

MICROWAVE AND INFRARED ASSISTED DEHULLING OF BLACKGRAM

BY

MUTTALURI MANOJ KUMAR

THESIS

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(PROCESSING AND FOOD ENGINEERING)



2017

**DEPARTMENT OF PROCESSING AND FOOD ENGINEERING
COLLEGE OF TECHNOLOGY AND ENGINEERING
MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
UDAIPUR-313001 (RAJASTHAN)**

**MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
COLLEGE OF TECHNOLOGY AND ENGINEERING, UDAIPUR**

Dated: 28 / 12 / 2016

CERTIFICATE - I

This is to certify that Mr. MUTTALURI MANOJ KUMAR has successfully completed the comprehensive examination held on 26/05/2016 as required under the regulations for Master of Technology in Processing and Food Engineering.

Dr. P.S. CHAMPAWAT

Head

Department of Processing and Food Engineering
College of Technology and Engineering, Udaipur

**MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
COLLEGE OF TECHNOLOGY AND ENGINEERING, UDAIPUR**

Dated: 28 /12/ 2016

CERTIFICATE - II

This is to certify that this thesis entitled “**MICROWAVE AND INFRARED ASSISTED DEHULLING OF BLACKGRAM**” submitted for the degree of Master of Technology in Agricultural Engineering in the subject of Processing and Food Engineering embodies bonafide research work carried out by Mr. Muttaluri Manoj Kumar under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of the thesis was also approved by the advisory committee on 26/ 07/2016.

Dr. R.C. VERMA
Major Advisor

Dr. P.S. CHAMPAWAT
Head
Department of Processing
& Food Engg.

Dr. S. S. Rathore
DEAN
CTAE, Udaipur

**MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
COLLEGE OF TECHNOLOGY & ENGINEERING, UDAIPUR**

Dated:

CERTIFICATE – III

This is to certify that this thesis entitled “**MICROWAVE AND INFRARED ASSISTED DEHULLING OF BLACKGRAM**” submitted by Mr. MUTTALURI MANOJ KUMAR to Maharana Pratap University of Agriculture & Technology, Udaipur, in partial fulfillment of the requirements for the degree of Master of Technology in agricultural engineering in the subject of Processing and Food Engineering, was approved after recommendation by the external examiner and defended by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination on his thesis has been found satisfactory; we therefore, recommend that the thesis be approved.

(Dr. R.C. VERMA)

Major Advisor

(Dr. S.K. JAIN)

Advisor

(Dr. H.K. JAIN)

Advisor

(Dr. M.S. KHIDIYA)

DRI Nominee

(Dr. S. S. Rathore)

Dean, C.T.A.E.

(Dr. P.S.CHAMPAWAT)

HEAD

Department of P. F. E

Approved

Director Resident Instruction

MPUAT, Udaipur

**MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
COLLEGE OF TECHNOLOGY AND ENGINEERING, UDAIPUR**

Dated:

CERTIFICATE – IV

This is to certify that Mr. MUTTALURI MANOJ KUMAR student of Master of Technology in Agriculture Engineering in the subject of Processing and Food Engineering, Department of Processing and Food Engineering has made all corrections/modifications in the thesis entitled “MICROWAVE AND INFRARED ASSISTED DEHULLING OF BLACKGRAM” which were suggested by the external examiner and the advisory committee in the oral examination held on/...../2017. The final copies of the thesis duly bound and corrected were submitted on/...../2017.

(Dr. R.C. VERMA)

Major Advisor

(Dr. P.S. CHAMPAWAT)

Head

Department of P.F.E,

CTAE, Udaipur

(Dr. S. S. Rathore)

Dean,

CTAE, Udaipur

ABSTRACT

Pulses are the edible seeds of pod-bearing plants belonging to the family of leguminosae and are widely grown throughout the world. They are known to be the reserves of nutrients providing energy, dietary fibre, protein, minerals and vitamins required for human health. Black gram (*Vigna mungo L*) or urad is one of the important pulses containing 24% protein, 59.6% carbohydrate and 1.4% fat.

Conversion of pulses into dhal is the third largest food processing industry in the country after rice and wheat milling industries. Majority of pulse milling is done at domestic, cottage and small to medium-scale industries. Losses during milling at domestic and cottage levels are high about 10-15%

According to estimate made by different scientists, the post-harvest losses in pulses were in the range of 25-30%. As per estimated of 15 million tonnes of pulse production, 11.25 million tonnes goes for milling, taking 15% losses into account, 1.69 million tonnes of produce is lost in milling alone, which can be saved by adopting improved pre-treatment milling methods and machineries.

Infrared treatment reduces cooking time of legumes by providing a more open microstructure that improves water absorption characteristics, provides softer texture, improves dehulling characteristics, increases degree of starch gelatinization, decreases protein solubility and reduces anti nutritional factors of legumes. Microwave heating technology has been used in pulse processing to reduce post-harvest losses during drying, milling, cooking and storage. By drying with microwave heating technology, a significant reduction of drying time with improved quality of the produce is obtained.

The present work was undertaken with an overall objective to study the effect of microwave and infrared application, *viz.*, energy input (power level), exposure and dosage, on the dehulling of black gram as well as its effect on the quality, *viz.*, colour and cooking time of dehulled pulses.

The dehulling time of the black gram samples decreased with increasing time and microwave power. It decreased from 29 to 22 s, 24 to 19 s and 22 to 17 s at 540, 720 and 900 W. A maximum dehulling yield observed was 85% at 900 W power levels at an exposure time of 5 minutes. The maximum dhal yield of 82% was observed at a microwave power level of 900 W at an exposure time of 5 minutes. The maximum dehulling loss observed was 11.50% at a microwave power level of 540 W for an exposure time of 5 minutes. It was observed that a minimum cooking time of 8.5 minutes was obtained at microwave power of 900 W and an exposure time of 9 minutes.

Increase of infrared treatment, the dehulling time of the black gram samples decreased with increasing exposure time and IR power. It decreased from 36 to 26s, 32 to 20 s and 26 to 19 s at 540, 720 and 900W respectively. Dehulling yield increased in the range of 79% to 86% for 540, 700 and 900 W respectively. The maximum dhal yield of 82% was observed at an IR power level of 720 W at an exposure time of 7 minutes. The losses range from a minimum of 4.5% to 9.50%. The maximum dehulling loss was observed was 9.50% at a IR power level of 720 W. cooking time was very high at IR power level of 540 W for an exposure time of 5 minutes which was 19.70 minutes

The colour values ranged from 51.25 to 41.36 for microwave treatment and 62.23 to 44.41 in the infrared treatment. The optimization step was performed in order to determine the right combination of treatment process variables in order to improve the dehulling of black gram.

Keywords: Microwave, infrared, dehulling, dhal yield and cooking time

CHAPTER I

INTRODUCTION

1.1 Background

Pulses are the edible seeds of pod-bearing plants belonging to the family of leguminosae and are widely grown throughout the world. They are known to be the reserves of nutrients providing energy, dietary fibre, protein, minerals and vitamins required for human health. Several research studies suggest that consumption of pulses have several potential health benefits including reduced risk of cardiovascular disease, cancer, diabetes, osteoporosis, hyper tension, gastro intestinal disorders, adrenal disease and reduction of LDL cholesterol (Hu, 2003; Jacobs & Gallaher, 2004; Pihlanto & Korhonen, 2000; Thranathan & Mahadevamma, 2003). They constitute an important source of dietary protein for a larger segment of the world population, particularly in those countries where consumption of animal protein is limited by non-availability or by self-imposed reasons such as religious and cultural habits (Liener, 1962). Hence pulses are also referred to as “poor man’s meal”.

India ranks first in pulse production by contributing about 27% to the global pulse production and about 30 percent of the total consumption in the world of 72 million tonnes (Food & Agril. Organization Statistics, 2014). However, the per capita availability of pulses is only around 32g as against the recommendation of 65 g per day by Indian Council of Medical Research (Reddy, 2013). This gap could be reduced through post-harvest losses reduction and improving the productivity of pulse milling industries. Moreover, in India, about 80% of the pulses produced are consumed in the form of dehulled splits (*dhal*) or powder which entails the need for pulse milling (Mangaraj and Kapur, 2005).

Black gram (*Vigna mungo L*) or urad is one of the important pulses containing 24% protein, 59.6% carbohydrate and 1.4% fat (Gopalan *et al.*, 1989). India is the largest producer and consumer of black gram which accounts for more than 40 % of total legume seeds traded in the world (CRN India, 2011). It was grown in about 31.92 lakh ha area to produce about 1.83 million tonnes in 2011-2012 (Reddy, 2013).

Black gram dhal is a common dish in South Asia. Pulses are reported to contain anti nutrients in seed coat. Also, the seed coat is hard and imparts a bitter taste, reducing the palatability of the pulses. In order to remove the anti-nutrients and improve the

palatability, it is common practice to dehull the pulses before using. Dehulling is a process of removal of hull from the cotyledon of pulses. It reduces the fibre content and improves appearance, texture, cooking quality, palatability and digestibility of grain legume (Tiwari *et al.*, 2007). Dehulling of black gram has been a difficult operation due to the presence of vitreous layer of gums and mucilages, which makes bond between hull and cotyledon stronger. Pulse dehulling constitutes two major steps, *viz.*, loosening of the hull followed by its removal in suitable milling machine (Narasimha *et al.*, 2003).

Pulses may be classified as easy-to-dehull and hard-to-dehull based on the ease of seed coat removal. Black gram belongs to the hard-to-dehull group because of the presence of layers of mucilage and gum forming a strong bond between the hulls and the cotyledons (Kurien, 1984). Hence, they are usually pre-treated to loosen the hulls before they can be separated by mechanical means to increase the recovery of dhal (Sahay *et al.*, 1985; Mangaraj *et al.*, 2004). The pre-treatment is generally designed to toughen the hull, weaken the bond between the hull and the cotyledon and harden the cotyledon in order to reduce the damage.

1.2 Statement of the problem

Conversion of pulses into dhal is the third largest food processing industry in the country after rice and wheat milling industries. Removal of seed coat (husk) reduces roughage and anti-nutritional elements presents in seed coat, improves nutritional values and palatability for consumption of pulses in various form. It also improves cooking quality and digestibility.

Majority of pulse milling is done at domestic, cottage and small to medium-scale industries. Losses during milling at domestic and cottage levels are high about 10-15% (Lal and Verma, 2007). About 10-25% of pulses are converted into dhal at the domestic level and the rest are sold in the market at low price for conversion into dhal by organized pulse milling industries. The extent of losses that takes place at different stages of post-harvest chain differs from grain to grain.

According to estimate made by different scientists, the post-harvest losses in pulses were in the range of 25-30% (Lal and Verma, 2007). The major losses are caused at the stages of drying, milling and storage. As per estimated from 15 million tonnes of pulse production, 75% *i.e.*, 11.25 million tonnes goes for milling, taking 15% losses into account, 1.69 million tonnes of produce is lost in milling alone, which can be saved by

adopting improved pre-treatment milling methods and machineries (Dhronachari & Yadav, 2015).

Black gram is traditionally pre-treated by the dry method which involves pitting and oiling the pulses followed by conditioning by sun drying for 2 to 3 days and tempering by adding water (2-5%) and heaping overnight before dehulling. The process is labour intensive, time consuming and needs a fair amount of edible oil for processing. In addition, losses in the form of powder and broken seeds lead to less milling yields, which varies from 65% to 70% in Indian pulse mills depending upon the variety, climatic conditions and milling machinery used (Tiwari *et al.*, 2011). This is far less than the theoretical yield of 87.5% for black gram and results in less productivity and less availability of dehulled pulse to meet the market demand and consequently, the protein requirements of the people (Kurien, 1980). Moreover, dehulling of black gram needs oil application. To save the non-renewable energy and maximize the productivity, increased efforts are essential to develop an alternative method of pretreatment which could increase the yield of dehulled kernels and eliminate the edible oil application.

Several methods were developed and proposed to replace the oil pretreatment method including chemical pretreatment, enzyme pretreatment, soaking pretreatment etc. to name a few. But these methods haven't achieved commercial success due to several drawbacks such as low yield, nutritional inferiority, non-viability of the technique, increased cooking time, batch mode of operation as well as scale-up limitation (Tiwari *et al.*, 2008; Srivastava *et al.*, 1988; Singh, 1995).

1.3 Justification

Pulses are well known for their nutritional and functional value (Gowen *et al.*, 2008). They are a rich source of essential amino acids, such as lysine, and contain health-promoting phytochemicals (Berrios *et al.*, 1999). Black gram (*Vignamungo. L*) occupies a predominant position among pulses of the Asian subcontinent with strong nutritional compositions.

Generally dehulling of pulses are carried in industries by traditional methods like wet and dry milling methods and can gain 65 to 75 % efficiency only. Based on the research studies it is known that we can recover up to 87 to 89 % dhal from pulses. Dehulling of pulses becomes difficult due to presence of vitreous layer of gums which

provides bondage between hull and cotyledon. This bondage needs to be breached during milling and this is a time consuming with the traditional methods.

It has been reported by several researchers that heat treatment significantly improves the protein quality in pulses by destruction or inactivation of the heat labile anti-nutritional factors. Soaking the grains in water before treating and milling will condition the grains as well as loosens the hull. It helps in dehusking and splitting of kernels during milling. Even toxins of some pulses can be removed by soaking in hot water. Therefore, it may be useful to apply treatments for loosening the hulls by hydrothermal means. The traditional thermal processing takes longer and exhibit all associated risk.

Several researchers reported some advantages of infrared treatment in legumes. Infrared treatment reduces cooking time of legumes by providing a more open microstructure that improves water absorption characteristics, provides softer texture, improves dehulling characteristics, increases starch gelatinization degree, decreases protein solubility and reduces anti nutritional factors of legumes (Fasina *et al.*, 2001).

Microwave heating technology has also been reported in pulse processing to reduce post-harvest losses during drying, milling, cooking and storage. By drying with microwave heating technology, a significant reduction in drying time with improved quality of the produce is obtained. Pre-milling treatment of microwave heating in milling of pulses reduces milling time and increases the milling efficiency compared to all traditional methods. Microwave cooking, although not convenient for mass cooking, is very convenient for cooking small quantities, especially in households helps in reducing energy consumption with retention of nutrients. Microwave disinfestations are non-chemical technique used in storage to heat the insects to a lethal temperature because they have high moisture content while leaving the drier food stuff unaffected or slightly warm. Several studies are focused on the uses of microwave energy for processing of pulse steps.

Heating by microwave and infrared would disrupt the bondage between the hull and cotyledon of pulses by denaturing the protein and gums present between them. The information on the rate of microwave and infrared power application, dosage required to get the desired effect are essential in order to assess the suitability of the process.

Advanced and immediate heating methods like microwave and infrared as an effective pre-treatment for dehulling pulses, which is hygienic and easy to apply, with the

benefit of heat treatment can be used. Also, the thermal treatment is expected to increase the pore sizes in the pulses which in turn reduce the water penetration time as well as reduce the cooking time (processing time for use as component in food product development) of the pulses. Microwave and infrared can also provide disinfestations of the grains and improve the shelf life of the dehulled grains.

So far, no study has reported the effect of microwave and infrared treatment on the dehulling of black gram and its effect on quality parameters of the dehulled pulses. Keeping this in view, the present work was undertaken with the specific following objectives:

1. To study the effect of microwave and infrared application on the dehulling parameters of black gram.
2. To study the effect of microwave and infrared application on the quality parameters of dehulled black gram.

CHAPTER II

REVIEW OF LITERATURE

In this chapter, the importance of pulse dehulling and the need for pre-treatments before dehulling have been discussed. Further, a brief review of the various pre-treatment methods for dehulling, different dehulling machineries and factors influencing the dehulling of pulses was provided.

2.1 Importance of dehulling

Pulses are consumed as whole, dehulled splits, canned, cooked, roasted or ground into flour to make a variety of desserts, noodles, snacks and main dishes. Before cooking or other processing operations, it is often necessary to remove the fibrous seed coat (hull). The hull is mechanically removed by a process called dehulling. In addition to reducing the fibre content by removing the hull, dehulling improves the appearance, texture, quality, and palatability of the pulses and also reduces the cooking time. Dehulled seeds are easily digested and efficiently utilized by the body (Sokhansanj & Patil, 2003).

Though pulses are rich in proteins and other nutrients, certain anti nutrients are also associated with them, most of which are concentrated on the seed coats. These compounds need to be eliminated for effective utilization of the pulse nutrients, which can be effectively facilitated by dehulling.

While more than 75% of the pulses produced in India are marketed and consumed as dhal (dehulled split form). In most African countries they are dehulled at home just before consumption. Dehulling, therefore, is an important primary processing activity in India and many other pulse-consuming countries (Narasimha *et al.*, 2003). The dehulling process also yields by-products which have their own nutritional and economic value. In the context of black gram, the by-products of dehulling such as husk and *chuni* (bran) are used to prepare nutritious feed for shrimps (Yoganandhan & Hameed, 2000) and poultry (Reddy *et al.*, 2000).

2.2 Pulse dehulling pre-treatments

Pulse dehulling usually consists of two operations (a) loosening of seed coat and (b) its removal. The chemical nature of the mucilage and gums present in the interface between the husk and cotyledons of pulses play an important role in the dehulling (Ramakrishnaiah & Kurien, 1983). These mucilages and gums of pulses are networks of cellulosic micro fibrils embedded in a matrix of non starch polysaccharides (NSP) and proteins. Pre-treatments before dehulling are usually employed to disrupt these mucilages and gums and loosen the seed coats facilitating the ease of the dehulling operation.

Chakraverty, (1994) described various methods of pulse milling by traditional and modern means. He also described about the hydrothermal treatment, conditioning during pulse milling as a pre-treatment which helps in gaining the efficiencies, nutritional qualities, and milling qualities.

Traditionally two pre-treatment methods are adopted for dehulling pulses-wet method and dry method. In wet method, pulses are thoroughly mixed with a paste of red earth after soaking in water for about 12 h and heaped for about 16 h. These grains are spread as thin layer on drying yards for 2-4 days. Then dried red earth is removed by sieving. The grains are then milled on power operated stone or emery-coated vertical *chakki*. Due to several disadvantages like leaching of nutrients during soaking, dust contamination of grains etc., this method went out of use gradually.

In dry method, cleaned and graded grains are subjected to pitting to increase soaking. Then these pitted grains are mixed thoroughly with 1% oil and spread for sun drying in thin layer for 2-3 days. At the end of drying, 2.5% water is sprayed and mixed thoroughly. For tempering grains are heaped overnight. Then the grains are milled with roller machine. This method gives better yield and is commercially practised.

Apart from these pre-treatments, several other pre-treatments have also been reported in scientific literatures including tempering, soaking, and/or heating, chemical, enzyme and hydrothermal pre-treatments (Singh *et al.*, 1992; Phirke & Bhole, 1999; Deshpande *et al.*, 2007; Tiwari *et al.*, 2008b; Sreerama *et al.*, 2009). However, these methods haven't achieved commercial acceptance as only little is known about the possible changes in the general properties of the seed coats and whole seeds of beans submitted to these processes.

2.2.1 Chemical pre-treatment

Chemical pre-treatment aimed at using chemicals to disintegrate the uronic acid present in the gums and mucilages between the seed coat and cotyledons, thereby loosening the seed coat. The first attempt of chemical pre-treatment for dehulling pulses was made by Krishnamurthy *et al.*, (1972) who used *sirka* (fermented sugarcane molasses) in commercial mills. This slightly improved dehulling efficiency and split yield.

Singh & Sokhansanj (1984) used sodium bicarbonate and sodium chloride at different concentrations and steeping times. Their study revealed that maximum dehulling efficiency of around 94% and higher product recovery was obtained when pigeon pea grain was soaked for 1 h in 6% sodium bicarbonate solution, sodium chloride being less effective.

Saxena *et al.*, (1990) investigated the effects of surface application of sodium bicarbonate on pigeon pea. The results revealed that maximum dehulling efficiency of 94% was achieved when pigeon pea grain (UPAS 120) was treated with a 10% solution in a 20:1 solution to grain proportion and a treatment time of 5h followed by oven-drying to 10% moisture. This treatment reduced the gum and pectin content, increased enzyme activity, but caused losses in protein and starch content of the dhal. Phirke *et al.*, (1992) tested this treatment on other cultivars (C11, No. 148, TAT 10 and BDN 2) using a 25:1 solution to grain proportion and observed similar results.

Phirke & Bhole (1999) studied the effect of different pre-treatments, i.e. grain scarification, chemical treatment and hot milling, on the strength and dehulling properties of pigeon pea grain. The grains were scarified for 10s; pre-treated by four chemicals *viz.*, sodium bicarbonate, ammonium hydroxide, urea and acetic acid (solution to grain ratio - 25:1) followed by heat treatment of the grains up to 60°C and subsequent milling (hot milling). The results revealed that a significant ($p < 0.05$) increase in the dehulling index (upto 0.81) for the grains, with subsequent reduction in dehulling time (upto 5s), resulting in a high product recovery of about 81%, and an increased quantity of intact pearled grain of about 39%.

Rout *et al.*, (2007) conducted experiment on non-traditional pulses (tribal pulses) namely *Kandulo* and *Bailo* and treated with different pre-treatments like water soaking, oil treatment, and chemical treatment and the changes in nutritive value of protein content

and carbohydrate content both in manually dehulled and finished product (*dhal*) were assessed over untreated manually dehulled sample. Various fractions of the milled product in the form of *dhal*, husk, broken, and *gota* (unsplit) were collected separately. *Dhal* yield was more in treated sample of both the pulses. The untreated samples of *Kandulo* and *Bailo* showed that the *dhal* yield was more in *Bailo*. In the water soaking treatment, both the seed showed almost same % of yield whereas in oil treatment, the yield was more in *Kandulo*. Chemical treated sample gave better result (80.76%) in *Kandulo* and in *Bailo* samples (81.89%) followed by water soaking treatment in *Kandulo* (79.87%) and in *Bailo* (79.95%). Protein content of untreated pulse was 20.31% in *Kandulo* and 19.94% in *Bailo* samples. Protein content of manually dehulled treated samples ranged from 15.56% to 20.31%.

