25	5.92	3.82	3.83	4.424	0.747	33.511	61.507
26	6.25	4.83	3.36	4.663	0.746	39.199	68.336
27	5.82	3.63	3.68	4.268	0.733	29.683	57.234
28	6.16	3.6	3.39	4.220	0.685	27.483	55.966
29	6.14	3.98	3.78	4.520	0.736	35.363	64.204
30	7.03	4.09	3.75	4.759	0.677	39.143	71.178
Total	**184.75**	**119.15**	**110.57**	**134.273**	**21.855**	**1038.314**	**1897.289**
Mean	**6.15833**	**3.97167**	**3.68567**	**4.475**	**0.728**	**34.610**	**63.242**

APPENDIX – B

Table B.1 Oleoresin content of Coriander powder

S. No.	Grinding methods	Moisture content	Oleoresin content, %		
			R_1	R_2	R_3
1	Pulverizer (hammer type)	7.2	10.056	9.021	9.806
		9.1	11.517	12.359	11.215
		11.2	11.362	11.657	13.214
2	Mixer grinder	7.2	6.928	6.746	11.976
		9.1	13.095	11.888	6.002
		11.2	11.222	12.554	7.527
3	Burr grinder	7.2	9.102	10.025	8.234
		9.1	10.247	9.959	11.502
		11.2	10.482	12.564	9.943
4	Ponding machine	7.2	10.418	11.225	9.187
		9.1	10.103	9.499	11.359
		11.2	10.624	10.926	9.786
5	Mortar pestle	7.2	6.104	6.984	7.397
		9.1	8.904	7.682	7.748
		11.2	9.977	7.338	8.705

Table B.2 Essential oil of Coriander powder

S. No.	Grinding methods	Moisture content	Essential Oil content, %	
			R_1	R_2
1	Pulverizer (hammer type)	7.2	0.11	0.13
		9.1	0.10	0.116
		11.2	0.09	0.09
2	Mixer grinder	7.2	0.18	0.16
		9.1	0.19	0.21
		11.2	0.21	0.16
3	Burr grinder	7.2	0.14	0.14

		9.1	0.16	0.14
		11.2	0.11	0.15
4	Ponding machine	7.2	0.32	0.29
		9.1	0.31	0.28
		11.2	0.31	0.33
5	Mortar pestle	7.2	0.29	0.31
		9.1	0.32	0.29
		11.2	0.32	0.32

Table B.3 Total phenolic content of Coriander powder

S. No.	**Grinding methods**	**Moisture content**	**Total Phenolic content, mg GE/g seed extract**	
			R_1	**R_2**
1	Pulverizer (hammer type)	7.2	27.869	29.525
		9.1	25.561	24.869
		11.2	19.984	18.842
2	Mixer grinder	7.2	25.745	26.937
		9.1	25.934	23.953
		11.2	21.897	21.622
3	Burr grinder	7.2	28.618	30.207
		9.1	24.090	23.452
		11.2	18.025	21.247
4	Ponding machine	7.2	33.226	34.092
		9.1	29.147	28.675
		11.2	27.266	28.320
5	Mortar pestle	7.2	34.630	32.801
		9.1	28.140	29.346
		11.2	25.295	23.699

Table B.4 Flavonoid content of Coriander powder

S. No.	Grinding methods	Moisture content	Flavonoid content, mg QE/g seed extract	
			R_1	R_2
1	Pulverizer (hammer type)	7.2	1.849	1.948
		9.1	1.697	1.875
		11.2	1.762	1.586
2	Mixer grinder	7.2	2.349	2.572
		9.1	2.301	2.395
		11.2	2.340	2.132
3	Burr grinder	7.2	2.726	2.869
		9.1	2.659	2.487
		11.2	2.343	2.579
4	Chilli ponding machine	7.2	3.697	3.471
		9.1	3.545	3.397
		11.2	3.273	3.445
5	Mortar pestle	7.2	3.249	3.493
		9.1	3.191	3.304
		11.2	3.201	3.092

APPENDIX- C

Table C.1 Specific energy consumption during grinding

S. No.	Grinding methods	Moisture content	Specific energy consumption, Wh/kg	
			R_1	**R_2**
1	Pulverizer (hammer type)	7.2	320.26	323.71
		9.1	499.63	496.94
		11.2	417.76	620.29
2	Mixer grinder	7.2	89.76	86.52
		9.1	109.39	106.48
		11.2	110.36	114.56
3	Burr grinder	7.2	359.78	353.89
		9.1	506.04	508.68
		11.2	718.63	725.64
4	Pounding machine	7.2	175.79	163.33
		9.1	293.49	309.63
		11.2	369.20	380.68

Table C.2 Particle size distribution of Coriander powder

S. No.	Grinding methods	Moisture content	Particle size, mm	
			R_1	**R_2**
1	Pulverizer (hammer type)	7.2	0.386	0.568
		9.1	0.442	0.514
		11.2	0.454	0.510
2	Mixer grinder	7.2	0.687	0.628
		9.1	0.592	0.749
		11.2	0.770	0.602
3	Burr grinder	7.2	0.519	0.544
		9.1	0.576	0.502
		11.2	0.523	0.572

4	Ponding machine	7.2	0.835	0.858
		9.1	0.878	0.823
		11.2	0.794	0.930
5	Mortar pestle	7.2	0.892	0.832
		9.1	0.826	0.910
		11.2	0.891	0.863

RESUME

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