The maximum protein content was in untreated whole grain sample and minimum in oil treated sample. In water soaked sample, protein content was 17.43% in *Kandulo* and 17.72% in *Bailo* sample. In water soaking method, there was about 2.88% and 2.22% loss in protein content over the control sample, which may be due to the solubilisation of protein in water. Maximum protein loss was found in manually dehulled oil treated sample, i.e. 4.75% in *Kandulo* and 5.21% in *Bailo*. The protein content of finished product was maximum in untreated *Kandulo* (17.49%) and *Bailo* (17.93%) samples than other treated samples. All the pre-milling treatments before milling were found to cause significant.

Tiwari *et al.*, (2008b) studied the effect of chemical pre-treatments on the dehulling qualities of black gram and reported that sodium bicarbonate, urea, acetic acid and ethanol gave better dehulling as compared with sodium carbonate and sodium chloride. Significant difference ($p < 0.05$) was observed in pitted and unpitted gains. Application of chemicals yielded better dehulling of grains in the case of pitted grains as compared with unpitted grains. Highest yield of 59.6% dehulled grains was obtained in pitted grains treated with 5% ethanol, as compared with 49.6% in unpitted grains. Chemical treatment yielded significantly higher dehulled grains at higher concentration (5% w/v).

2.2.2 Enzyme pre-treatment

Partial hydrolysis of the non starch polysaccharides (NSP) and/or proteins by enzymatic reactions may facilitate the easy dehulling of legumes (Verma *et al.*, 1993;

Sreerama *et al.*, 2009). Enzymatic pre-treatment was first attempted by Verma *et al.*, (1993) for dehulling of pigeon pea. Enzyme derived from the species *Aspergillus fumigatus* NCIM 902 was used, and a dehulling efficiency of 88.9% was reported.

Sreerama *et al.*, (2009) investigated the influence of xylanase and protease pre-treatments on the dehulling properties of green gram, black gram, red gram and horse gram. Xylanase-mediated degradation of non-starch polysaccharides (NSP) facilitated the easy dehulling of green gram, black gram and horse gram. Xylanase pre-treatment resulted in 84.4% dehulled kernels in horse gram, whereas, 78.4% and 75.7% dehulled kernels were produced in green gram and black gram, respectively. However, protease pre-treatment was more efficient in improving the dehulling properties of green gram (83.3%) and black gram (82.8%) in addition to red gram (78.4%) with higher amount of dehulled kernels and lower amount of fines. Selective improvements in the degree of dehulling, dehulling index and dehulling efficiency was observed in enzyme treatments compared to buffer- and oil-treated controls. Also, enzyme pre-treatments did not alter the cooking properties of dehulled legumes.

It was reported that enzyme pretreatment can also improve the nutritional and functional properties of the grains. Xylanase mediated degradation of cell wall polysaccharides of horse gram, green gram and black gram resulted in expansion of the grain with improved nutritional and functional properties upon thermal treatment (Sreerama *et al.*, 2008). Further, improvement in the physical and expansion properties of pigeon pea (red gram) and horse gram was achieved by protease pre-treatment (Sreerama *et al.*, 2008).

2.2.3 Soaking pre-treatment

Soaking as a pre-treatment to dehulling facilitates easy removal of the husk or skin. Grains that are soaked in water for a short time lend themselves to easy dehulling. In this instance, the husk takes up more water than the rest of the grain, whereby it becomes more easily separable. In addition, legumes may be steeped, soaked in hot water that is below its boiling point, to allow the seed coat to swell and loosen from the cotyledon.

Anton *et al.*, (2008) studied the effect of pre-dehulling treatments using low and high temperatures (35 & 110°C) on some nutritional and physical properties of navy and pinto beans. Beans were exposed to water (14%, 28% and soaking 1:5, w/v for 6 h, and 16 h, respectively) to facilitate seed coat detachment prior to freeze drying (FD) for 48 h

or heat drying (HT) for 20 or 60 min. Exposure to the highest moisture levels produced the largest seed coat yields (17.38–20.91%) and was independent of the drying conditions. The total phenolic content was positively correlated to the 1,1-diphenyl-2-picrylhydrazyl (DPPH) antioxidant activity and increased as the exposure time to HT increased, but it was unaffected by the FD. The nutritional properties of the bean varieties differed significantly, phytic acid was unaffected, and the highest antioxidant activity was observed on the seed coats of HT pinto beans (69.24, 84.46% of DPPH discoloration). Significant physical changes were observed for the HT seeds, with the highest yellowness and the lowest peak viscosity detected in the soaked and HT (60 min) beans. Soaked and HT had given significant seed coat detachment than FD.

Kurien (1981) reported that dehulling of pigeon pea can be rendered easier by prolonged soaking in water for 12 h or more, but the dhal so obtained remains uncooked and tough even with prolonged boiling (Singh, 1995).

With regard to the effect of soaking on the nutritive value of navy beans (*Phaseolus vulgaris*), Kakade & Evans (1966) found that soaking the beans for 4 days destroyed about 28% of the trypsin-inhibitor activity and 75% of haemagglutinin activity. It appeared, therefore, that these anti nutritional factors were destroyed or inactivated or possibly leached out of the beans as a result of the soaking process. Further, in the case of trypsin inhibitor inactivation using dry heat, more positive results were found when the legumes had been previously soaked for 14 h (Gallardo *et al.*, 1974).

2.2.4 Heating / Thermal pre-treatment

Thermal pre-treatment involving soaking the grains in water or oil followed by heating by hot air was found to improve the dehulling. When moistened grains are subjected to heat, the cotyledons have a tendency to shrink more than the husk, resulting in the husk being loosened from the cotyledon (Kurien & Parpia, 1968). The effect of moisture content (6-20%) and temperature (-40°C to 40°C) on seed coat durability of field peas was studied by Ehiwe *et al.*, (1987). At all temperature levels, seed coat breakage increased linearly with decreasing moisture content. At higher temperatures the tissues between the seed coat and cotyledons begin to lose moisture and so there is an increase in brittleness caused either by an increase in crystallization or by a change in cell orientation (Dorrell, 1968). Ramakrishnaiah & Kurien (1983) also reported that when

pigeon pea seed was heat-treated by blowing hot air into the sample, the dehulling efficiency increased progressively levelling off at 100°-150°C.

Ikebudu *et al.*, (2000) investigated several conditioning treatments to promote dehulling of canola grain (*Brassica napus L.*). The tested treatment sequences were: (1) moistening, heating; (2) heating, moistening; and (3) heating. Moistening was done by spraying a predetermined quantity of water on the grain. A thin layer dryer and a fluidized bed dryer were used to heat/dry the grain. Following each treatment, the samples were dehulled in an abrasive dehuller and fractionated on an aspirator. The maximum dehulling index of 0.88 (dehulling index ranges from -1 to +1) was achieved by moistening the grain to about 15% moisture content (wet basis) for 10 min followed by heating at 70-75°C for 5 min.

Sokhansanj & Patil (2003) reported that heat treatment of soybeans at 93°C for 15 min breaks the bond between hulls and cotyledon. Higher temperature, short time and uniform heating are the factors enabling easier dehulling.

Tiwari *et al.*, (2007) studied application of oil and subsequent heating of black gram as a pre-treatment for dehulling and observed that 85.5% of dehulling was obtained at 0.8% oil and drying at a temperature of 90°C for 30 min. But drying temperatures above 50°C affected the fermentation ability of the black gram.

Grain surface scarification and dehulling at high temperature after heat treatment at elevated temperatures improved the dehulling quality of pigeon pea grain (Kurien, 1981; Phirke *et al.*, 1994, and 1996). Thus it can be inferred that heating can improve the dehulling qualities of pulses. However, temperature and duration of heating must be carefully determined, as prolonged heating at high temperatures may adversely affect the sensorial and functional properties of dhal in addition to facilitating husk removal. Heating can be effective in destroying toxic factors present in legumes (Khamgaonkar *et al.*, 2013). The nutritive value and protein digestibility of raw seeds of pulses are poor and hence they have to be subjected to thermal treatment (Liener, 1962). Most anti-nutritional or toxic factors in pulses such as trypsin inhibitors, haemagglutinins, goiterogenic agents, cyanogenicglucosides, alkaloids, and saponins can also be partially or wholly eliminated by the proper application of heat (Liener, 1962). A study of toxic factors in Chilean legumes (*P.vulgaris*, *Viciafaba*, *Pisumsativum*, *L. esculenta*, and *C. arietinum*) indicated that humid heat treatments over 100°C eliminated trypsin-inhibitor and

haemagglutinating activities (Gallardo et al., 1974). Partial inactivation was found when dry heat was used.

2.2.5 Microwave & Infrared heating as pre-treatment

Chua & Chou (2005) conducted a systematic experimental study of both intermittent microwave (MW) and infrared (IR) drying to compare the efficacy of the two methods when batch drying did namely on potato and carrot. The controllable parameters examined in this study were MW power and IR intensity level, MW and IR intermittencies and the transition period from convective to MW drying. A comparison of the drying kinetics showed intermittent MW drying to be an effective method for shortening the drying time that was required to reach certain moisture content when it was compared with intermittent IR drying and convective-MW drying. A comparison of the colour degradation of the product showed that step variation of the IR intensity during intermittent drying reduced the colour change of the product less than constant radiate intermittent IR drying.

Dronachari and Yadav, (2015) reviewed the application of microwave heat treatment in processing of pulses. They proposed that substantial amount of avoidable loss take place at all stages of milling. Losses vary from 15-20% depending upon the type and quality of grain milled, the process and machinery used for milling. For easy milling and to improve milling efficiency, pre-treatment of pulses is required. In traditional pulse processing unit where pulse pre-treatment is a big problem as modern pre-treatment like microwave treatment leading to higher product recovery will help the pulse processing industry and the farmers as well. Heat pre-treatment of pulses improves dehulling time and dehulling efficiency as well as increased product recovery which are free from infestations during handling with improved dehulled dhal quality and quantity.

Fasina *et al.*, (2001) conducted an experiment on five legume seeds (kidney beans, green peas, black beans, lentil and pinto beans). They were heated by infrared to a surface temperature of 140 °C. The changes in chemical composition, physical, mechanical and functional properties of the processed seeds were measured and compared to those of the raw seeds. Significant changes in the properties of the seeds in terms of increased volume, lower rupture point and toughness, higher water uptake and higher leaching losses (when the seeds were soaked in water) were obtained. The changes in the physical and

mechanical properties were attributed to possible cracking of the seed. Even though trypsin inhibitor activity was reduced, infrared heating did not significantly affect the starch and protein components of the seeds. The functional characteristics of flour from the infrared-heated seeds were superior to those of flour from untreated seeds.

Oomah *et al.*, (2014) conducted an experiment on the effect of microwave and infrared on dehulling characteristics and bioactive contents of beans. This study therefore evaluated microwave and micronization heat treatments in improving the dehulling characteristics, phenolic composition and antioxidant and α -amylase activities of bean cultivars from three market classes. Heat treatments improved dehulling characteristics (hull yield and reduced abrasive hardness index) depending on bean cultivar, whereas treatment effects increased with dehulling time. Heat treatment had variable effects on the phenolic composition of bean hulls obtained by abrasive dehulling without significantly altering the antioxidant activity of black and pinto bean hulls. Principal component analysis on 22 constituents analyzed in this study demonstrated the differences in dehulling characteristics and phenolic components of beans and hulls as major factors in segregating the beneficial heat treatment effects.

Purohit *et al.*, (2013) studied the use of microwave energy for reducing cooking time of dehulled mung beans. Mung beans having initial moisture contents (m.c.) of 10%, 12%, 14%, 16%, and 18% (wet basis) were exposed to 400, 600, and 800 W power levels for 14, 28, and 56 s exposure time in a pilot-scale industrial microwave drier operating at 2450 MHz frequency. Exposure to microwave energy significantly reduced the cooking time of mung beans with untreated 10% m.c. mung beans having the highest (11.8 min) and 12% m.c. mung bean treated at 600 W for 56 s having the lowest (4.8 min). Due to exposure to microwave energy, dhal yield increased and dehulling time decreased. A decrease in particle density of microwave-treated mung beans demonstrated structural changes in mung bean due to exposure to microwave energy. Crude protein content and colour of dehulled mung bean were not affected by microwave treatment.

[Singh](#) *et al.*, (2012) conducted an experiment on disinfestation of pulses and also studied the effect of optimized microwave exposure time on viability, germination, cooking and milling characteristics of chickpea, pigeon pea and green gram. The seed viability and germination of chickpea, pigeon pea and green gram was affected by microwave exposure time and power level. It was observed that as the power level is decreasing the germination and viability of all the pulses are increasing. The effect of

optimized microwave exposure time on dal recovery and cooking time characteristics of chickpea, pigeon pea and green gram were examined. The dal recovery varied between 76.2 and 71.4 % for chickpea, 69.0 and 73.7 % for pigeon pea and 72.8 and 76.7 % for green gram. However, the cooking time varied between 33.1 and 42.6 min for chickpea, 18.3 and 22.3 min for pigeon pea and 13.3 and 15.2 min for green gram. In all the cases, the power level of microwave exposure affected a little extent on dal recovery and cooking time. The power level of microwave exposure on dal recovery and cooking time differ non-significantly at 5 % level.

Tiwari *et al.*, (2007) conducted experiments on application of oil and subsequent heating of black gram as a premilling treatment. In this investigation, effect of different concentrations of oil viz. 0.0, 0.2, 0.4, 0.6, 0.8 and 1.0% and different drying temperatures of 40, 50, 60, 70 and 90 °C on the removal of husk was studied. It was observed that 85.25% and 85.5% of dehulling were obtained at 0.4% and 0.8% oil and at drying temperature of 90 °C, respectively, and the powdering loss was 7.15% and 6.98%, respectively.

Vadivambal *et al.*, (2007) used a pilot-scale industrial microwave system operating at 2.45 GHz to determine the mortality, milling and baking of wheat samples. Three common species of stored-grain insects namely *Tribolium castaneum*, *Cryptolestes ferrugineus*, and *Sitophilus granaries* in wheat grains were taken to determine mortality. Wheat samples (50 g each) at 14%, 16%, and 18% moisture content (wet basis) were infested with 5, 10, or 15 insects. The infested samples were then exposed to microwave energy at four different power levels 250, 300, 400, and 500 W for two exposure times of 28 and 56 s. Mortality of insects increased with either power or exposure time or both. Germination of wheat kernels was lower after treatment with microwave energy. Milling and baking tests were done for the samples at which 100% mortality was obtained. There was no significant difference in the quality of grain protein, flour protein, flour yield, flour ash, and loaf volume of wheat treated with microwave energy.

Joyner & Yadav (2013) studied the application of microwave exposure on the dehulling characteristics of the black gram and the properties of the dehulled grains. Black gram was exposed to 3 microwave power levels, viz., 450, 630 and 810 W for 7 different exposure, ranging from 60 to 150 s at an interval of 15 s with a view to determine the suitable combination of dosage in order to get the maximum yield with little change in colour. Related changes in properties were also studied. It was observed

that the surface temperature of the grain increased from 58 to 123 °C with the increase in microwave power level as well as exposure time from 60 to 150 s while the dehulling time reduced from 445 to 170 s. The dehulling yield increased with increasing microwave dosage in the beginning and reached to the maximum value followed by decreasing trend beyond 1000W. The colour of the dehulled grain changed slowly up to a microwave dosage of 972 J/g after that it changed vividly darker than the control. The highest yield of 73.7 % was achieved at about 972 J/g with a little change in colour (CIELAB ΔE^* value of 2.58). The corresponding dehulling time, cooking time and losses during dehulling were respectively 185 s, 10 min and 15.1 % as compared to 492 s, 20 min and 31.5 % for control respectively. It is concluded that a dosage of about 972 J/g was the best for the black gram dehulling at a rate of 630 W or higher power level.

2.3 Pulse dehulling

Pulse dehulling, as has already been indicated, usually consists of two operations (a) loosening of husk and (b) its removal. Loosening of the seed coat is facilitated by different pre-treatment methods discussed in earlier sections. The loosened seed coats of the pre-treated pulses are removed in the subsequent operation of dehulling. Dehulling of pulses is done at both home-scale and industrial levels.

In home-scale operation, simple equipment such as pestle and mortar or hand-driven disk mills (popularly known in India as *chakki*) is used. The pulses are pounded using the pestle and mortar or the *chakki* after drying the grains in the sun or after mixing with a small amount of water. The husk is then winnowed off to obtain clean cotyledons (Kurien, 1984).

Industrial level dehulling operation involves much more sophisticated equipments such as power operated grinders and aspirators. Although all dehulling systems operate on the same basic principle of friction between the seed and a surface or another seed, a variety of horizontal and vertical shaft configurations exist.

Industrial dehulling systems include attrition-type dehullers and abrasive-type dehullers. In attrition-type dehuller, grains are passed through a cylindrical head where a drum rubs the grains against a cylindrical metal screen (DeMan *et al.*, 1973; Reichert & Youngs, 1976). This enables removal of seed coat. Attrition-type dehullers are particularly suitable for pulses with loose seed coats (Kurien, 1984).

Abrasive type dehullers are used for dehulling of pulses especially for those with more tightly adhering seed coats (Kurien & Parpia, 1968; Kurien, 1984) this type of dehuller uses a carborundum or emery surface to gradually abrade the seed coat from the cotyledon (Reichert *et al.*, 1984). In a continuous operation, grains are fed into the machine through a hopper located at one end and after the action of the stones, are released through an overflow outlet (Reichert & Youngs, 1976).

Other designs of dehulling systems include a Pulse Processing Laboratory from the Central Institute of Agricultural Engineering, Bhopal, India (Sahay & Bisht, 1988), a Schule design, used by European manufacturers, and a minimill dehuller from the Central Food Technological Research Institute, (CFTRI) in Mysore, India (Sokhansanj & Patil, 2003).

Hiregoudar *et al.*, (2014) studied about the *dhal* recovery from three popular varieties of North Karnataka using CFTRI mini *dhal* mill at three different levels. The selected pigeonpea varieties viz., *Maruti*, *Gulyal* and *Arhar* were subjected to different pre-treatments before milling in CFTRI mini *dhal* mill. The pre-treatments viz., water treatment, mustard oil treatment, acetic acid treatment, sodium bicarbonate treatment, PGPR treatment and control were considered to study the effect and quality of *dhal* recovery on milling. Among the varieties, with water spray treatment significantly higher hulling efficiency was recorded in *Maruti* which was at par with *Gulyal*. The finished product recovery was high in *Maruti* which was at par with *Gulyal* and superior to *Asha*. Among the three varieties the hulling efficiency (65.3%) was recorded more at Level I. However, Level II and Level III were at par with each other and higher than the control. It was observed that *Gulyal* variety treated with mustard oil recorded maximum hulling efficiency (79.4%) and finished product (68.8%) when compared to a *Maruti* and *Asha* variety. However, acetic acid treatment recorded higher hulling efficiency (76.5%) for *Maruti* followed by *Asha* (56.9%). The plant growth promoting rhizobacteria (PGPR) treatment yielded minimum hulling efficiency and finished product recovery for all the varieties. Variations in milling responses obtained with the three varieties were possibly the result of varying extent of loosening of husk from the cotyledons after pre-milling treatments reducing the influence of gums.

Realising the importance of dehulling of pulses and to conduct multivariate studies on pulse dehulling the industrial dehuller designs have been simulated for laboratory use. One of the most widely used abrasive-type dehullers for research studies

is the tangential abrasive dehulling device (TADD), which was developed in the Prairie Regional Laboratory (PRL) of the National Research Council of Canada in Saskatoon (Sokhansanj & Patil, 2003). It has been reported that the average results from the TADD are comparable to those of commercial dhal mills in India (Singh, 1995). Another commonly used mill for laboratory analysis of dehulling is the Satake testing mill. Wang (2005) reported that a laboratory was suitable for dehulling lentils with good reproducibility. This testing mill works with an abrasive stone rotating at variable speeds. The stone, which is surrounded by a screen, crushes the lentils causing the hulls to break and the seeds to split. This mill has been used for red lentils (Wang, 2008), pigeon peas (Goyal *et al.*, 2008; Goyal *et al.*, 2009), black gram (Tiwari *et al.*, 2008b) and field peas (Black *et al.*, 1998).

Other types of dehullers used for laboratory analyses are Barley pearlers (Singh *et al.*, 1992), the AGT mill (Iyer *et al.*, 1998), the SK Engineering mill (Wood *et al.*, 2008) and the CIAE mill (Mangaraj & Singh, 2009).

2.4 Factors affecting dehulling of pulses

Although the efficiency of dehulling will depend largely on the method and milling machinery used, several factors such as environment, physical and chemical seed characteristics and pre-treatments influence the dehulling process in pulses (Wang, 2005).

2.4.1 Genetics and Environment of pulses

The environment and genotype of pulses also have considerable effect on the dehulling characteristics. Ehiwe *et al.*, (1986) reported that variations in field pea seed characteristics are controlled by both hereditary and environmental conditions, the most important environmental factors being temperature at seed maturation and moisture content during maturation and harvest. When studying seed coat breakage in field pea, Reichert and Ehiwe (1987) reported significant differences due to both cultivar and environment. They found that hot or dry fall conditions in the Canadian prairies produced peas with reduced seed coat durability. Thomson (1979) also had reported similar results. Siddique & Goodwin (1980) found that high temperature during seed maturation increased susceptibility to mechanical damage in snap bean seeds, the reason being attributed to high temperature leading to rapid desiccation of pods and seeds. Therefore, such conditions may in turn lead to favourable milling qualities in pulses. However, if the

seed is brittle which is caused by low temperature, it may produce more fines during dehulling (Ehiwe *et al.*, 1987).

In a study on common bean seed, Stanley (1992) explained that storage of seed at high temperate and humidity leads to seed coat hardening. Studies by Erskine *et al.*, (1985) and Williams & Singh (1998) revealed that dehulling efficiency of pulses is a varietal characteristic which may be strongly influenced by growing season and location. Later research by Erskine *et al.*, (1991) contradicted this result. When they compared dehulling efficiencies of lentil grown at three locations in Lebanon and Syria, they found location to be of only minor importance and variations in genotype to be of greater importance. Black *et al.*, (1998) supported these findings when studying field pea. Their research noted large variability in dehulling quality when 23 genotypes were compared.

2.4.2 Chemical composition of the seed coat

The seed coat is structurally important for the protection of the cotyledons and embryo axis from damage caused by insects, weathering, harvest and handling (McEwen *et al.*, 1974). The seed coat of pulses may range in colour from black and solid grey to brown, tan or green, and may also exhibit a variety of patterns due to Vandenberg & Slinkard, 1990), their genetic and phenotypic variability (Kannenberg & Allard (1964) reported that white-seeded Lima beans (*Phaseolus lunatus* L.) to be agronomically inferior to coloured-seeded varieties. They also observed that white seed had thinner seed coats with broader and shorter cells in the palisade layer, resulting in fewer cells per unit area as well as a tendency to exchange moisture more rapidly and to sustain physical damage more easily. Seed coat strength may also be affected by its fibre content.

Kannenberg & Allard (1964) found that for lima bean, lignin comprised 15% of the total seed coat weight of coloured seed but only 1% in white seed. Because of the importance of lignin as a structural and protective component of the seed coat, they further postulated that the lack, or reduced level, of lignin in white seeds leads both directly and indirectly to increased susceptibility to seed damage. To support the notion that lignin may be an important factor related to seed coat durability, Dorrell (1968) also reported an inverse relationship between seed coat breakage and crude fibre content. However, work done by Reichert & Ehiwe (1987) on seed coat durability in field pea refutes the importance of lignin for resistance to damage. In fact, they found no

significant relationship between seed coat breakage and lignin, neutral detergent fibre or hemicellulose content.

Bate-Smith (1958) reported a connection between phenolic substances and textural quality in common bean seed. It was further observed that lignin was not the only material responsible for the incrustation and toughening of plant cell walls. According to this study, condensed tannins, formed by polymerized leuco anthocyanins, are found in the testa and contribute to seed coat durability. Stanley (1992) also reported the contribution of tannins to the seed coat hardening. Moise *et al.*, (2005) noted that in red clover (*Trifolium pratense L.*), medium-sized vacuoles located in the cytoplasm of the microsclereids contained tannins which contributed to coat hardening.

Other studies have shown that seed coat is aided by cell walls in the palisade layer and by hourglass cells (Algan & Buyukkartal, 2000; Wang & Grusak; 2005) Ehiwe *et al.*, (1987) suggested that seed coat durability was directly proportional to the presence of Magnesium and Calcium (Dickson *et al.*, 1973) and pectic substances (Dorrell, 1968). Thus it is observed that presence of different chemical compounds contribute to the seed coat strength which ultimately influences the dehulling of pulses.

2.4.3 Physical characteristics of seeds

Seed characteristics, including the content and structure of seed coat and size of seed have an effect on the dehulling properties of pulses. If the content of seed coat is higher, the cotyledon yield will be lower (Singh, 1995). The structure of the seed coat influences the dehulling, in that, smooth seed coats dehull more satisfactorily than those with thin, rough seed coats (Sefa-Dedeh & Stanley, 1979). Ehiwe *et al.*, (1987) considered that the major factor responsible for good dehulling quality was how loosely the seed coat is bound to the cotyledon.

The other major factor affecting dehulling of pulses is the seed size including seed diameter and thickness (Ehiwe & Reichert, 1987; Singh *et al.*, 1992). Larger-seeded lentils tend to have lower percentage loss during dehulling because the proportion of hull to seed mass is lower.

Erskine *et al.*, (1991) found significant differences in dehulling efficiency among large and small seeds of red lentil. Smaller seeds (4 mm) showed higher yield (82.0%) than larger (4-5 mm) seeds (80.1% yield). This difference in efficiency resulted from a higher level of broken seeds and split seeds with the fraction of larger seeds. They also

noted that large seeds yielded higher percentages of split seeds following milling. While studying dehulling in field pea, Black *et al.*,(1998) noted that dehulling efficiency positively correlated with seed size and negatively correlated with both seed breakage and hull content.

2.4.4 Moisture content of seeds

Moisture content is an important parameter which affects the dehulling qualities of pulses. It also determines the weight and appearance of the grain. Higher equilibrium moisture in pulse seeds lead to spoilage during storage and reduced milling values during processing. Conversely, seeds with lesser moisture content and too dry are more prone to mechanical damage and losses during handling and dehulling. Hence optimum moisture content is important in the handling, storage and dehulling of pulses. The optimal moisture content for storage of red lentil is 13% (w.b.) as recommended by Canadian Grain Commission (2006) which is responsible for establishing and maintaining Canada's grain quality standards.

Few reports on the effect of moisture content on dehulling of pulses are available. Ramakrishnaiah & Kurien (1983) studied the effect of moisture on the degree of dehusking in three selected varieties of pigeon pea (S-141-31, T-2I, and a commercial U.P. variety), for all the three varieties, as the moisture level goes down, the degree of dehusking increases until it reaches a maximum. The effect of moisture content (6-20%) on seed coat durability of field peas was studied by Ehiwe *et al.*, (1987). They reported linear increase in dehulling efficiency with decreasing moisture content. Similar trend was observed by Barriga (1961) for navy beans, Mazza & Campbell (1985) for buckwheat, Zhang *et al.*, (2008 b) for red lentil.

Wang (2005) also reported that the dehulling efficiency reduced as the moisture content of red lentil was increased from 9.0 to 17.0% (w.b.). This was attributed to the tight adhesion of the seed coat to the cotyledons at higher moisture content. On the other hand, as the moisture content increased the powder fraction decreased. The recommended maximum moisture content for maximizing dehulling efficiency (DE), as well as minimizing seed coat adherence (SCA) is 12.5% (w.b.).

Goyal *et al.* (2010) conducted a study to investigate the effect of grain moisture content on pigeon pea hull during pitting. Pitting of the grain was done at 6%, 8%, 10%, 12%, and 14% moisture contents using dhal mill developed by Central Institute of

Agricultural Engineering, Bhopal (India). Pitted grains of pigeon pea were treated with 0.28% cottonseed oil to study the effect of moisture content and pitting on dehulling efficiency, which was maximum (86.7%) at 10% moisture content.

Maximum finished product in the form of dehulled whole and & hulled splits (dhal) was also obtained at 10% moisture content.

Optimal hydration levels may differ among pulse varieties. For example, Wood *et al.*, (2008) equilibrated their desi chickpea samples to 10% equilibrium moisture prior to milling. In a study on red lentil milling, Erskine *et al.*, (1991) found that dehulling efficiency was highest with seed moisture content of approximately 8% followed by immersion in water for 1 min compared to 5, 10 and 30 min immersion times. Thus the key to productive pulse dehulling lies in understanding the relationship between seed moisture content and dehulling efficiency.

2.4.5 Machine parameters

Finally, dehulling yield is influenced by the dehulling method machinery used and the parameters involved in it including the type of mill, the speed, and the dehulling time (Wang, 2005; Reichert & Youngs, 1976). Generally, increase in dehulling time and speed of the motor used increases dehulling efficiency. But on the other hand, with increasing dehulling time, broken and powder fractions were also higher (Wang, 2005). Hence, the efficiency can be optimized in the dehulling systems by adjusting factors such as stone speed, diameter, texture and clearance, as well as the time each batch remains in the mill. Wang, (2005) recommended the optimized dehulling conditions for pigeon pea as an abrasive wheel speed of 1100 rpm, seed moisture of 12.5% and dehulling time of 38s.

2.5 Summary

Dehulling is a vital step in pulse processing. Each pre-treatment method has its own advantages and disadvantages. Some pre-treatment methods have shown quite good potential to serve as an alternative to the dry processing method. But little research has been conducted to explore the feasibility of using these processes in large scale. To the pulse milling industries the operation of pre-treatment steps in a continuous mode is of particular importance. Also, when it comes to commercial usage, the quality of end

product is of utmost importance. Hence, more research is required to scale up the pre-treatments through continuous operation while special emphasis should be placed on studying the end product quality.

CHAPTER 3

MATERIALS AND METHODS

This chapter describes the raw materials and machinery used for the study. Further, the methods used for determining the dehulling quality of black gram and the methods used for determining the quality of dehulled dhal of black gram were described.

3.1 Materials

3.1.1 Samples

Black gram of good quality was purchased from the local market. It was cleaned well to remove the extraneous matter before conducting the experiments. The moisture content of the samples was then found out before starting the experiment.

3.1.2 Microwave oven

A domestic microwave oven (Bajaj 2800 ET-B) having the operation frequency of 2,450 MHz and maximum input power of 1,300 W was used to conduct the experiment. The rated power output from the microwave oven was 900W corresponding to 100 % power level. The oven has facility to change the power levels from 10 to 100 % at an interval of 10% (Plate 3.1).



Plate 3.1 Microwave oven

3.1.3 Prototype infrared dryer

A laboratory scale infrared-convective dryer was used in present study and is shown in Plate 3.2. The dryer consisted of a drying chamber made of plywood with inner surfaces cladded with aluminium foil for enhanced reflection of infrared radiations, an air heating unit and a blower. The dryer had a provision to vary the infrared power, air temperature and air velocity within the experimental range. The detail of each of the components of dryer is furnished here under.

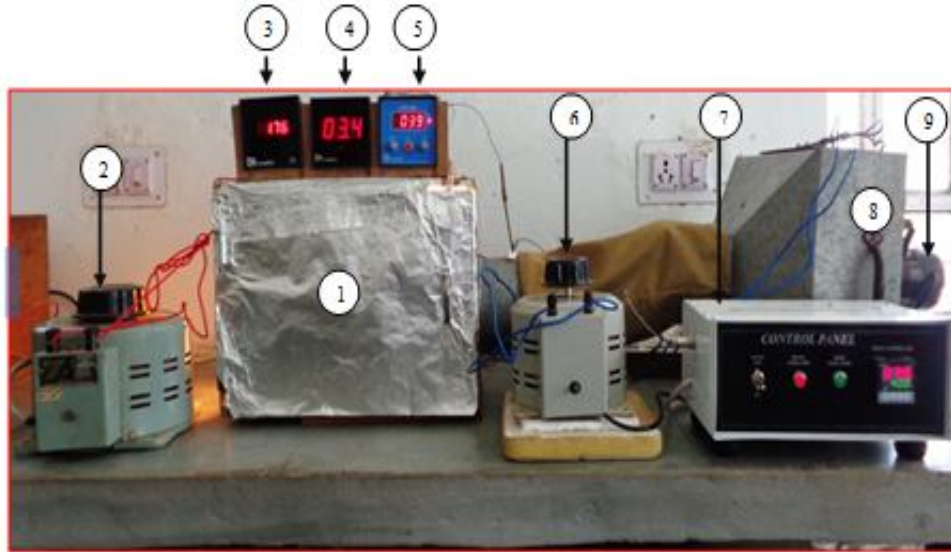


Plate 3.2 Laboratory Scale Infrared-Convective Dryer

- | | |
|----------------------------------|------------------------------|
| 1. Drying chamber | 6. Variac for air heater |
| 2. Variac for IR heater | 7. Temperature control panel |
| 3. Digital voltmeter | 8. Electric heater |
| 4. Digital ammeter | 9. Blower |
| 5. Digital temperature indicator | |

A cylindrical infrared heater of 1000 W having diameter of 18 mm and length 300 mm was installed inside at top of the drying chamber. The power supply 240V AC to the infrared heater was made through variac so as to vary the infrared power by varying voltage to heater.

The drying chamber was made of plywood sheet of thickness 8 mm. The chamber had 400 (L) × 300 (B) × 300 (H) mm internal dimensions with a single door opening at front side. Two holes were at two opposite sides of chamber, one of 150 mm diameter

and another square in shape of 150×150 mm. Both openings served the purpose of entrance and exit of air in the dryer.

3.1.4 Emery roll polisher

A small laboratory model emery roll polisher attached with a motor was used for milling the treated samples. The rpm of the roller was kept constant (Plate 3.3).

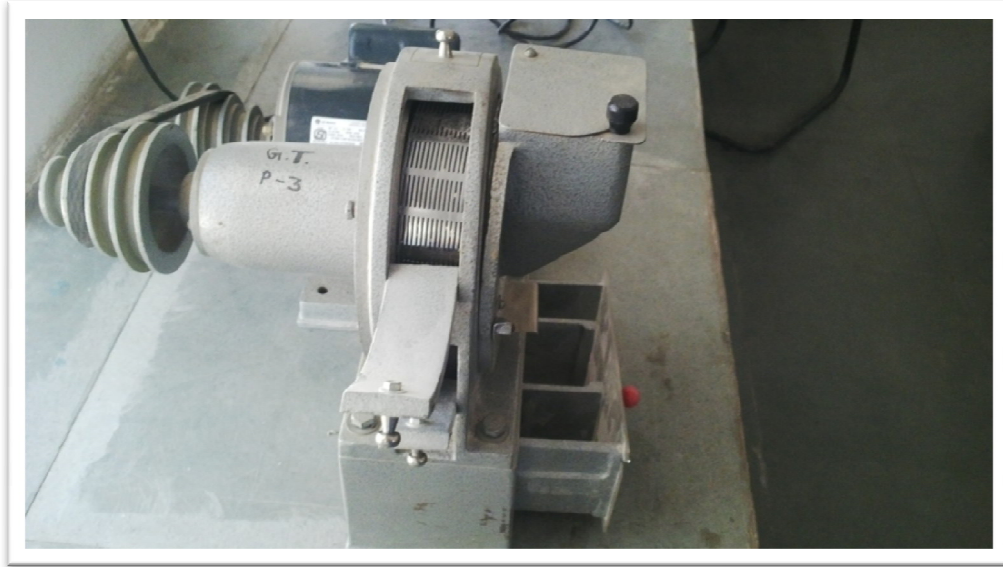


Plate 3.3 Emery roll polisher

3.1.5 Gun thermometer

A portable gun thermometer (Metravi MT-16) was used in the experiment to find out the average surface temperatures of the grains during treatment process. The thermometer has got a range to measure the temperature between -50°C to 1800°C .

FLOW CHART OF THE EXPERIMENTAL PROCESS

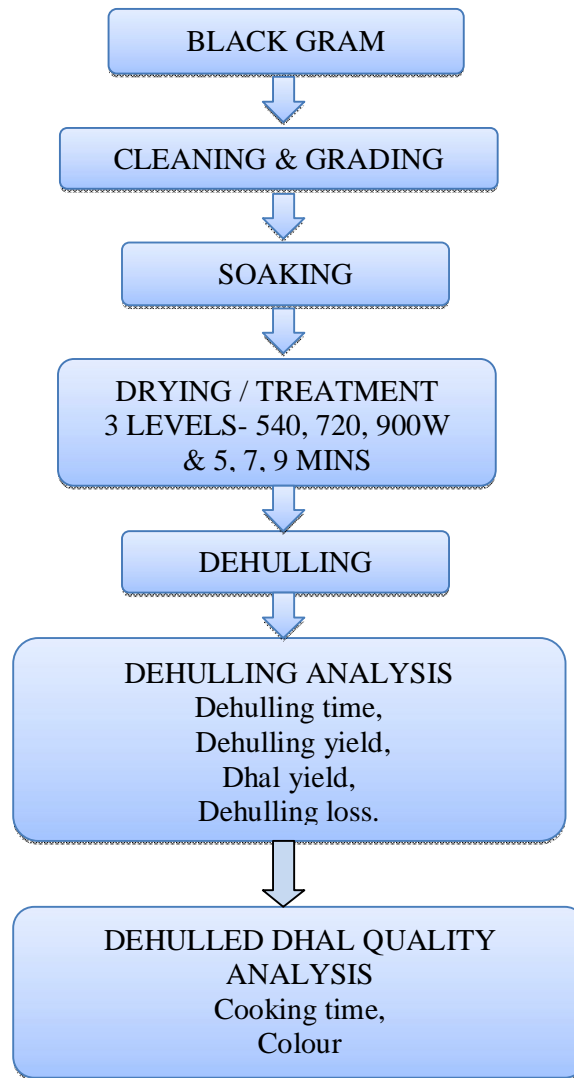


Fig 3.1: Flow chart of experiment conducted

3.2 Methodology

3.2.1 Moisture content measurement

Moisture content was measured as suggested by Henderson *et al.*, (1997). Grain sample of 5 g was taken in triplicates into weighed moisture boxes. The moisture boxes were placed in a forced convection oven and dried at 130°C for 18 h (ASAE, 2003).

3.2.2 Conditioning by soaking

A cleaned black gram of 100 g size was soaked into the beakers of 100 ml size which was filled with normal tap water. The soaking time was 3 hour, constant to each

and every sample. After 3 hour of soaking time these samples were allowed to dry in microwave oven and infrared chamber to bring down the moisture content to below 13% which is a standard milling moisture content as well as like a parallel treatment (Chakraverty 1994).

3.2.3 Microwave treatment

A sample of 100 g conditioned black gram was taken into a petry dish of 155 mm diameter and transferred on the turn table in the microwave oven. Three levels of microwave energy input, viz., 540, 720 and 900W, were applied each for 3 different exposure times ranging from 5 min to 9 min at an interval of 2 min. The depth of sample in the dryer was maintained to single grain height that was approximately 5 mm. The maximum exposure time was set through preliminary study corresponding to the beginning of the emergence of roasted smell. The microwave dosage supplying to the black gram was calculated as described by Joyner and Yadav (2013)

$$\text{Microwave dosage (J/g)} = \frac{(P_m \times ET)}{W_i} \quad \dots(3.1)$$

Where, P_m - Microwave power (W),

ET - Exposure time (s),

W_i - Initial weight of black gram (g).

3.2.4 Infrared treatment

Sample of conditioned 100 g was used for infrared treatment too. The sample was placed in a 155 mm diameter petry dish and placed in infrared drying chamber. In that prototype we had given same levels of power and exposure timings as in microwave treatment viz., 540, 720 and 900W for 5 min to 9 min. Temperature in the chamber was maintained constant at 30 degrees and air velocity at 1.2 m/s. The depth of grain layer was approximately 5 mm. The maximum exposure time was set through preliminary study corresponding to the beginning of the emergence of roasted smell. The infrared dosage supplying to the black gram is calculated as described by Joyner and Yadav (2013).

$$\text{Infrared dosage (J/g)} = \frac{(P_i \times ET)}{W_i} \quad \dots(3.2)$$

Where, P_i - Infrared power (W),

ET - Exposure time (s),

W_i - Initial weight of black gram (g).

3.2.5 Temperature measurement

The average surface temperatures of the grains were measured using gun thermometer. Samples of grain, after treatment was taken on a tray and by allowing the thermometer laser to pass through the samples gave the direct reading of the temperature, of samples on the monitor of thermometer.

3.2.6 Dehulling procedure

Dehulling of black gram was performed in the laboratory model emery roll polisher (Indosaw) (Plate 3.3). Dehulling was continued till the complete removal of husk achievement in all grains and corresponding dehulling time was noted. After dehulling, the different fractions were collected and graded as dehulled whole and split, broken, fine broken and powder. They were weighed separately and noted for further analysis. All samples were hulled in triplicates.

3.3 Plan of Work

The experiment was conducted in department laboratory with different combination of treatments and timings as described below.

3.3.1 Fixed parameters

1. Soaking time (1 hour)
2. Soaking temperature (Room temp.)
3. Air velocity (1.2 m/s)
4. Air temperature (40°C)
5. Type of polisher (Emery roll rice polisher)

3.3.2 Independent variables

1. Type of heating equipment (2 levels) : Microwave, Infrared
2. Power levels (3 levels) : 540, 720, 900 W
3. Treatment periods (3 levels in Microwave & Infrared) : 5, 7, 9 min

3.3.3 Dependent variables

1. Dehulling time
2. Dehulling loss

3. Dhal yield
4. Dehulling yield
5. Colour
6. Cooking time

3.4 Analysis of dehulling properties of black gram

The dehulling properties of black gram were assessed in terms of dehulling time, dehulling yield, dhal yield and losses as described by Goyal *et al.*, (2008).

3.4.1 Dehulling time

Dehulling time was taken as the duration of dehulling of black gram for complete removal of husk from the cotyledons, i.e., 100 % dehulling of the grains.

3.4.2 Dehulling yield

Dehulling yield was taken as the quantity of total whole dehulled kernels and broken kernels (except fine broken, powder and husk) that were produced in the dehulling of pulses. Dehulled dhal was divided into head kernels, broken and fines. Head kernels were defined as the kernels retained over the sieve no. 10 (BSS mesh). Broken were defined as cotyledon retained on sieve no. 30 and was passed through sieve no. 10 (BSS mesh). Fine were broken that passed through sieve no. 30 (BSS mesh). The dehulling yield was calculated as follows.

$$\text{Dehulling yield (\%)} = \frac{(W_k + W_b)}{W_i} \times 100 \quad \dots(3.3)$$

Where, W_k - Weight of dehulled kernel (g),

W_b - Weight of broken (g),

W_i - Initial weight of black gram (g).

3.4.3 Dhal yield

Dhal yield (from APQ Method 104.1, Burrige *et al.*, 2001) was taken as the yield of dehulled whole and split kernels (dhal) as a percentage of original seed weight. It was calculated as follows.

$$\text{Dhal yield (\%)} = \frac{(W_w)}{W_i} \times 100 \quad \dots(3.4)$$

Where, W_w - Weight of dehulled whole and split seeds (g),

W_i - Initial weight of black gram (g).

1.4.4 Dehulling loss

Dehulling loss was calculated as the weight fraction of the powder and fine broken relative to the total weight of the grain used for dehulling. It was calculated as follows.

$$\text{Loss (\%)} = \frac{(W_p + W_{fb})}{W_i} \times 100 \quad \dots(3.5)$$

Where, W_p - Weight of powder obtained (g),

W_{fb} - Weight of fine broken (g),

W_i - Initial weight of black gram (g).

3.5 Analysis of the quality of dehulled dhal

3.5.1 Colour

Colour is an important to consumer as a mean of identification, as a method of judging quality and for its basic aesthetic value and food is no exemption. The overall objective of colour to the food is to make it appealing and recognizable. A Hunter lab Colorimeter (Model: Colour Quest XE, USA) was used in present investigation as presented in Plate 3.4. Calibration of this machine was done using black and white standardizing templates. The sample was placed over the eye and the L, a and b values was monitored for each sample as the average of six readings. The variation of the L, a and b values with the ET and power levels were monitored.

The colour values obtained as 'L' is the lightness coefficient, ranging from 0 (black) to 100 (white), 'a' is purple-red (positive 'a' value) and blue-green (negative 'a' value) and 'b', that represents yellow (positive 'b' value) and blue (negative 'b' value) colour (McGuire, 1992).



Plate 3.4 Hunter lab Colorimeter



Plate 3.5 Colour scale presenting relationship of colour index (L,a,b)

3.5.2 Cooking time

A gas stove was used to maintain uniform and constant temperature during experimentation of cooking. Approximately 200 ml of tap water was taken for boiling in 250 ml beakers and 20g each of microwave treated, infrared treated and control grains (dhal) of black gram were added in separate beakers. Boiling was continued and few kernels were withdrawn for every 30s after specific time with spatula and placed between two glass slides. Then the slides were pressed against each other with no lateral movement. Cooking was considered complete when the cooked kernels had no longer opaque or uncooked centres and the time required for this was taken as the optimum cooking time (Ranghino, 1966). Slides were cleaned and dipped in water after every usage.

3.6 Statistical analysis:

Design-expert version 10.02 was used for designing of the experiment. In design expert under response surface the hybrid design was suggested according to the preliminary studies and the further research was under gone by using the hybrid design of the experiment. Further optimization of process parameters were done by using the same software (Walia, 2014).

The design tables which are suggested to follow during the experimental process, to take the right combination of treatment with their maximum possibilities are given in Table 3.1 & 3.2.

Table 3.1: Combinations of various parameters used in MW design

Standard	Run	MW power (W)	Exposure time (min)	Dehulling time (min)	Dehulling yield (%)	Dhal yield (%)	Dehulling loss (%)	Cooking time (min)
8	1	720	9	19	81	77	9	11.20
13	2	720	7	21	83	78	8	13.60
4	3	540	7	25	81	78	7.5	14.70
6	4	900	7	19	80	78	6	10.60
3	5	900	5	22	85	82	8	13.80
1	6	540	5	29	79	75	11.5	16.80
11	7	720	7	21	83	78	8	13.60
5	8	720	7	21	83	78	8	13.60
10	9	720	7	21	83	78	8	13.60
9	10	900	9	17	78	75	10	8.50
7	11	540	9	22	83	80	9	13.40
12	12	720	7	21	83	78	8	13.60
2	13	720	5	24	80	77	10	14.90

Table 3.2: Combinations of various parameters used in IR design

Standard	Run	IR power (W)	Exposure time (min)	Dehulling time (min)	Dehulling yield (%)	Dhal yield (%)	Dehulling loss (%)	Cooking time (min)
3	1	900	5	26	81	79	6.5	14.8
1	2	540	5	36	78	75	8.5	19.7
5	3	720	7	25	84	80	8	14.4
8	4	720	9	20	85	82	6	12.2
2	5	720	5	32	80	77.5	9.5	16.9
11	6	720	7	25	84	80	8	14.4
10	7	720	7	25	84	80	8	14.4
13	8	720	7	25	84	80	8	14.4
12	9	720	7	25	84	80	8	14.4
7	10	540	9	26	82	79.5	6.5	15.4
9	11	900	9	19	82	78	5.5	9.8
4	12	540	7	31	81	77	7.5	17.2
6	13	900	7	22	86	80	4.5	11.7

CHAPTER 3

MATERIALS AND METHODS

This chapter describes the raw materials and machinery used for the study. Further, the methods used for determining the dehulling quality of black gram and the methods used for determining the quality of dehulled dhal of black gram were described.

3.1 Materials

3.1.1 Samples

Black gram of good quality was purchased from the local market. It was cleaned well to remove the extraneous matter before conducting the experiments. The moisture content of the samples was then found out before starting the experiment.

3.1.2 Microwave oven

A domestic microwave oven (Bajaj 2800 ET-B) having the operation frequency of 2,450 MHz and maximum input power of 1,300 W was used to conduct the experiment. The rated power output from the microwave oven was 900W corresponding to 100 % power level. The oven has facility to change the power levels from 10 to 100 % at an interval of 10% (Plate 3.1).



Plate 3.1 Microwave oven

3.1.3 Prototype infrared dryer

A laboratory scale infrared-convective dryer was used in present study and is shown in Plate 3.2. The dryer consisted of a drying chamber made of plywood with inner surfaces cladded with aluminium foil for enhanced reflection of infrared radiations, an air heating unit and a blower. The dryer had a provision to vary the infrared power, air temperature and air velocity within the experimental range. The detail of each of the components of dryer is furnished here under.

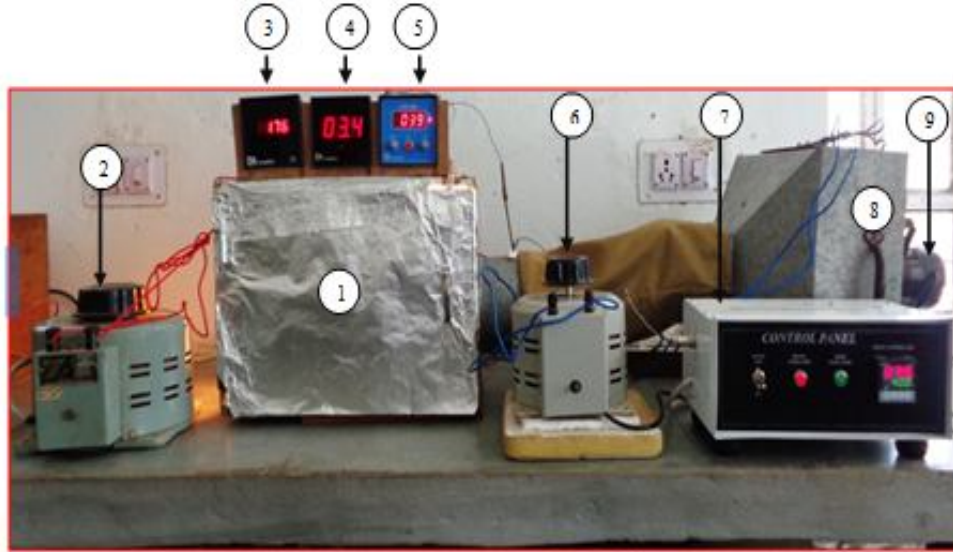


Plate 3.2 Laboratory Scale Infrared-Convective Dryer

- | | |
|-----------------------------------|-------------------------------|
| 6. Drying chamber | 10. Variac for air heater |
| 7. Variac for IR heater | 11. Temperature control panel |
| 8. Digital voltmeter | 12. Electric heater |
| 9. Digital ammeter | 13. Blower |
| 10. Digital temperature indicator | |

A cylindrical infrared heater of 1000 W having diameter of 18 mm and length 300 mm was installed inside at top of the drying chamber. The power supply 240V AC to the infrared heater was made through variac so as to vary the infrared power by varying voltage to heater.

The drying chamber was made of plywood sheet of thickness 8 mm. The chamber had 400 (L) × 300 (B) × 300 (H) mm internal dimensions with a single door opening at front side. Two holes were at two opposite sides of chamber, one of 150 mm diameter

and another square in shape of 150×150 mm. Both openings served the purpose of entrance and exit of air in the dryer.

3.1.4 Emery roll polisher

A small laboratory model emery roll polisher attached with a motor was used for milling the treated samples. The rpm of the roller was kept constant (Plate 3.3).



Plate 3.3 Emery roll polisher

3.1.5 Gun thermometer

A portable gun thermometer (Metravi MT-16) was used in the experiment to find out the average surface temperatures of the grains during treatment process. The thermometer has got a range to measure the temperature between -50°C to 1800°C .

FLOW CHART OF THE EXPERIMENTAL PROCESS

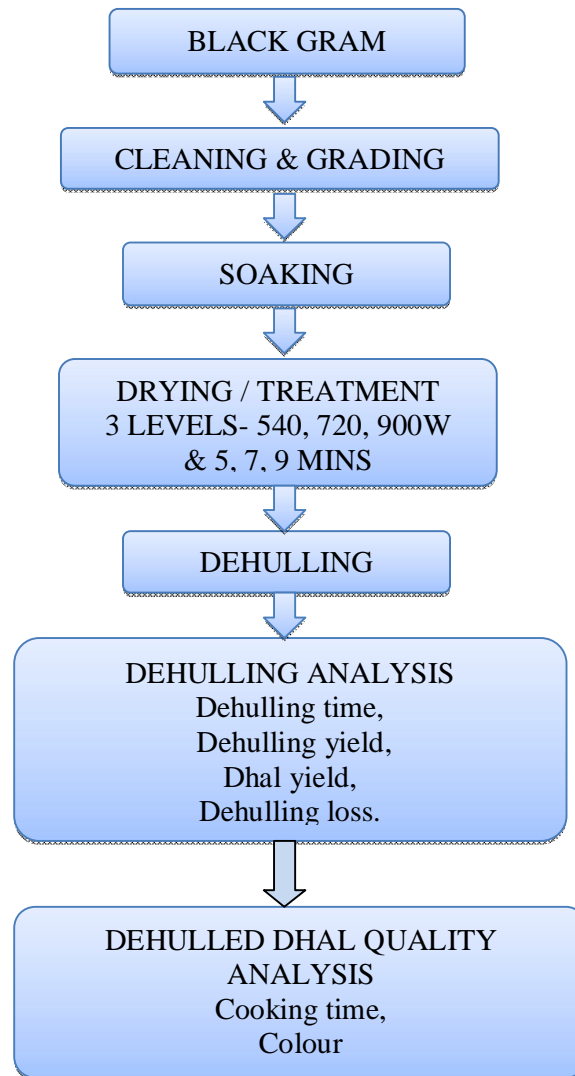


Fig 3.1: Flow chart of experiment conducted

3.2 Methodology

3.2.1 Moisture content measurement

Moisture content was measured as suggested by Henderson *et al.*, (1997). Grain sample of 5 g was taken in triplicates into weighed moisture boxes. The moisture boxes were placed in a forced convection oven and dried at 130°C for 18 h (ASAE, 2003).

3.2.2 Conditioning by soaking

A cleaned black gram of 100 g size was soaked into the beakers of 100 ml size which was filled with normal tap water. The soaking time was 3 hour, constant to each

and every sample. After 3 hour of soaking time these samples were allowed to dry in microwave oven and infrared chamber to bring down the moisture content to below 13% which is a standard milling moisture content as well as like a parallel treatment (Chakraverty 1994).

3.2.3 Microwave treatment

A sample of 100 g conditioned black gram was taken into a petry dish of 155 mm diameter and transferred on the turn table in the microwave oven. Three levels of microwave energy input, viz., 540, 720 and 900W, were applied each for 3 different exposure times ranging from 5 min to 9 min at an interval of 2 min. The depth of sample in the dryer was maintained to single grain height that was approximately 5 mm. The maximum exposure time was set through preliminary study corresponding to the beginning of the emergence of roasted smell. The microwave dosage supplying to the black gram was calculated as described by Joyner and Yadav (2013)

$$\text{Microwave dosage (J/g)} = \frac{(P_m \times ET)}{W_i} \quad \dots(3.1)$$

Where, P_m - Microwave power (W),

ET - Exposure time (s),

W_i - Initial weight of black gram (g).

3.2.4 Infrared treatment

Sample of conditioned 100 g was used for infrared treatment too. The sample was placed in a 155 mm diameter petry dish and placed in infrared drying chamber. In that prototype we had given same levels of power and exposure timings as in microwave treatment viz., 540, 720 and 900W for 5 min to 9 min. Temperature in the chamber was maintained constant at 30 degrees and air velocity at 1.2 m/s. The depth of grain layer was approximately 5 mm. The maximum exposure time was set through preliminary study corresponding to the beginning of the emergence of roasted smell. The infrared dosage supplying to the black gram is calculated as described by Joyner and Yadav (2013).

$$\text{Infrared dosage (J/g)} = \frac{(P_i \times ET)}{W_i} \quad \dots(3.2)$$

Where, P_i - Infrared power (W),

ET - Exposure time (s),

W_i - Initial weight of black gram (g).

3.2.5 Temperature measurement

The average surface temperatures of the grains were measured using gun thermometer. Samples of grain, after treatment was taken on a tray and by allowing the thermometer laser to pass through the samples gave the direct reading of the temperature, of samples on the monitor of thermometer.

3.2.6 Dehulling procedure

Dehulling of black gram was performed in the laboratory model emery roll polisher (Indosaw) (Plate 3.3). Dehulling was continued till the complete removal of husk achievement in all grains and corresponding dehulling time was noted. After dehulling, the different fractions were collected and graded as dehulled whole and split, broken, fine broken and powder. They were weighed separately and noted for further analysis. All samples were hulled in triplicates.

3.3 Plan of Work

The experiment was conducted in department laboratory with different combination of treatments and timings as described below.

3.3.1 Fixed parameters

6. Soaking time (1 hour)
7. Soaking temperature (Room temp.)
8. Air velocity (1.2 m/s)
9. Air temperature (40°C)
10. Type of polisher (Emery roll rice polisher)

3.3.2 Independent variables

4. Type of heating equipment (2 levels) : Microwave, Infrared
5. Power levels (3 levels) : 540, 720, 900 W
6. Treatment periods (3 levels in Microwave & Infrared) : 5, 7, 9 min

3.3.3 Dependent variables

7. Dehulling time
8. Dehulling loss

9. Dhal yield
10. Dehulling yield
11. Colour
12. Cooking time

3.4 Analysis of dehulling properties of black gram

The dehulling properties of black gram were assessed in terms of dehulling time, dehulling yield, dhal yield and losses as described by Goyal *et al.*, (2008).

3.4.1 Dehulling time

Dehulling time was taken as the duration of dehulling of black gram for complete removal of husk from the cotyledons, i.e., 100 % dehulling of the grains.

3.4.2 Dehulling yield

Dehulling yield was taken as the quantity of total whole dehulled kernels and broken kernels (except fine broken, powder and husk) that were produced in the dehulling of pulses. Dehulled dhal was divided into head kernels, broken and fines. Head kernels were defined as the kernels retained over the sieve no. 10 (BSS mesh). Broken were defined as cotyledon retained on sieve no. 30 and was passed through sieve no. 10 (BSS mesh). Fine were broken that passed through sieve no. 30 (BSS mesh). The dehulling yield was calculated as follows.

$$\text{Dehulling yield (\%)} = \frac{(W_k + W_b)}{W_i} \times 100 \quad \dots(3.3)$$

Where, W_k - Weight of dehulled kernel (g),

W_b - Weight of broken (g),

W_i - Initial weight of black gram (g).

3.4.3 Dhal yield

Dhal yield (from APQ Method 104.1, Burrige *et al.*, 2001) was taken as the yield of dehulled whole and split kernels (dhal) as a percentage of original seed weight. It was calculated as follows.

$$\text{Dhal yield (\%)} = \frac{(W_w)}{W_i} \times 100 \quad \dots(3.4)$$

Where, W_w - Weight of dehulled whole and split seeds (g),

W_i - Initial weight of black gram (g).

1.4.5 Dehulling loss

Dehulling loss was calculated as the weight fraction of the powder and fine broken relative to the total weight of the grain used for dehulling. It was calculated as follows.

$$\text{Loss (\%)} = \frac{(W_p + W_{fb})}{W_i} \times 100 \quad \dots(3.5)$$

Where, W_p - Weight of powder obtained (g),

W_{fb} - Weight of fine broken (g),

W_i - Initial weight of black gram (g).

3.5 Analysis of the quality of dehulled dhal

3.5.1 Colour

Colour is an important to consumer as a mean of identification, as a method of judging quality and for its basic aesthetic value and food is no exemption. The overall objective of colour to the food is to make it appealing and recognizable. A Hunter lab Colorimeter (Model: Colour Quest XE, USA) was used in present investigation as presented in Plate 3.4. Calibration of this machine was done using black and white standardizing templates. The sample was placed over the eye and the L, a and b values was monitored for each sample as the average of six readings. The variation of the L, a and b values with the ET and power levels were monitored.

The colour values obtained as 'L' is the lightness coefficient, ranging from 0 (black) to 100 (white), 'a' is purple-red (positive 'a' value) and blue-green (negative 'a' value) and 'b', that represents yellow (positive 'b' value) and blue (negative 'b' value) colour (McGuire, 1992).



Plate 3.4 Hunter lab Colorimeter



Plate 3.5 Colour scale presenting relationship of colour index (L,a,b)

3.5.2 Cooking time

A gas stove was used to maintain uniform and constant temperature during experimentation of cooking. Approximately 200 ml of tap water was taken for boiling in 250 ml beakers and 20g each of microwave treated, infrared treated and control grains (dhal) of black gram were added in separate beakers. Boiling was continued and few kernels was withdrawn for every 30s after specific time with spatula and placed between two glass slides. Then the slides were pressed against each other with no lateral movement. Cooking was considered complete when the cooked kernels had no longer opaque or uncooked centres and the time required for this was taken as the optimum cooking time (Ranghino, 1966). Slides were cleaned and dipped in water after every usage.

3.6 Statistical analysis:

Design-expert version 10.02 was used for designing of the experiment. In design expert under response surface the hybrid design was suggested according to the preliminary studies and the further research was under gone by using the hybrid design of the experiment. Further optimization of process parameters were done by using the same software (Walia, 2014).

The design tables which are suggested to follow during the experimental process, to take the right combination of treatment with their maximum possibilities are given in Table 3.1 & 3.2.

Table 3.1: Combinations of various parameters used in MW design

Standard	Run	MW power (W)	Exposure time (min)	Dehulling time (min)	Dehulling yield (%)	Dhal yield (%)	Dehulling loss (%)	Cooking time (min)
8	1	720	9	19	81	77	9	11.20
13	2	720	7	21	83	78	8	13.60
4	3	540	7	25	81	78	7.5	14.70
6	4	900	7	19	80	78	6	10.60
3	5	900	5	22	85	82	8	13.80
1	6	540	5	29	79	75	11.5	16.80
11	7	720	7	21	83	78	8	13.60
5	8	720	7	21	83	78	8	13.60
10	9	720	7	21	83	78	8	13.60
9	10	900	9	17	78	75	10	8.50
7	11	540	9	22	83	80	9	13.40
12	12	720	7	21	83	78	8	13.60
2	13	720	5	24	80	77	10	14.90

Table 3.2: Combinations of various parameters used in IR design

Standard	Run	IR power (W)	Exposure time (min)	Dehulling time (min)	Dehulling yield (%)	Dhal yield (%)	Dehulling loss (%)	Cooking time (min)
3	1	900	5	26	81	79	6.5	14.8
1	2	540	5	36	78	75	8.5	19.7
5	3	720	7	25	84	80	8	14.4
8	4	720	9	20	85	82	6	12.2
2	5	720	5	32	80	77.5	9.5	16.9
11	6	720	7	25	84	80	8	14.4
10	7	720	7	25	84	80	8	14.4
13	8	720	7	25	84	80	8	14.4
12	9	720	7	25	84	80	8	14.4
7	10	540	9	26	82	79.5	6.5	15.4
9	11	900	9	19	82	78	5.5	9.8
4	12	540	7	31	81	77	7.5	17.2
6	13	900	7	22	86	80	4.5	11.7

CHAPTER IV

RESULTS AND DISCUSSION

This chapter describes the results obtained from the experimental work and the inferences drawn from them. The effect of the treatment process on the different dehulling properties and the qualities of dehulled dhal were discussed individually. The optimization step performed in order to determine the right combination of treatment process variables in order to improve dehulling of black gram, has been discussed. Finally, the performance of the treatments and their comparison under optimized condition has been described.

4.1 Moisture and temperature attained by the black gram during soaking and treating

4.1.1 Moisture

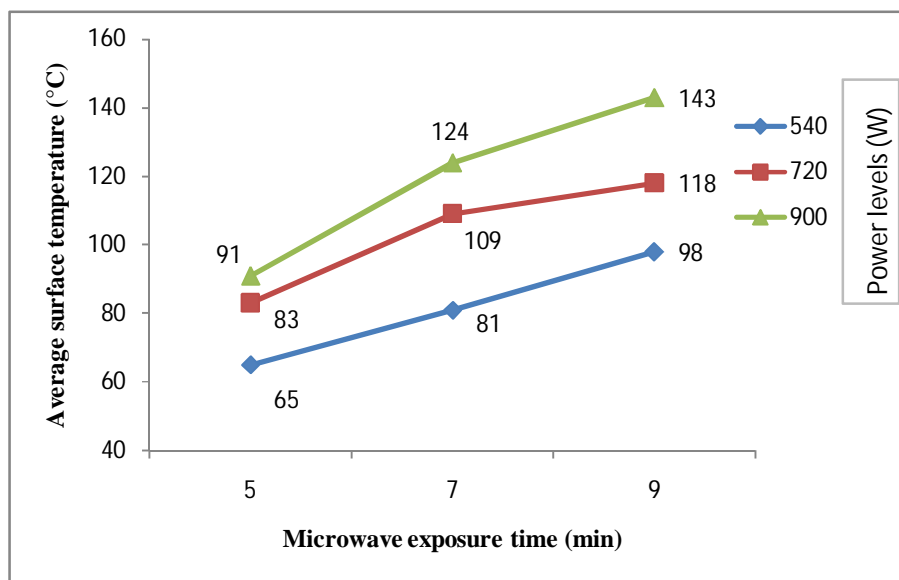
The average moisture attained by the black gram samples when soaked for constant one hour intervals was analyzed and noticed that there is no much difference in the range of the moisture attained by the samples. This may be due to, that all the samples were soaked at same temperature (room temperature) for same intervals of time (1 hour). The moisture content was determined by the method as described in section 3.2.1. The average moisture content was found to be from 22 to 24% d.b. This moisture content was reduced to below 13% with the combined effect of treatment and drying.

4.1.2 Temperature

The average surface temperature of the black gram grains subjected to microwave treatments has been recorded and presented in Table 4.1. The average surface temperature increased with the increase in exposure time at all power levels (Fig 4.1). It was also observed that with the increase in the microwave power the average surface temperature of the grains increased. At 540 W, as the exposure time was increased from 5 to 9 min the average surface temperature of the grains increased from 65 to 98 °C. Corresponding increase in temperature at 720 and 900 W for the same timings of treatment were 83 to 118 °C and 91 to 143 °C respectively (Fig 4.1). The average surface temperature varied approximately linearly with the exposure time at all the microwave power levels. But the rate of temperature increase per unit dosage was different at different power level (Fig 4.3). The grain surface temperature were also determined with the MW dosage and presented in this figure.

Table 4.1: Effect of MW exposure on the average surface temperature

MW power (W)	MW exposure time (min)	Average surface temperature (°C)
540	5	65
	7	81
	9	98
720	5	83
	7	109
	9	118
900	5	91
	7	124
	9	143

**Fig 4.1: Variation of average surface temperature (°C) with different microwave exposure timings at different power levels.**

It was found that for same microwave dosage, the grain surface temperature attained at 540 W was lower than that of 720 and 900 W (Fig 4.3). This might be due to insufficient microwave power available at 540 W to be absorbed by the sample. On the other hand, at 720 and 900 W, the temperature rise i.e. the temperature build up for a particular microwave dosage was slightly greater in 900 W.

The average surface temperature of the black gram grains subjected to infrared treatments at various power levels is presented in Table 4.2. It was observed that with the

increase in the infrared power and exposure time, the average surface temperatures of the grains were also increased. As the exposure time was increased from 5 to 9 min the average surface temperature of the grains increased from 58 to 84 °C at 540 W. Corresponding increase in temperature at 720 and 900 W for the same timings of treatment were 78 to 105 °C and 86 to 121 °C respectively. The effect of exposure timings and infrared dosage on average surface temperature is shown in Fig 4.2 and Fig 4.4.

Table 4.2: Effect of IR exposure on the average surface temperature

IR power (W)	IR exposure time (min)	Average surface temperature (°C)
540	5	58
	7	71
	9	84
720	5	78
	7	89
	9	105
900	5	86
	7	108
	9	121

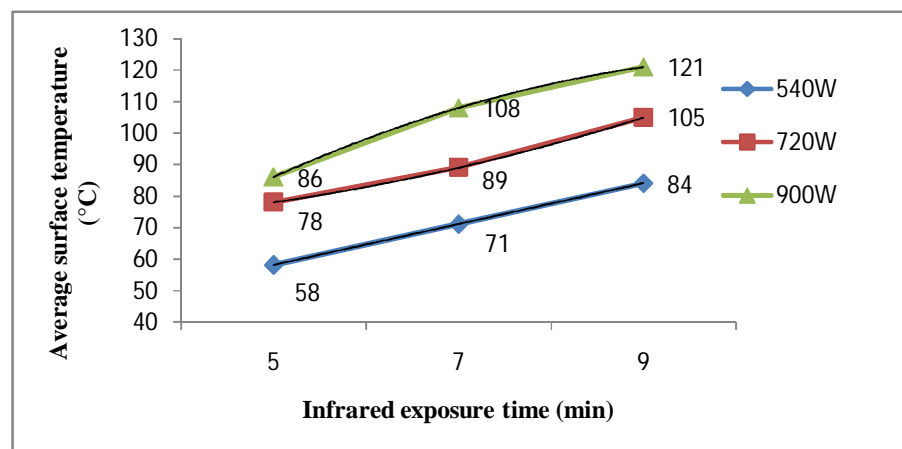


Fig 4.2: Variation of average surface temperature (°C) with different infrared exposure timings at different power levels.

Even though for same MW and IR dosages there was a difference in the surface temperatures attained by the grains, this might be due to the even power dosage

distribution and heating in MW pre-treatment. The dosage was calculated by the equation given by Yadav et al., (2013) as described in the section 3.2.3. As the power and exposure time (ET) increases the dosage also increased from 1620 J/g to 4860 J/g (Table 4.3). The calculated dosages are equal in both equipments as the power and ET are taken constant. The real effect of dosage are variant in both the equipments. Based upon these variation the temperature reached by the surface of grains are different (Table 4.1 & 4.2). The effect of dosage on the avg. surface temperatures of the grains is shown in Fig 4.3 & 4.4.

Table 4.3: Effect of MW/IR dosages with respect to power and exposure timings

Power (W)	Exposure time (min)	Dosage (J/g)
540	5	1620
	7	2268
	9	2916
720	5	2160
	7	3024
	9	3888
900	5	2700
	7	3780
	9	4860

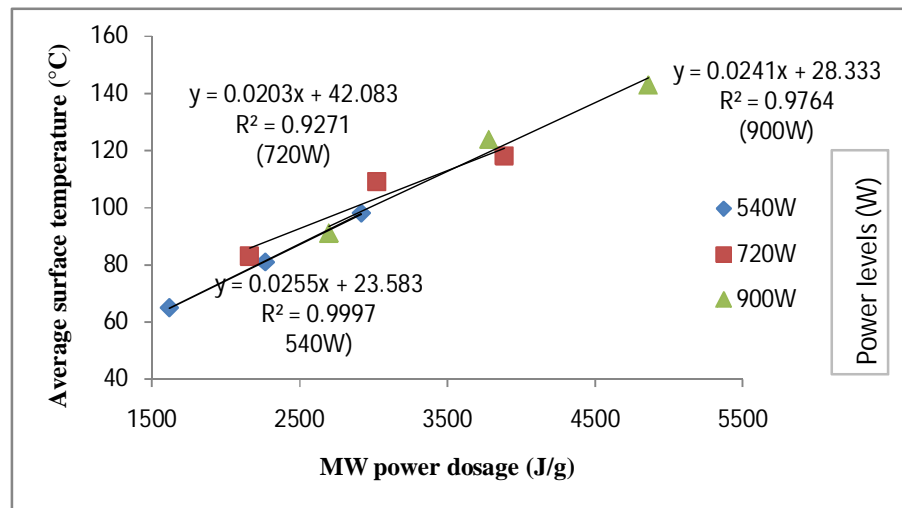


Fig 4.3: Variation of average surface temperature (°C) with different microwave dosages at different power levels.

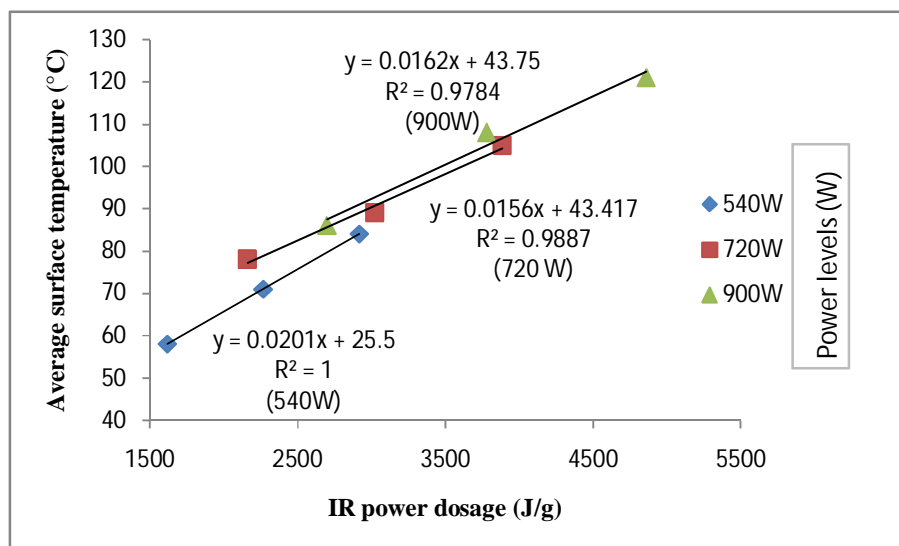


Fig 4.4: Variation of average surface temperature (°C) with different infrared dosages at different power levels.

Plate 4.1 depicted when the pulse obtained after treating the samples and performing dehulling operation. There is a slight difference in dehulling parameters and colour as we observe at 540W power level. As we move from 540W to 900W the difference in the appearance gradually increases with higher dehulling percentages and changing the colour to yellowishness. At 900W, 7 min better results were observed with good appearance level by removing maximum seed coat.

4.2 Effect of microwave treatment on the dehulling properties of black gram

Various dehulling parameters such as dehulling time, dehulling yield, dhal yield, dehulling loss were analysed to study the effect of MW treatment as described in the section 3.4 and presented in Table 4.4. The effect of MW power & ET and the individual parameters have been presented and described in the following sections.

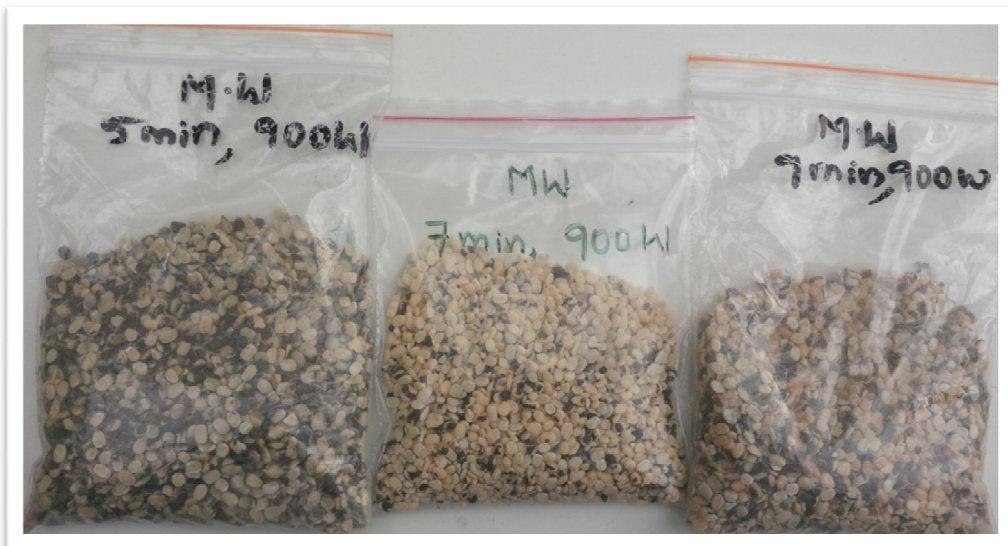


Plate 4.1 MW treated samples after dehulling process

Table 4.4 Effect of microwave treatment on the dehulling qualities of black gram

MW power (W)	MW exposure time (min)	Dehulling parameters			
		Dehulling time (s)	Dehulling yield (%)	Dhal yield (%)	Dehulling loss (%)
540	5	29	79	75	11.5
	7	25	81	78	7.5
	9	22	83	80	9
720	5	24	80	77	10
	7	21	83	78	8
	9	19	81	77	9
900	5	22	85	82	8
	7	19	80	78	6
	9	17	78	75	10

4.2.1 Dehulling time

The dehulling time of the black gram samples decreased with increasing exposure time and microwave power. It was found to decrease from 29 to 22 s, 24 to 19 s and 22 to 17 s at 540, 720 and 900 W power levels (Table 4.4). It might be due to the grains subjected to higher temperature which might have caused disruption of the bonds between the seed coat and the cotyledon made of gums and mucilages. Similar effect was also reported by Joyner & Yadav (2013). When the grains are dried they shrink more than the seed coat which creates the gap between the seed coat and the cotyledon. The seed coat thus loosened enabling its easy removal. The variation in dehulling time with microwave power level and exposure time is presented in Fig 4.5

It can be inferred from Fig 4.5 that the dehulling time decreased with the increase in the MW power and exposure time at all points of levels. It might be due to increase in the shrinkage with increased exposure time which leads to the easy removal of outer layers.

Randomized quadratic 3 level factorial model was best suited out of several models and the second order polynomial analysis equation was developed as a function of real values of independent variables viz., MW power and exposure time for the dependent

dehulling time. The developed relation with actual values (after omitting non-significant terms) has been given in Eq. 4.1.

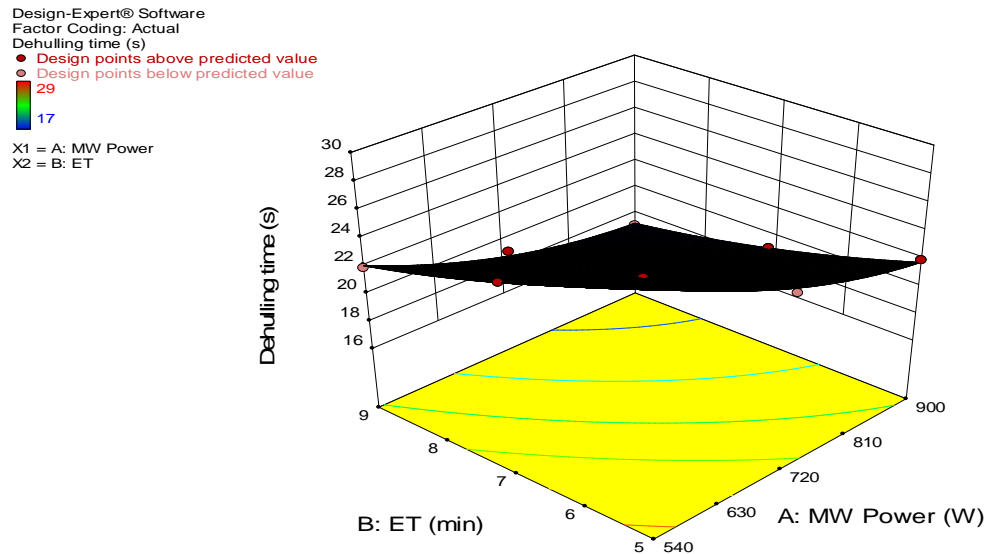


Fig 4.5: Variation of dehulling time with micro wave power and exposure time

ANOVA was conducted to determine the significance of the effect of MW power and exposure time on dehulling time (Appendix A₁). The ANOVA shows very high calculated F value (455.43) which is much greater than tabulated F value (16.21) suggesting that the model can be successfully used to fit the experimental data at 0.1% level of significance (p<0.001). Calculated F value of the linear terms of independent variables viz., microwave power, exposure time and quadratic term of microwave power > F_{tab} (29.25) indicated the significance affecting the dehulling time at p<0.001. However, the interaction term and quadratic terms of exposure time affected dehulling time at 1% level of significance (p<0.01) (Appendix E₁) (Table 4.5). The second order polynomial equation to describe the dehulling time is given as follows.

$$R_1 = 21 - 3A - 2.83 B + 0.50 AB + A^2 + 0.5 B^2 \quad \dots(4.1)$$

Where R₁ - Dehulling time (s)

A - Microwave power (W)

B - Microwave exposure time (min)

Table 4.5: Effect of MW process variables and their interactions on dehulling time

Source	Sum of squares	Df	Mean squares	F _{cal} Value	F _{tab} Value
Model	108.44	5	21.69	455.43 ^{***}	16.21
A-MICRO WAVE POWER	54.00	1	54.00	1134.00 ^{***}	29.25
B-EXPOSURE TIME	48.17	1	48.17	1011.50 ^{***}	29.25
AB	1.00	1	1.00	21.00 ^{**}	12.25
A ²	2.76	1	2.76	58.00 ^{***}	29.25
B ²	0.69	1	0.69	14.50 ^{**}	12.25
Residual	0.33	7	0.048		
Lack of Fit	0.33	3	0.11	2.29 ^{ns}	5.59
Total	108.77	12			

^{***} 0.1% level of significance; ^{**} 1% level of significance; ^{ns} non-significant

The model showed high coefficient of determination ($R^2 = 0.9688$) which indicated that the model could be used to predict the dehulling time of black gram subjected to MW power and exposure time. The difference of predicted R^2 (0.9688) and adjusted R^2 (0.9947) less than 0.20 indicated that the developed model was fitted well. The value of CV (1.01) less than 10, and APR (78.696) greater than 4 (Appendix A₁) shows the adequate precision and reliability of the experiment and model (Walia 2014). Non-significant lack of fit (Table 4.5) indicated that the regression equation was well fitted for the experimental values.

4.2.2 Dehulling yield

The Dehulling yield was recorded for each microwave power levels viz., 540W, 720W and 900W for each exposure time varying from 5 to 9 min and presented in Table 4.4. It was found that the dehulling yield varied from 79% to 83% at 540W, 80%, 83% & 81% at 720W and 85% to 78% at 900W with increase in exposure time from 5 to 9 min. The variation in dehulling yield with microwave power level and exposure time is shown in Fig 4.6. It can be inferred from the Fig 4.6 that dehulling yield increased with increase in micro wave power levels upto 720W and then decreased at higher exposure time. It was observed that the dehulling yield increased from 79% to 85% when power levels were increased from 540 to 900W at 5 min exposure time. The yield decreased in a manner of 85% to 78% for 900W at the exposure time of 9 min. A maximum dehulling yield 85% was observed at 900 watts power level with 5 minutes of exposure time.

This increase of dehulling yield in the starting levels of power may be due to pre-treatment effect that causes the grains to heat up and breaking their seed coat bonds enabling easy split of grain and the removal of the seed coat. At the higher levels of power and exposure time, the temperature of the grains reached maximum and breaks up easily while dehulling making the grains into powder enabling its reduction of dehulling yield at the peak limits.

Dehulling yield was modeled as a function of MW power and exposure time by response surface methodology using design expert version 10.02. Second order polynomial was fitted best to find the relationship between dehulling yield & MW power and exposure time (ET) and shown in Eq. 4.2.

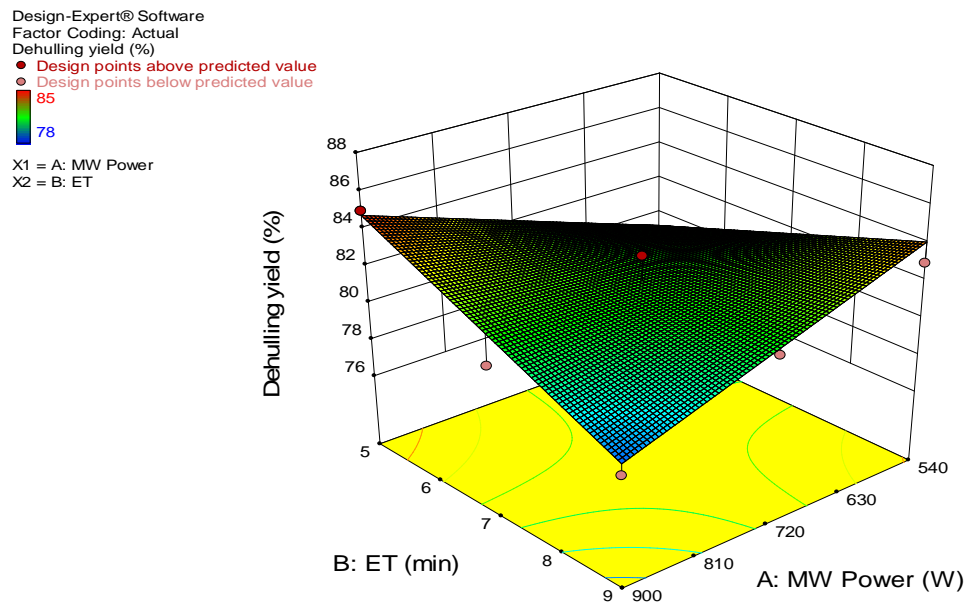


Fig 4.6: Variation of dehulling yield with micro wave power and exposure time

The ANOVA shows calculated model F value (5.35) greater than F_{tab} (3.97) suggesting that the model can be successfully used to fit the experimental data at 5% level of significance ($p < 0.05$) (Appendix E₁). F_{cal} value indicated that no significant effect was observed in the linear terms of independent variables viz., microwave power, exposure time and quadratic terms of both microwave power and exposure time. No significant effect was observed in all the independent variables as well as quadratic terms. However, the interaction term affected dehulling yield at 1% level of significance ($p < 0.01$) (Appendix E₁) (Table 4.6). The second order polynomial equation was developed as a

function of real values of independent variables viz., MW power and exposure time for the dependent dehulling yield. The developed relation with actual values (after deleting non-significant terms) has been given in Eq. 4.2.

Equation in Terms of Factors:

$$R_2 = 82.55 - 0.33 B - 2.75 AB - 0.93 A^2 - 0.93 B^2 \quad \dots(4.2)$$

Where R_2 - Dehulling yield (%)

A - Microwave power (W)

B - Microwave exposure time (min)

The model showed coefficient of determination ($R^2 = 0.7925$) which indicated that the model could be used to predict the dehulling yield of black gram subjected to MW power and exposure time. The difference of predicted R^2 (0.6096) and adjusted R^2 (0.6443) less than 0.20 indicated that the developed model was well fitted (Walia 2014). The value of CV (1.47) less than 10, and APR (7.550) greater than 4 shows the adequate precision and reliability of the experiment and model (Appendix A₂). Non-significant lack of fit indicated that the regression equation was well fitted for the experimental values.

Table 4.6: Effect of MW process variables and their interactions on dehulling yield

Source	Sum of squares	Df	Mean squares	F _{cal} Value	F _{tab} Value
Model	38.65	5	7.73	5.35*	3.97
A-MICRO WAVE POWER	0.000	1	0.000	0.000 ^{ns}	5.59
B-EXPOSURE TIME	0.67	1	0.67	0.46 ^{ns}	5.59
AB	30.25	1	30.25	20.93**	12.25
A ²	2.39	1	2.39	1.66 ^{ns}	5.59
B ²	2.39	1	2.39	1.66 ^{ns}	5.59
Residual	10.12	7	1.45		
Lack of Fit	10.12	3	3.37	2.32 ^{ns}	5.59
Total	48.77	12			

** 1% level of significance; * 5% level of significance; ^{ns} Non-significant

4.2.3 Dhal yield

The Dhal yield was recorded at 540W, 720W and 900W microwave power levels for each exposure time varying from 5 to 9 min and presented in Table 4.4. It was found that the dhal yield varied from 75% to 80% at 540W, 77%, 78% & 77% at 720W and 82% to 75% at 900W with increase in exposure time from 5 to 9 min. The variation of

dhal yield with microwave power level and exposure time is shown in Fig 4.7. It can be inferred from Fig 4.7 that the dhal yield increased with increase in microwave power level and exposure time & it decreased at the higher exposure time and power level (9 min 900W). The dhal yield increased in a manner of 75 to 82% in the process.

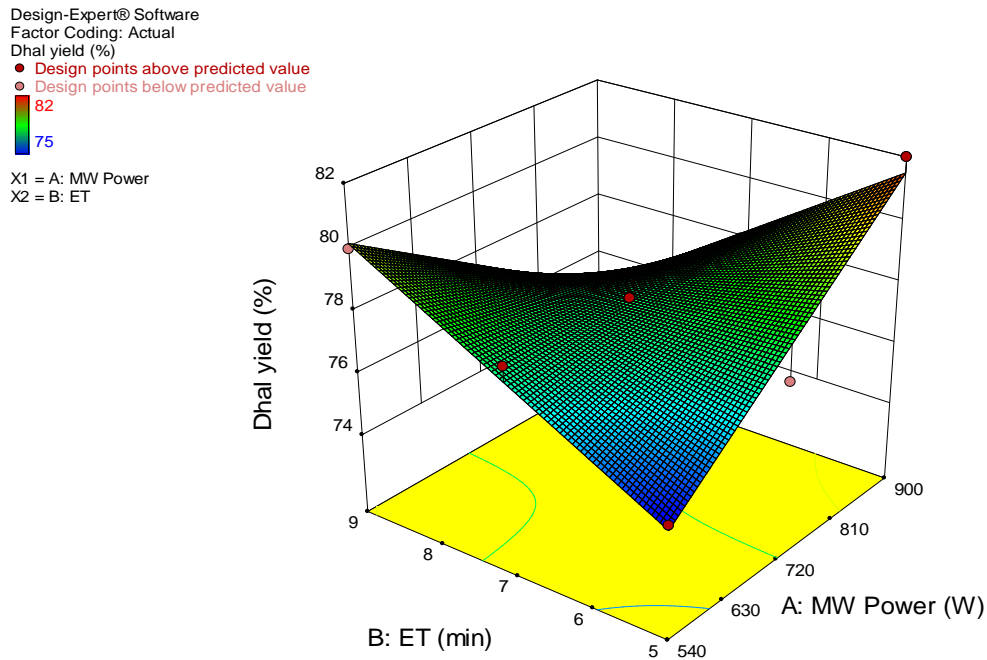


Fig 4.7: Variation of dhal yield with exposure time and micro wave power

The maximum dhal yield of 82% was observed at a microwave power level of 900 watts and minimum of 75% at 540 watts for exposure time of 5 minutes. This high dhal yield may be due to its pre-treatment effect that causes the reduction of moisture content there by breaking the bond between the coat and cotyledon. Slight decrease in the yield at the higher limits of power and ET is observed this might be due to the overheating of the grains that leads to easy breakage of grains into splits and powder thus reducing the yield at the peak limits.

The RSM suggested the 3 level factorial quadratic model to suit the design and the experimental data of dhal yield were analysed by a second order polynomial equation as shown in Eq. 4.3. ANOVA was conducted to determine the significance of the effect of MW power and exposure time on dhal yield Appendix A₃.

The ANOVA data shows F_{cal} value (39.57) > F_{tab} value (16.21) suggesting that the model can be successfully used to fit the experimental data at 0.1% level of significance ($p < 0.001$). F_{cal} value indicated that no significant effect was observed in the linear terms of independent variables viz., microwave power, exposure time and quadratic terms of both microwave power and exposure time (Appendix E₁). No significant effect was observed in all the independent variables as well as quadratic terms. However, the interaction term affected dhal yield at 0.1% level of significance ($p < 0.001$) (Table 4.7). The second order polynomial equation was developed as a function of real values of independent variables viz., MW power and exposure time for the dependent dhal yield. The developed relation with actual values (after deleting non-significant terms) has been given in Eq. 4.3.

$$R_3 = 77.86 + 0.33 A - 0.33 B - 3 AB + 0.48 A^2 - 0.52 B^2 \quad \dots(4.3)$$

Where R_3 - Dhal yield (%)

A - Microwave power (W)

B - Microwave exposure time (min)

Table 4.7: Effect of MW process variables and their interactions on dhal yield

Source	Sum of squares	Df	Mean squares	F_{cal} Value	F_{tab} Value
Model	38.34	5	7.67	39.57 ^{***}	16.21
A-MICRO WAVE POWER	0.67	1	0.67	3.44 ^{ns}	5.59
B-EXPOSURE TIME	0.67	1	0.67	3.44 ^{ns}	5.59
AB	36.00	1	36.00	185.80 ^{***}	29.25
Residual	1.36	7	0.19		
Lack of Fit	1.36	3	0.45	2.36 ^{ns}	5.59
Total	39.69	12			

^{***} 0.1% level of significance; ^{ns} Non-significant

The model showed high coefficient of determination ($R^2 = 0.9658$) which indicated that the model could be used to predict the dhal yield of black gram subjected to MW power and exposure time. The difference of predicted R^2 (0.8106) and adjusted R^2 (0.9414) less than 0.20 indicated that the developed model is well fitted. The value of CV (0.57) less than 10, and APR (22.293) greater than 4 shows the adequate precision and

reliability of the experiment and model (Walia 2014) (Appendix A₃). Non-significant lack of fit indicated that the regression equation was well fitted for the experimental values.

4.2.4 Dehulling loss

The Dehulling loss was recorded for each microwave power levels viz., 540W, 720W and 900W for each exposure time varying from 5 to 9 min and presented in Table 4.4. It was found that the dehulling loss varied from 11.5% to 7.5% at 540W, 10%, 8% & 9% at 720W and 8%, 6% & 10% at 900W with increase in exposure time from 5 to 9 min. The variation of dehulling loss with micro wave power level and exposure time is shown in Fig 4.8. The dehulling losses gradually decreased from 11.5% to 8% at 5 min exposure time at 540 W power level. The losses range from a minimum of 6% to 11.50%. The maximum dehulling loss was observed was 11.50% at a microwave power level of 540 watts for an exposure time of 5 minutes while it was minimum at a maximum microwave power level of 900 watts for an exposure time of 7 minutes which was 6% (Fig 4.8)

As the thermal effect increases with increase in power and exposure time the bond strength between seed coat and cotyledon decreases the effort to split the grains thereby decreasing the dehulling loss. Overheating of grains makes easy removal of seed coat and in addition by allowing more dehulling time in order to get complete removal of the cotyledon, some of the grains got powdered enabling the increase in loss at 900W with 9 min exposure time.

The experimental data of dehulling loss were analysed by a second order polynomial equation (Eq. 4.4). The significance of the effect of MW power and exposure time on dehulling loss was determined by conducting analysis of variance (Appendix A₄).

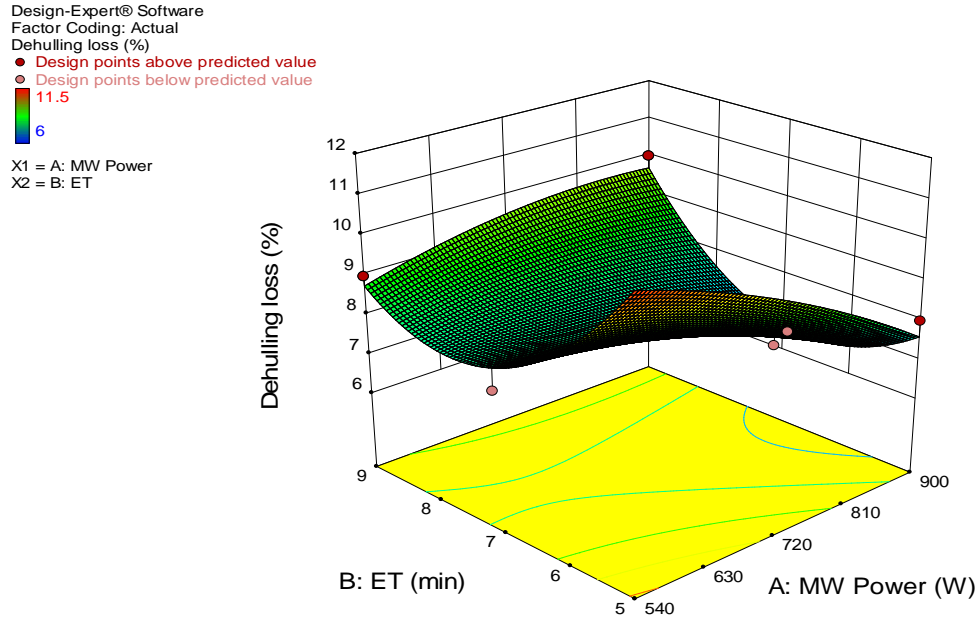


Fig 4.8: Variation of dehulling loss with exposure time and microwave power

F_{cal} value (19.64) > F_{tab} value (16.21) suggests that the model can be successfully used to fit the experimental data at 0.1% level of significance ($p < 0.001$). F_{cal} value of linear terms of independent variable microwave power, and interaction term greater than F_{tab} (12.25) significantly affected the dehulling loss at 1% level of significance ($p < 0.01$). However, the quadratic term of exposure time affected dehulling loss at 0.1% level of significance ($p < 0.001$) (Table 4.8) (Appendix E₁). No significant effect was observed in the independent variable exposure time as well as quadratic term of microwave power. The second order polynomial equation was developed as a function of real values of independent variables viz., MW power and exposure time for the dependent dehulling loss. The developed relation with actual values (after deleting non-significant terms) has been given in Eq. 4.4.

Final Equation in Terms of Factors:

$$R_4 = 7.81 - 0.67 A - 0.25 B + 1.13 AB - 0.15 A^2 + 2.16 B^2 \quad \dots(4.4)$$

Where, R_4 - dehulling loss (%)

A - Microwave power (W)

B - Microwave exposure time (min)

The model showed high coefficient of determination ($R^2 = 0.9335$) which indicated that the model could be used to predict the dehulling loss of black gram subjected to MW power and exposure time. The difference of predicted R^2 (0.6957) and adjusted R^2 (0.8860) less than 0.20 indicated that the developed model fitted well. The value of CV (5.44) less than 10, and APR (15.430) greater than 4 shows the adequate precision and reliability of the experiment and model (Walia 2014) (Appendix A₄). Non-significant lack of fit indicated that the regression equation was well fitted for the experimental values.

Table 4.8: Effect of MW process variables and their interactions on dehulling loss

Source	Sum of squares	Df	Mean squares	F _{cal} Value	F _{tab} Value
Model	21.22	5	4.24	19.64 ^{***}	16.21
A-MICRO WAVE POWER	2.67	1	2.67	12.34 ^{**}	12.25
B-EXPOSURE TIME	0.38	1	0.38	1.74 ^{ns}	5.59
AB	5.06	1	5.06	23.43 ^{**}	12.25
A ²	0.95	1	0.95	4.39 ^{ns}	5.59
B ²	12.93	1	12.93	59.86 ^{***}	29.25
Residual	1.51	7	0.22		
Lack of Fit	1.51	3	0.50	2.27 ^{ns}	5.59
Total	22.73	12			

^{***} 0.1% level of significance; ^{**} 1% level of significance; ^{ns} Non-significant

4.3 Effect of MW treatment on the quality properties of dehulled dhal

Various dehulled dhal quality parameters such as cooking time and colour were analysed to study the effect of MW treatment as described in the section 3.5. The effect of MW power & ET and the individual parameters have been presented and described in the following sections.

4.3.1 Cooking time

It was observed that the cooking time gradually decreased with increase in micro wave power level and exposure time. Cooking time was recorded for each microwave power levels viz., 540W, 720W and 900W for each exposure time varying from 5 to 9 min and presented in Table 4.9. It was found that cooking time varied from 16.8 min to 13.4 min at 540W, 14.9 min to 11.2 min at 720W and 13.8 min to 8.5 min at 900W with

increase in exposure time from 5 to 9 min. The variation of cooking time with microwave power level and exposure time is shown in the Fig 4.9. It can be inferred that minimum cooking time was obtained at microwave power of 900 watts and an exposure time of 9 minutes which was 8.5 minutes and the cooking time was very high at micro wave power level of 540 watts for an exposure time of 5 minutes which was 16.8 minutes.

Table 4.9: Effect of MW treatment on quality aspects of dehulled black gram

MW power (W)	MW exposure time (min)	Quality parameters			
		Colour difference			Cooking time (min)
		L	a	B	
540	5	51.25	2.35	11.72	16.8
	7	49.89	3.62	12.34	14.7
	9	46.84	4.72	13.47	13.4
720	5	50.67	3.79	12.45	14.9
	7	47.65	4.68	13.61	13.6
	9	44.91	5.52	14.72	11.2
900	5	49.78	3.54	13.08	13.8
	7	46.52	5.01	13.74	10.6
	9	41.36	5.82	15.61	8.5

The decrease in the cooking time with microwave power levels & exposure time might be due to the cooking effect of grains while pre-treating with microwave and this thermal treatment is expected to increase the pore sizes in the pulses which in turn reduce the water penetration time and thereby reducing the time in actual cooking.

The experimental data of cooking time were fitted to a quadratic model and functioned as a second order polynomial equation as shown in Eq. 4.5. ANOVA was conducted to determine the significance of the effect of MW power and exposure time on cooking time Appendix A₅. F_{cal} value (82.23) is much greater than F_{tab} (16.21) suggesting that the model can be successfully used to fit the experimental data ($p < 0.001$).

Design-Expert® Software
 Factor Coding: Actual
 Cooking time (min)
 ● Design points above predicted value
 ○ Design points below predicted value
 16.8
 8.5
 X1 = A: MW Power
 X2 = B: ET

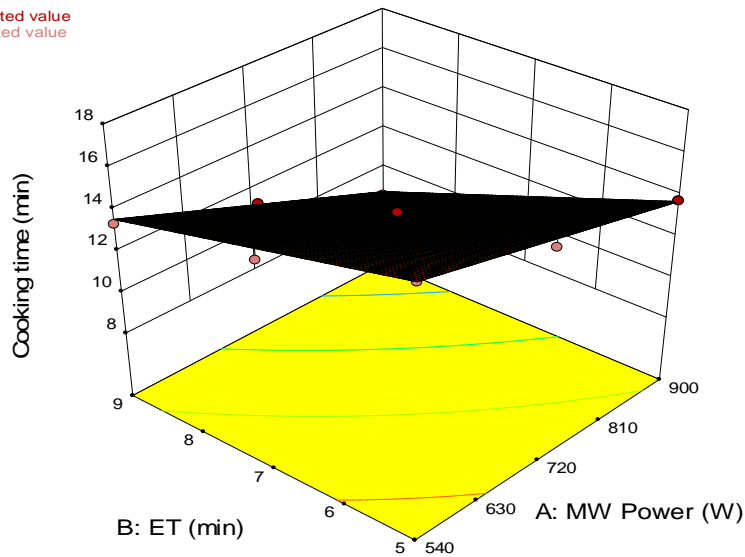


Fig 4.9: Variation of cooking time with exposure time and micro wave power level

F_{cal} value indicated that the linear terms of independent variables microwave power, and exposure time significantly affected the cooking time at 0.1% level of significance ($p < 0.001$) (Appendix E₁). However, the interaction term affected cooking time at 5% level of significance ($p < 0.05$) (Table 4.10). No significant effect was observed in all quadratic terms. The second order polynomial equation was developed as a function of real values of independent variables viz., MW power and exposure time for the dependent cooking time. The developed relation with actual values (after deleting non-significant terms) has been given in Eq. 4.5.

$$R_5 = 13.46 - 2 A - 2.07 B - 0.48 AB - 0.48 A^2 - 0.055 B^2 \quad \dots(4.5)$$

Where, R_5 - Cooking time (min)

A - Microwave power (W)

B - Microwave exposure time (min)

The model showed high coefficient of determination ($R^2 = 0.9833$) which indicated that the model could be used to predict the cooking time of black gram subjected to MW power and exposure time. The difference of predicted R^2 (0.8763) and adjusted R^2 (0.9713) less than 0.20 indicated that the developed model was well fitted. The value of CV (2.67) less than 10, and APR (33.902) greater than 4 shows the adequate

precision and reliability of the experiment and model (Appendix A₅). Non-significant lack of fit indicated that the regression equation was well fitted for the experimental values.

Table 4.10: Effect of MW process variables and their interactions on cooking time

Source	Sum of squares	Df	Mean squares	F _{cal} Value	F _{tab} Value
Model	51.27	5	10.25	82.23 ^{***}	16.21
A-MICRO WAVE POWER	24.00	1	24.00	192.5 ^{***}	29.25
B-EXPOSURE TIME	25.63	1	25.63	205.5 ^{***}	29.25
AB	0.90	1	0.90	7.24 [*]	5.59
A ²	0.57	1	0.57	4.59 ^{ns}	5.59
B ²	8.4*10 ⁻³	1	8.407*10 ⁻³	0.067 ^{ns}	5.59
Residual	0.87	7	0.12		
Lack of Fit	0.87	3	0.29	2.41 ^{ns}	5.59
Total	52.14	12			

^{***} 0.1% level of significance; ^{*} 5% level of significance; ^{ns} Non-significant

4.3.2 Colour

The color of black gram samples was determined by using Hunter Lab. The color was measured in terms of Hunter L, a, and b values. The samples were directly kept on the eye of the hunter for color measurements. For each sample, three replications of the color test were performed. The average values of the colour for each microwave power levels viz., 540W, 720W and 900W and exposure time varying from 5 to 9 min is presented in Table 4.9. It was found that hunter L value varied from 51.25 to 46.84 at 540W, 50.67 to 44.91 at 720W and 49.78 to 41.36 at 900W with increase in exposure time from 5 to 9 min. It can be inferred from Fig 4.10 that L value decreases, a & b value increases making the colour of samples change. At the higher exposure time and power levels the colour was noticeably different with white yellowness. The L, a and b values were changing variably as the power level increases which means the samples were having light red and yellowness. This might be due the power and exposure time increase which causes the grains to achieve a light cooking effect which makes the samples change from white to red yellowishness.

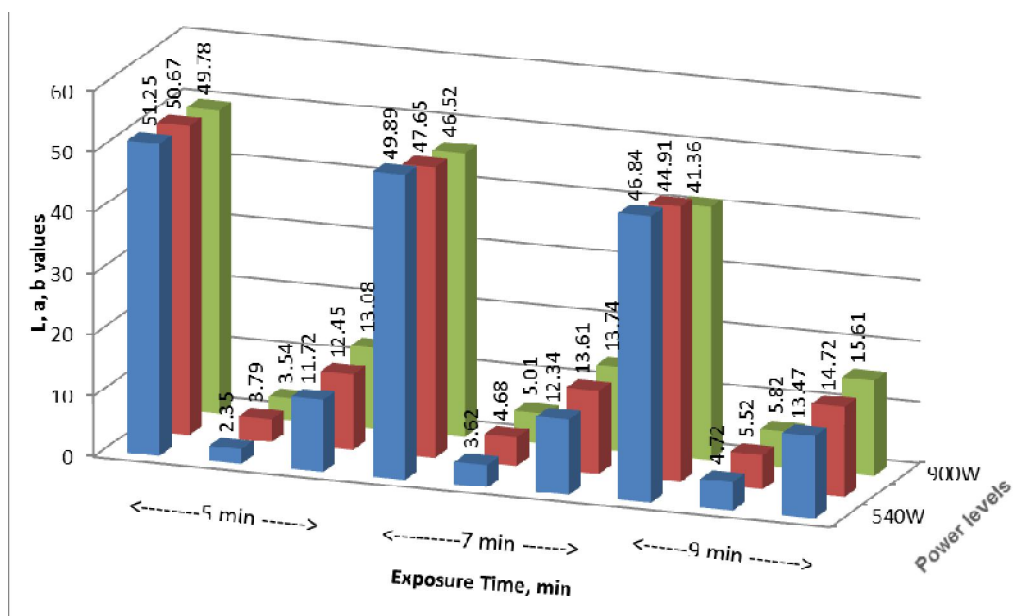


Fig 4.10: Variation in L, a and b values with exposure time and MW power level

4.4 Effect of Infrared treatment on the dehulling properties of black gram

Various dehulling parameters such as dehulling time, dehulling yield, dhal yield, dehulling loss were analysed to study the effect of IR treatment as described in the section 3.4 and presented in Table 4.11. The effect of IR power & ET and the individual parameters have been presented and described in the following sections.

Table 4.11 Effect of IR treatment on the dehulling properties

IR power (W)	IR exposure time (min)	Dehulling parameters			
		Dehulling time (s)	Dehulling yield (%)	Dhal yield (%)	Dehulling loss (%)
540	5	36	78	75	8.5
	7	31	81	77	7.5
	9	26	82	79.5	6.5
720	5	32	80	77.5	8
	7	25	84	80	7
	9	20	85	82	6
900	5	26	81	79	6.5
	7	22	86	80	4.5
	9	19	82	78	5.5

Plate 4.2 depicted after treating the samples with IR and performing dehulling operation. There is a slight difference in dehulling percentage and colour at 540 power levels. As we move from 540W to 900W the difference in the appearance gradually increases with higher dehulling percentages and changing the colour to yellowishness. At

900W, 7 min better results were observed with good appearance level by removing maximum seed coat.



Plate 4.2 IR treated samples after dehulling operation

4.4.1 Dehulling time

The dehulling time of the black gram samples decreased with increasing exposure time and IR power levels. It was found to decrease from 36 to 26s, 32 to 20 s and 26 to 19 s at 540, 720 and 900 power levels (Table 4.11). The grains were subjected to higher temperature which might have caused disruption of the bonds between the seed coat and the cotyledon made of gums and mucilages. When the grains are dried they shrink more than the seed which creates the gap between the seed coat and the cotyledon. The seed coat thus loosened enabling its easy removal. The variation of dehulling time with IR power level and exposure time is shown in the Fig 4.11.

It can be inferred from Fig 4.11 that the dehulling time decreased with the increase in the exposure time and power at all points of levels. It might be due to increase in shrinkage with increased exposure time there by enabling easy dehull resulting in less dehulling time.

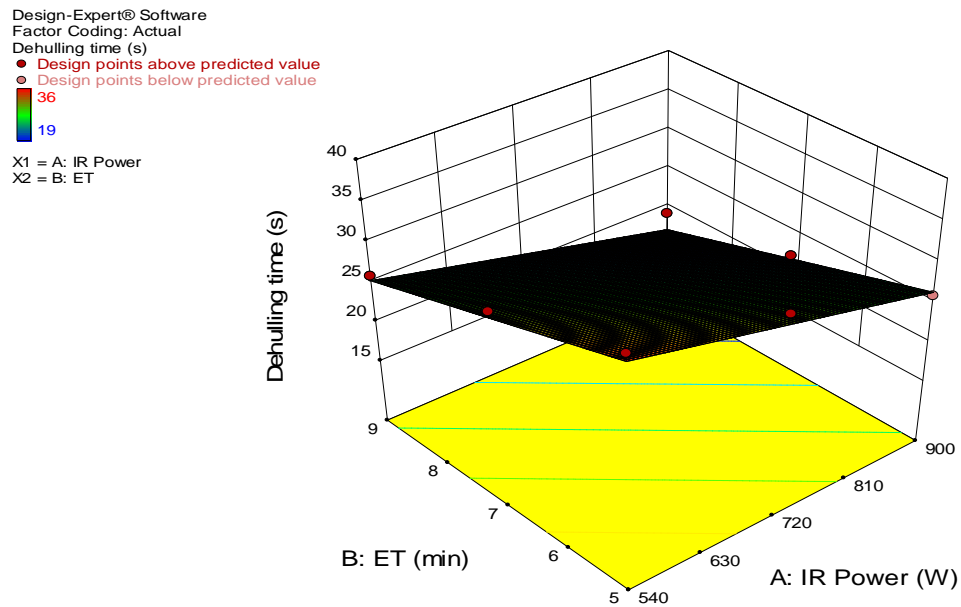


Fig 4.11: Variation of dehulling time with exposure time and power level

Dehulling time was modeled as a function of IR power and exposure time by response surface methodology using design expert software. Out of several models it was found the relationship between dehulling time and IR power and exposure time was satisfactorily represented by randomized quadratic 3 level factorial model. The ANOVA shows F_{cal} value (80.65) greater than F_{tab} value (16.21) suggesting that the model can be

successfully used to fit the experimental data at 0.1% level of significance ($p < 0.001$). Calculated F value indicated that the linear terms of independent variables infrared power, and exposure time significantly affected the dehulling time ($p < 0.001$) (Appendix E₁). No significant effect was observed in the interaction term and quadratic terms of exposure time and infrared power (Table 4.12). The second order polynomial equation was developed as a function of real values of independent variables viz., IR power and exposure time for the dependent dehulling time. The developed relation with actual values (after deleting non-significant terms) has been given in Eq. 4.6.

$$R_6 = 25.10 - 4.33 A - 4.83 B + 0.75 AB + 1.14 A^2 + 0.64 B^2 \quad \dots(4.6)$$

Where R_6 - Dehulling time (min)

A - Infrared power (W)

B - Infrared exposure time (min)

Table 4.12: Effect of IR process variables and their interactions on dehulling time

Source	Sum of squares	Df	Mean squares	F _{cal} Value	F _{tab} Value
Model	262.37	5	52.47	80.65 ^{***}	16.21
A-IR POWER LEVEL	112.67	1	112.67	173.16 ^{***}	29.25
B-EXPOSURE TIME	140.17	1	140.17	215.42 ^{***}	29.25
AB	2.25	1	2.25	3.46 ^{ns}	5.59
A ²	3.58	1	3.58	5.50 ^{ns}	5.59
B ²	1.12	1	1.12	1.73 ^{ns}	5.59
Residual	4.55	7	0.65		
Lack of Fit	4.55	3	1.52	2.33 ^{ns}	5.59
Total	266.92	12			

^{***} 0.1% level of significance; ^{ns} Non-significant

The model showed high coefficient of determination ($R^2 = 0.9829$) which indicated that the model could be used to predict the dehulling time of black gram subjected to IR power and exposure time. The difference of predicted R^2 (0.8312) and adjusted R^2 (0.9707) less than 0.20 indicated that the developed model was fitted. The value of CV (3.11) less than 10, and APR (33.455) greater than 4 shows the adequate precision and reliability of the experiment and model (Appendix B₁). Non-significant lack of fit indicated that the regression equation was well fitted for the experimental values.

4.4.2 Dehulling yield

The Dehulling yield was recorded for each infrared power levels viz., 540W, 720W and 900W for each exposure time varying from 5 to 9 min and presented in Table 4.11. It was found that the dehulling yield varied from 78% to 82% at 540W, 80% to 85% at 720W and 81% to 82% at 900W with increase in exposure time from 5 to 9 min. The variation of dehulling yield with IR power level and exposure time is shown in the Fig 4.12. It can be inferred from the Fig 4.12 that dehulling yield was increased with increase in IR power level upto higher levels (720W) and then decreased at the higher power levels and exposure time (900W & 9 min). It was observed that the dehulling yield increased in the range of 78% to 86% for 540, 700 and 900W respectively and decreased in a manner of 86% to 82% for 900W at the exposure time of 9 min. A maximum dehulling yield 86% was observed at 900 watts power level and at an exposure time of 7 minutes and minimum 78% at 540 watts power level with exposure time of 5 minutes.

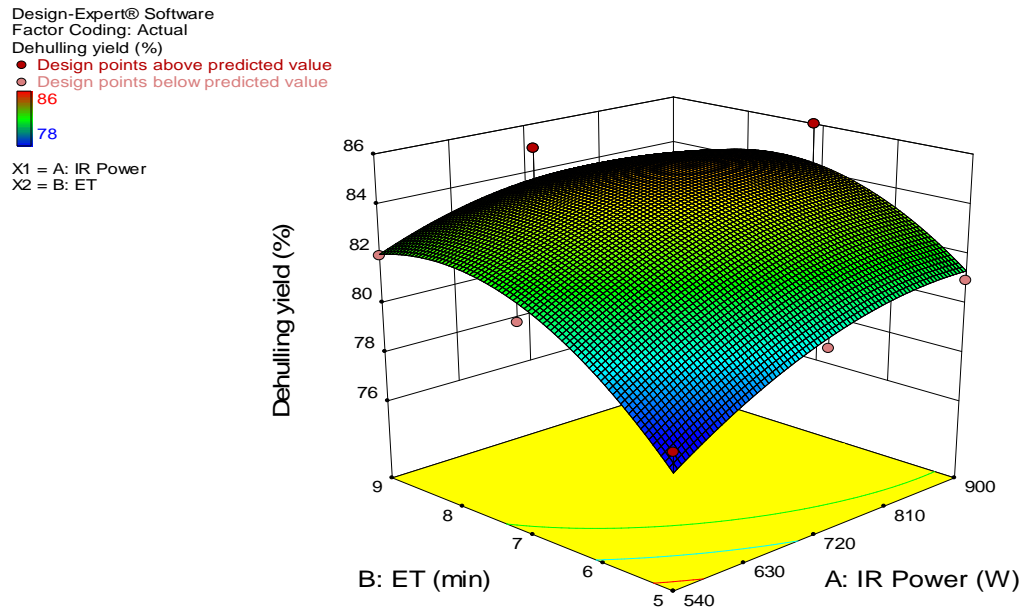


Fig 4.12: Variation of dehulling yield with exposure time and power level

This increase of dehulling yield in the levels of power may be due to pre-treatment effect and breakage of the bond between cotyledon and coat enabling easy removal of the seed coat. At the peak levels and exposure time, the temperature of the grains reached maximum and breaks up easily while dehulling thus reducing dehulling yield.

Dehulling yield was modeled as a function of IR power and exposure time by response surface methodology using design expert version 10.02. Second order polynomial was fitted best to find the relationship between dehulling yield & IR power and exposure time and shown in Eq. 4.7. F_{cal} value (10.34) > F_{tab} value (7.46) suggesting that the model was fitted at 1% level of significance ($p < 0.01$). F_{cal} value of independent variable exposure time (16.67) greater than F_{tab} (12.25) significantly affected the dehulling yield at 1% level of significance. The individual term IR power and quadratic term of exposure time was fitted at 5% level of significance (Appendix E₁). No significant effect was observed in the interaction term as well as quadratic term of IR power (Table 4.13). The second order polynomial equation was developed as a function of real values of independent variables viz., IR power and exposure time for the dependent dehulling yield. The developed relation with actual values (after deleting non-significant terms) has been given in Eq. 4.7

Source	Sum of squares	DF	Mean squares	F_{cal} Value	F_{tab} Value
Model	53.52	5	10.70	10.34 ^{**}	7.46
A-IR POWER LEVEL	10.67	1	10.67	10.31 [*]	5.59
B-EXPOSURE TIME	16.67	1	16.67	16.10 ^{**}	12.25
AB	2.25	1	2.25	2.17 ^{ns}	5.59
A ²	3.36	1	3.36	3.25 ^{ns}	5.59
B ²	12.22	1	12.22	11.81 [*]	5.59
Residual	7.24	7	1.03		
Lack of Fit	7.24	3	2.41	2.33 ^{ns}	5.59
Total	60.77	12			

^{**} 1% level of significance; ^{*} 5% level of significance; ^{ns} Non-significant

$$R_7 = 84.17 + 1.33 A + 1.67 B - 0.75 AB - 1.10 A^2 - 2.10 B^2 \quad \dots(4.7)$$

Where R₇- Dehulling yield (%)

A - Infrared power (W)

B - Infrared exposure time (min)

The model showed high coefficient of determination ($R^2 = 0.8808$) which indicated that the model could be used to predict the dehulling yield of black gram subjected to IR power and exposure time. The difference of predicted R^2 (0.6541) and adjusted R^2 (0.7956) less than 0.20 indicated that the developed model is well fitted. The value of CV (1.23) less than 10, and APR (10.399) greater than 4 (Appendix B₂) shows the adequate precision and reliability of the experiment and model (Walia 2014). Non-significant lack of fit indicated that the regression equation was well fitted for the experimental values.

4.4.3 Dhal yield

The Dhal yield was recorded at each infrared power levels viz., 540W, 720W and 900W with exposure time varying from 5 to 9 min and presented in Table 4.11. It was found that the dhal yield varied from 75% to 79.5% at 540W, 77.5%, 80% & 82% at 720W and 79% to 78% at 900W with increase in exposure time from 5 to 9 min. The variation of dhal yield with IR power level and exposure time is shown in Fig 4.13. It can be inferred from Fig 4.13 that dhal yield increased with increase in IR power level and exposure time up to higher levels (720W) and then decreased at the higher levels of the exposure time and power levels (9min & 900W). The dhal yield increased in the range of 75 to 82% for the respective power levels of 540, 720, and 900 W.

The maximum dhal yield of 82% was observed at an IR power level of 720 watts with an exposure time of 9 minutes and minimum 75% at 540 watts for an exposure time of 5 minutes. This high dhal yield may be due to pre-treatment effect that causes the grains to heat up and breaking their seed coat bonds enabling easy split of grain and the removal of the seed coat. At the higher levels of power and exposure time, the temperature of the grains reached maximum and breaks up easily while dehulling making the grains into powder enabling its reduction of dhal yield at the peak limits.

Design-Expert® Software
 Factor Coding: Actual
 Dhal yield (%)
 ● Design points above predicted value
 ○ Design points below predicted value
 82
 75
 X1 = A: IR Power
 X2 = B: ET

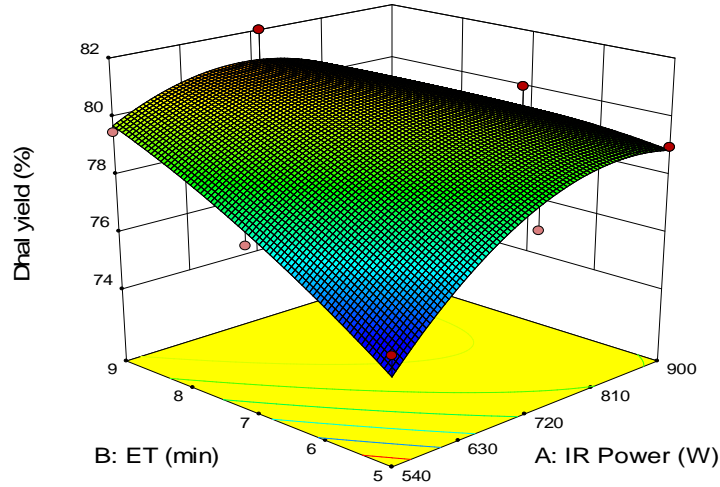


Fig 4.13: Variation of dhal yield with exposure time and power level

The experimental data of dhal yield were fitted to a quadratic model and functioned as a second order polynomial equation as shown in Eq. 4.8. ANOVA was conducted to determine the significance of the effect of IR power and exposure time on dhal yield (Appendix B₃). It shows that the calculated F value (13.38) greater than F_{tab} (7.46) suggesting that the model can be successfully used to fit the experimental data at 1% level of significance ($p < 0.01$). F_{cal} value of the independent variable exposure time, interaction term and quadratic term of IR power was well fitted at 1% level of significance (Appendix E₁). No significant effect was observed in quadratic term of exposure time. However, the independent variable IR power affected dhal yield at 5% level of significance ($p < 0.05$) (Table 4.14). The quadratic equation was developed as a function of real values of independent variables viz., IR power and exposure time for the dependent dhal yield. The developed relation with actual values (after deleting non-significant terms) has been given in Eq. 4.8.

$$R_8 = 80.05 + 0.92 A + 1.33 B - 1.37 AB - 1.68 A^2 - 0.43 B^2 \quad \dots(4.8)$$

Where,
 R_8 - Dhal yield (%)
 A - Infrared power (W)
 B - Infrared exposure time (min)

The model showed high coefficient of determination ($R^2=0.9053$) which indicated that the model could be used to predict the dhal yield of black gram subjected to IR power

and exposure time. The difference of predicted R^2 (0.6443) and adjusted R^2 (0.8377) less than 0.20 indicated that the developed model is successfully fitted. The value of CV (0.91) less than 10, and APR (13.555) greater than 4 (Appendix B₃) shows the adequate precision and reliability of the experiment and model (Walia 2014). Non-significant lack of fit indicated that the regression equation was well fitted for the experimental values.

Table 4.14: Effect of IR process variables and their interactions on dhal yield

Source	Sum of squares	Df	Mean squares	F _{cal} Value	F _{tab} Value
Model	34.78	5	6.96	13.38**	7.46
A-IR POWER LEVEL	5.04	1	5.04	9.70*	5.59
B-EXPOSURE TIME	10.67	1	10.67	20.52**	12.25
AB	7.56	1	7.56	14.55**	12.25
A ²	7.80	1	7.80	15.01**	12.25
B ²	0.51	1	0.51	0.99 ^{ns}	5.59
Residual	3.64	7	0.52		
Lack of Fit	3.64	3	1.21	2.32 ^{ns}	5.59
Total	38.42	12			

** 1% level of significance; * 5% level of significance; ^{ns} Non-significant

4.4.4 Dehulling loss

The Dehulling loss was recorded for each infrared power levels viz., 540W, 720W and 900W for each exposure time varying from 5 to 9 min and presented in Table 4.11. It was found that the dehulling loss varied from 8.5% to 6.5% at 540W, 9.5%, 8% & 6% at 720W and 6.5%, 4.5% & 5.5% at 900W with increase in exposure time from 5 to 9 min. The variation of dehulling loss with IR power level and exposure time is shown in the Fig 4.14. The dehulling losses gradually decreased from 8.5% to 4.5% with the increase in IR power level and exposure time. The losses increased at the higher levels of ET & power (9min & 900W). The losses range from a minimum of 4.5% to 8.50%. The maximum dehulling loss observed was 8.50% at an IR power level of 540W for an exposure time of 5 minutes while the minimum dehulling losses were observed at a maximum microwave power level of 900 watts for an exposure time of 7 minutes which was 4.5%.

As the thermal effect increases with increase in power and exposure time the bond strength between seed coat and cotyledon decreases thereby decreasing the dehulling loss.

The loss increased at the final peak limits from 4.5 to 5.5% due to the overheating of grains and more dehulling time enabling the breakage of some grains.

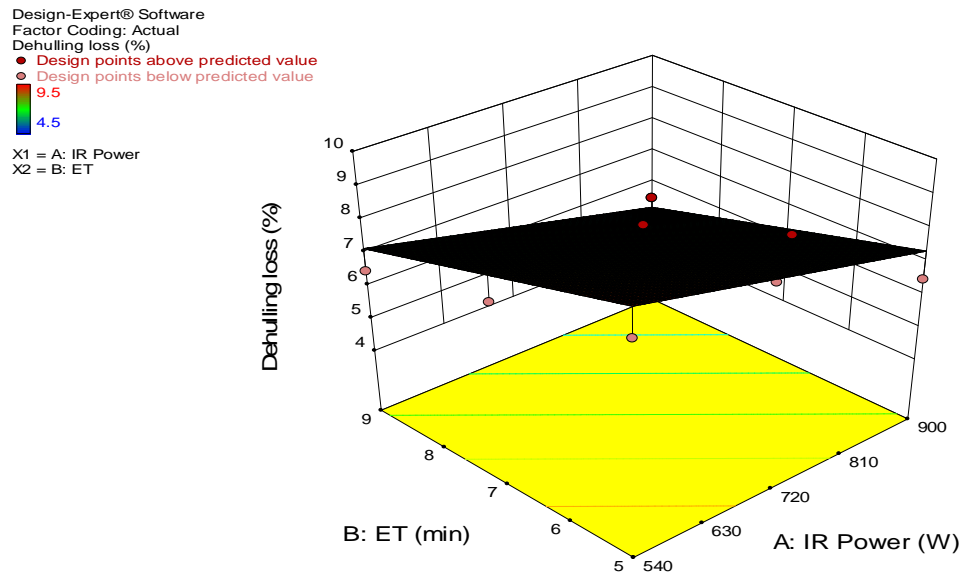


Fig 4.14: Variation of dehulling loss with exposure time and power level

The experimental data of dehulling loss were fitted to a quadratic model as shown in Eq. 4.9. ANOVA was conducted to determine the significance of the effect of IR power and exposure time on dehulling loss Appendix B₄. F_{cal} value (10.11) > F_{tab} value (7.46) suggesting that the model can be successfully used to fit the experimental data at 1% level of significance ($p < 0.01$). The independent variables IR power, exposure time and quadratic term of IR power significantly affected the dehulling loss at 1% level of significance ($p < 0.01$) (Appendix E₁). No significant effect was observed in the quadratic term of exposure time and interaction term (Table 4.15). The second order polynomial equation was developed as a function of real values of independent variables viz., IR power and exposure time for the dependent dehulling loss. The developed relation with actual values (after deleting non-significant terms) has been given in Eq. 4.9.

$$R_9 = 7.86 - A - 1.08B + 0.25AB - 1.52 A^2 + 0.23B^2 \quad \dots(4.9)$$

Where, R_9 - Dehulling loss (%)
 A -Infrared power (W)
 B-Infrared exposure time (min)

The model showed high coefficient of determination ($R^2 = 0.8784$) which indicated that the model could be used to predict the dehulling loss of black gram subjected to IR power and exposure time. The difference of predicted R^2 (0.6361) and

adjusted R^2 (0.7916) less than 0.20 indicated that the developed model was well fitted. The value of CV (8.66) less than 10, and APR (10.369) greater than 4 (Appendix B₄) shows the adequate precision and reliability of the experiment and model (Walia 2014). Non-significant lack of fit indicated that the regression equation was well fitted for the experimental values.

Table 4.15: Effect of IR process variables and their interactions on dehulling loss

Source	Sum of squares	Df	Mean squares	F _{cal} Value	F _{tab} Value
Model	20.03	5	4.01	10.11 ^{**}	7.46
A-IR POWER LEVEL	6.00	1	6.00	15.15 ^{**}	12.25
B-EXPOSURE TIME	7.04	1	7.04	17.78 ^{**}	12.25
AB	0.25	1	0.25	0.63 ^{ns}	5.59
A ²	6.36	1	6.36	16.05 ^{**}	12.25
B ²	0.15	1	0.15	0.38 ^{ns}	5.59
Residual	2.77	7	0.40		
Lack of Fit	2.77	3	0.92	2.3 ^{ns}	5.59
Total	22.81	12			

^{**} 1% level of significance; ^{ns} Non-significant

4.5 Effect of Infrared treatment on the quality properties of dehulled black gram

The results of the study investigating the effect of infrared treatment on the quality of dehulled black gram are shown in the following table. The effects on specific qualities of dehulled dhal are discussed in following subsections.

4.5.1 Cooking time

Cooking time was recorded for each infrared power levels viz., 540W, 720W and 900W for each exposure time varying from 5 to 9 min and presented in Table 4.16. It was found that cooking time varied from 19.7 min to 15.4 min at 540W, 16.9 min to 12.2 min at 720W and 14.8 min to 9.8 min at 900W with increase in exposure time from 5 to 9 min. From the Fig 4.15 it can be inferred that cooking time gradually decreased with increasing IR power level and exposure time. It was observed that a minimum cooking time 9.8 min was obtained at IR power of 900 watts and an exposure time of 9 minutes and the cooking time were very high at IR power level of 540 watts for an exposure time of 5 minutes which was 19.70 minutes.

Table 4.16 Effect of IR treatment on quality aspects of dehulled dhal

IR power (W)	IR exposure time (min)	Quality parameters			Cooking time (min)
		Colour difference			
		L	a	B	
540	5	62.23	0.24	8.68	19.7
	7	54.42	1.69	9.72	17.2
	9	49.72	2.34	11.69	15.4
720	5	58.62	1.84	7.63	16.9
	7	51.76	2.76	10.08	14.4
	9	47.09	3.72	13.26	12.2
900	5	51.38	3.64	9.78	14.8
	7	46.48	4.34	13.07	11.7
	9	44.41	5.36	14.12	9.8

This decrease in the cooking time might be due to the initial heating of the grain by treating with infrared and this thermal treatment is expected to increase the pore sizes in the pulses which in turn reduce the water penetration time as well as reduce the cooking time.

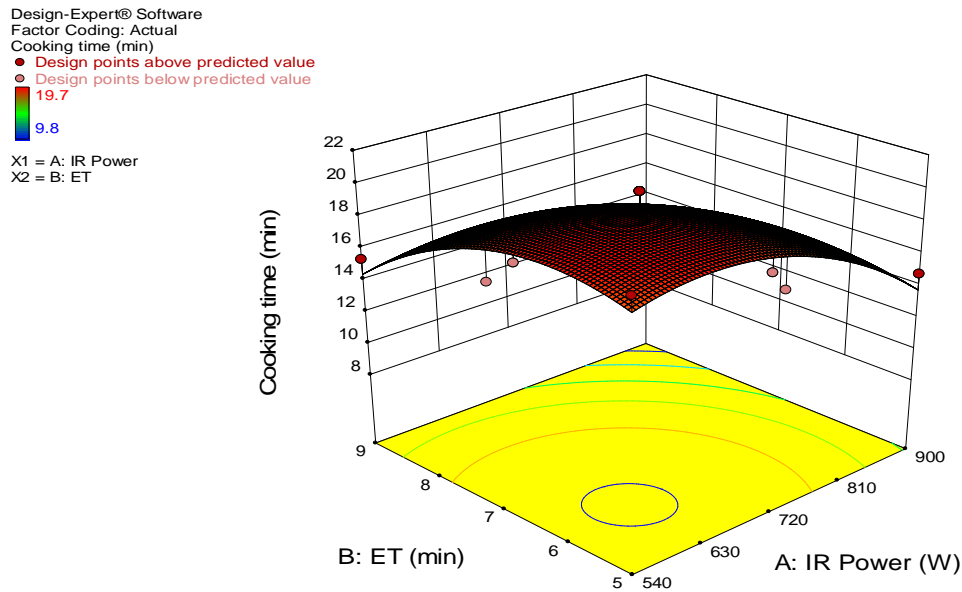


Fig 4.15: Variation of cooking time with exposure time and power level

The experimental data of cooking time were fitted to a quadratic 3 factorial model. They were functioned by a second order polynomial analysis as shown in Eq. 4.10. ANOVA was conducted to determine the significance of the effect of IR power and

exposure time on cooking time Appendix B₅. The ANOVA data shows very high calculated F value (1126.60) greater than F_{tab} (16.21) suggesting that the model can be successfully used to fit the experimental data at 0.1% level of significance (p<0.001). F_{cal} value indicated that the linear terms of independent variables infrared power, and exposure time significantly affected the cooking time at 0.1% level of significance (p<0.001). However, the interaction term and quadratic term of IR power affected cooking time at 5% level of significance (p<0.05) Appendix E₁. Quadratic term of exposure time affected cooking time at 1% level of significance (Table 4.17).

Table 4.17: Effect of IR process variables and their interactions on cooking time

Source	Sum of squares	Df	Mean squares	F Value	F Value
Model	76.05	5	15.21	1126.60 ^{***}	16.21
A-IR POWER LEVEL	42.67	1	42.67	3160.11 ^{***}	29.25
B-EXPOSURE TIME	32.67	1	32.67	2419.46 ^{***}	29.25
AB	0.12	1	0.12	9.07 [*]	5.59
A ²	0.12	1	0.12	8.76 [*]	5.59
B ²	0.26	1	0.26	19.27 ^{**}	29.25
Residual	0.095	7	0.014		
Lack of Fit	0.095	3	0.032	2.28 ^{ns}	5.59
Total	76.15	12			

^{***} 0.1% level of significance; ^{**} 1% level of significance; ^{*} 5% level of significance; ^{ns} Non significance;

The second order polynomial equation was developed as a function of real values of independent variables viz., IR power and exposure time for the dependent cooking time. The developed relation with actual values (after deleting non-significant terms) has been given in Eq. 4.10.

$$R_{10} = 14.36 - 2.67 A - 2.33 B - 0.18 AB + 0.21 A^2 + 0.31 B^2 \quad \dots(4.10)$$

Where, R₁₀- Cooking time (min)

A - Infrared power (W)

B - Infrared exposure time (min).

The model showed high coefficient of determination (R²= 0.9988) which indicated that the model could be used to predict the cooking time of black gram

subjected to IR power and exposure time. The difference of predicted R^2 (0.9906) and adjusted R^2 (0.9979) less than 0.20 indicated that the developed model was well fitted. The value of CV (0.80) less than 10, and APR (126.678) greater than 4 shows the adequate precision and reliability of the experiment and model (Appendix B₅). Non-significant lack of fit indicated that the regression equation was well fitted for the experimental values.

4.5.2 Colour

Colour measurements was recorded for each infrared power levels viz., 540W, 720W and 900W for each exposure time varying from 5 to 9 min and is presented in Table 4.16. It was found that hunter L value varied from 62.23 to 49.92 at 540W, 58.62 to 47.09 at 720W and 51.39 to 44.49 at 900W with increase in exposure time from 5 to 9 min. It can be inferred from Fig 4.16 that, as the power and ET increases L value decreases, a & b values increases. At the higher exposure time and power levels the colour was noticeably different with white yellowness.

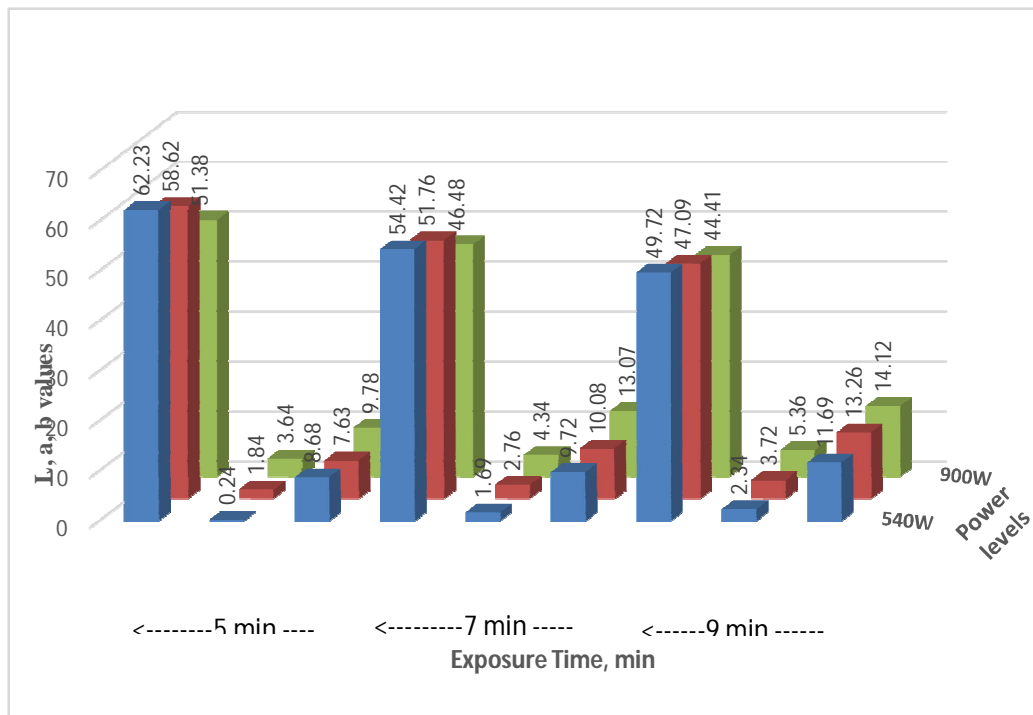


Fig 4.16: Variation of L a and b values with exposure time and power level in IR

The L, a and b values were changing variably as the power level increases which means the samples were having light red and yellowness. This might be due to the power and exposure time increase which causes the grains to achieve a light cooking effect which makes the samples change from white to red yellowness.

4.6 Comparison of MW and IR and their effects on various dehulling parameters

4.6.1 Average Dehulling time

Average dehulling time at power levels of 540W, 720W & 900W when the exposure time was varied from 5 to 9 min was observed to be 25.33 min, 21.33 min & 19.33 min and 31 min, 25.66 min & 22.33 min for the microwave treatment and infrared treatment respectively (Fig 4.17). From the Fig it can be inferred that the average dehulling time in both the treatments *i.e.*, in microwave and infrared goes on decreasing with the increase in power level and exposure time. It could be inferred that the dehulling time is low in case of microwave treatment compared to that of infrared treatment at all the power levels *i.e.* from 540 to 900 watts.

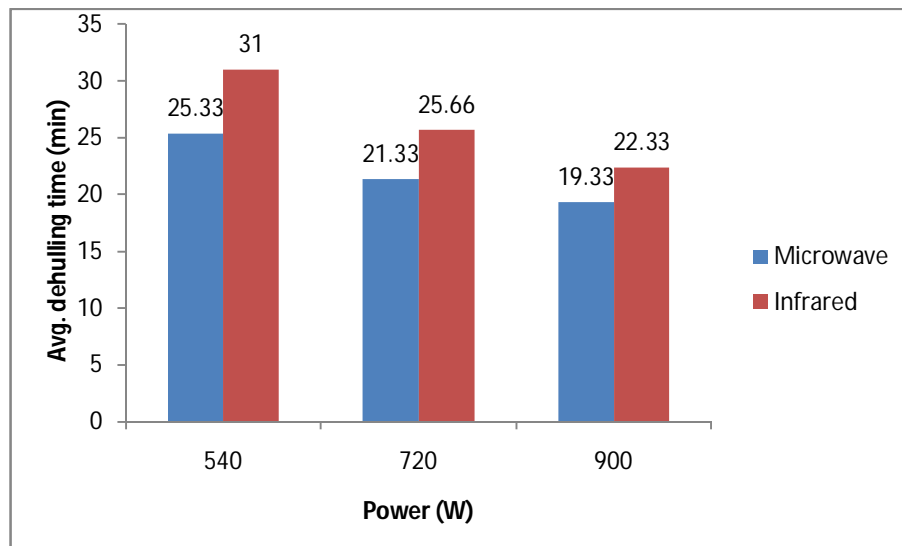


Fig 4.17: Effect of power levels of MW & IR on average dehulling time

4.6.2 Average Dehulling yield

Average dehulling yield were observed to be 81%, 81.33% & 81% and 80.33%, 83% & 83% at the power levels of 540W, 720W& 900W when the exposure time was varied from 5 min to 9 min in both the treatments microwave and infrared respectively (Fig 4.18). From the it can be inferred that the average dehulling yield in both the treatments *i.e.*, in microwave and infrared goes on increasing with the increase in microwave power level and exposure time. It is also clear that the dehulling yield was high in case of infrared treatment compared to that of microwave treatment at higher power levels 720 and 900 watts. At the starting levels of power levels microwave yield is higher than infrared.

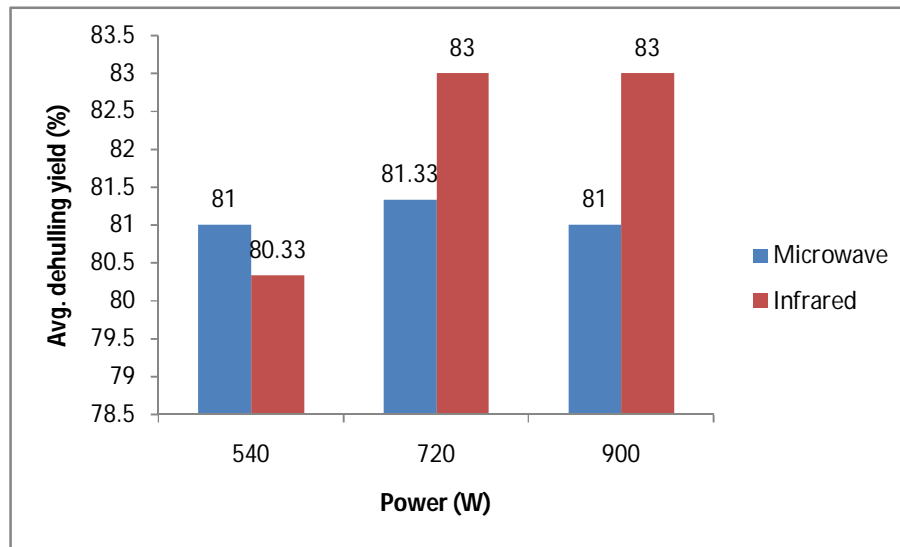


Fig 4.18: Effect of power levels of MW & IR on average dehulling yield

4.6.3 Average Dhal yield

Average dhal yield were observed to be 77.6%, 77.33% & 78.33% and 77.16%, 79.83% & 79% at the power levels of 540W, 720W & 900W when the exposure time was varied from 5 min to 9 min in both the treatments microwave and infrared respectively (Fig 4.19).

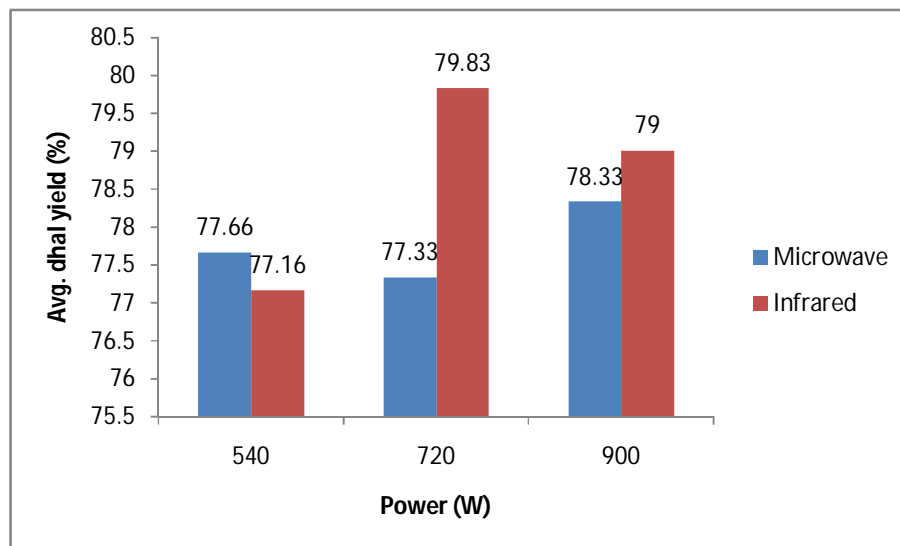


Fig 4.19: Effect of power levels of MW & IR on average dhal yield

From the Fig it can be inferred that the average dhal yield doesn't follow any regular trend in both the treatments i.e., in microwave and infrared. In comparison of both treatments the maximum dhal yield is obtained in infrared at 720 & 900 watts. The average dhal yield is higher in microwave at lower levels of power i.e. at 540W.

4.6.4 Average dehulling loss

Average dehulling loss at microwave power levels viz., 540W, 720W and 900W for with exposure time varying from 5 to 9 min was 9.33%, 9% & 8% respectively and the average dehulling loss in IR treatment at different power levels and exposure time was 7.5%, 7.83% & 5.5% respectively (4.20). From the figure it can be inferred that the average dehulling loss in both the treatments i.e., in microwave and infrared goes on decreasing with the increase in power level and exposure time. It can be inferred from the figure that the dehulling loss is high at minimum power levels and low at higher power levels in both the treatments. The minimum dehulling losses are obtained in infrared treatment compared to that of microwave treatment.

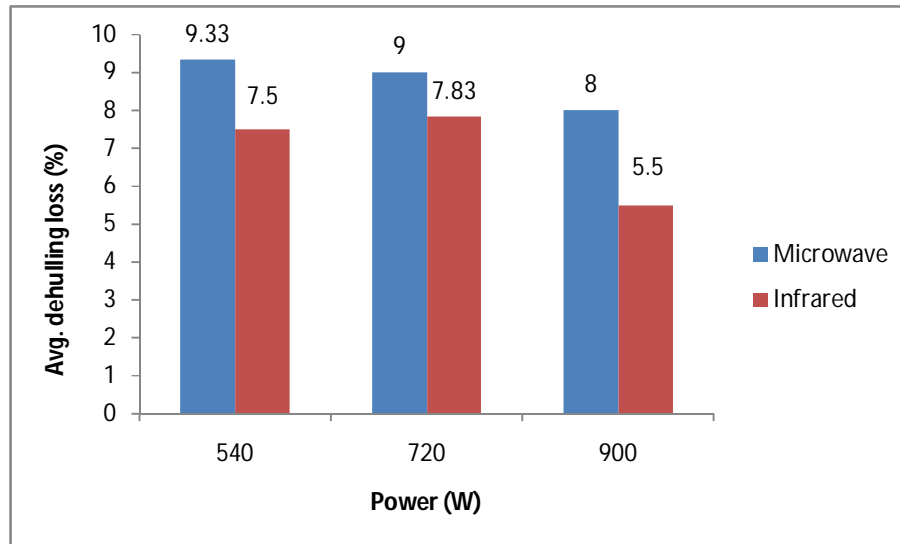


Fig 4.20: Effect of power levels of MW & IR on average dehulling loss

4.6.5 Average Cooking time

Avg. cooking time at each microwave power levels viz., 540W, 720W and 900W with exposure time varying from 5 to 9 min is 14.96 min, 13.23 min & 10.96 min respectively and the average cooking time in infrared treatment at different power levels and exposure time is 17.43 min, 14.5 min & 12.1 min respectively (4.21). From the figure it can be inferred that average cooking time in both the treatments i.e., in microwave and infrared goes on decreasing with the increase in power level and exposure time. It is clear that the cooking time is low in case of microwave treatment compared to that of infrared

1	<u>900.000</u>	<u>5.309</u>	21.33	83.562	81.127	7.365	13.113	<u>0.806</u>	<u>Selected</u>
2	900.000	5.331	21.29	83.545	81.099	7.334	13.086	0.806	
3	900.000	5.268	21.39	83.593	81.177	7.422	13.163	0.806	
4	900.000	5.362	21.24	83.521	81.061	7.292	13.048	0.805	
5	900.000	5.213	21.48	83.632	81.243	7.503	13.230	0.805	
6	900.000	5.128	21.62	83.691	81.345	7.635	13.334	0.803	
7	900.000	5.667	20.77	83.263	80.671	6.936	12.674	0.797	
8	900.000	6.048	20.22	82.878	80.148	6.632	12.201	0.768	
9	540.000	8.551	22.71	82.935	79.769	8.126	13.736	0.665	
10	540.002	8.575	22.68	82.947	79.791	8.150	13.715	0.665	
11	540.000	8.591	22.66	82.954	79.805	8.166	13.703	0.665	

Table 4.19: Optimization of process parameters for IR treatment

Number	IR Power	ET	R ₁	R ₂	R ₃	R ₄	R ₅	Desirability	Status
1	<u>900.000</u>	<u>7.668</u>	<u>20.616</u>	<u>84.474</u>	<u>79.225</u>	<u>5.093</u>	<u>11.092</u>	<u>0.755</u>	<u>Selected</u>
2	899.983	7.650	20.648	84.478	79.229	5.099	11.113	0.755	
3	899.999	7.709	20.541	84.463	79.218	5.079	11.045	0.755	
4	899.980	7.622	20.701	84.484	79.233	5.109	11.146	0.755	

CHAPTER V

SUMMARY AND CONCLUSIONS

5.1 Summary

This chapter deals with the summary of the findings from the present research and the conclusions inferred there from. Black gram is known to be the reserves of nutrients providing energy, dietary fibre, protein, minerals and vitamins required for human health. India ranks first in pulse production by contributing about 27% to the global pulse production and about 30 percent of the total consumption in the world of 72 million tonnes. Black gram (*Vignamungo L*) or urad is one of the important pulses containing 24% protein, 59.6% carbohydrate and 1.4% fat.

According to estimate made by different scientists, the post-harvest losses in pulses were in the range of 25-30%. 75% of the production i.e., 11.25 million tonnes goes for milling, taking 15% losses into account, 1.69 million tons of produce is lost in milling alone, which can be saved by adopting improved pre-treatment milling methods and machineries.

Infrared treatment reduces cooking time of legumes by providing a more open microstructure that improves water absorption characteristics, provides softer texture, improves dehulling characteristics, increases degree of starch gelatinization, decreases protein solubility and reduces anti nutritional factors of legumes. Microwave heating technology has been used in pulse processing to reduce post-harvest losses during drying, milling, cooking and storage. By drying with microwave heating technology, a significant reduction of drying time with improved quality of the produce is obtained. Pre-milling treatment of microwave and infrared heating in milling of pulses is reported to reduce milling time and increases the milling efficiency compared to all traditional methods.

The present work was therefore undertaken with the following specific objectives:

1. To study the effect of microwave and infrared application on dehulling parameters of black gram.
2. To study the effect of microwave and infrared application on quality parameters of dehulled black gram.

The summary of the results is presented below:

Microwave treatment

1. Increase in the microwave power and exposure time increases the surface temperature of the grains. At 540 W, as the exposure time was increased from 5 to 9 min the average surface temperature of the grains increased from 65 to 98 °C. Corresponding increase in temperature at 720 and 900 W for the same timings of treatment were respectively, 83 to 118 °C and 91 to 143 °C.
2. The dehulling time of the black gram samples decreased with increasing exposure time and microwave power. It decreased from 29 to 22 s, 24 to 19 s and 22 to 17 s at 540, 720 and 900 watts.
3. Dehulling yield was increased with increase in micro wave power level and exposure time, it was observed that the dehulling yield increased in the range of 79% to 85% for 540, 700 and 900 watts respectively. A maximum dehulling yield observed was 85% at 900 watts power level and an exposure time of 5 minutes.
4. The maximum dhal yield of 82% was observed at a microwave power level of 900 watts and an exposure time of 5 minutes. A minimum dhal yield was observed at 540 watts for an exposure time of 5 minutes which was 75%.
5. The maximum dehulling loss observed was 11.50% at a microwave power level of 540 watts for an exposure time of 5 minutes. The minimum dehulling losses (6%) were observed at a maximum microwave power level of 900 watts for an exposure time of 7 minutes.
6. Minimum cooking time was obtained at microwave power of 900 watts and an exposure time of 9 minutes which was 8.5 minutes and the cooking time were very high at micro wave power level of 540 watts for an exposure time of 5 minutes which was 16.8 minutes.
7. The colour of the samples was reduced from 51.25 L values to 41.36 in microwave decreasing its whiteness.

Infrared treatment

1. Increase in the infrared power and exposure time increases the surface temperature of the grains.
2. The dehulling time of the black gram samples decreased with increasing exposure time and IR power. It decreased from 36 to 26s, 32 to 20 s and 26 to 19 s at 540, 720 and 900 watts respectively.
3. The dehulling yield increased in the range of 79% to 86% for 540, 700 and 900 watts respectively. A maximum dehulling yield observed was 86% at 900W power level and an exposure time of 7 minutes.

4. The maximum dhal yield of 82% was observed at a IR power level of 720 watts and an exposure time of 7 minutes. A minimum dhal yield was observed at 540 watts for an exposure time of 5 minutes which was 75%.
5. The minimum dehulling losses were observed at a maximum microwave power level of 900 watts for an exposure time of 7 minutes which was 4.5%.
6. A minimum cooking time was obtained at IR power of 900 watts and an exposure time of 9 minutes which was 9.8 minutes and the cooking time was very high at IR power level of 540 watts for an exposure time of 5 minutes which was 19.70 minutes.

Conclusion

The conclusions drawn from the present study are as follows:

Microwave & Infrared treatments on black gram play an important role in improving the dehulling qualities of black gram. The dehulling time for black gram was reduced by 41.3 % in microwave and to that of the infrared sample reduces by 47.2% and found less dehulling time in MW. Using the microwave treatment a maximum dehulling yield of 85 % and dhal yield of 82% was achieved as compared to 86% and 82% respectively for infrared sample. Even by the oil treatment method, maximum yield has been reported to be about 74.1 % which needed about 4 days in processing such as pitting, oil mixing, drying, water mixing and tempering before dehulling as well as use of a fair amount of edible oil (Sreerama et al., 2009). Also, the process poses risk for contamination. Using the microwave treatment minimum dehulling loss of 6% was achieved as compared to 4.5% respectively for infrared sample.

MW & IR pre-treatments eliminates these unit operations and thus reduces the total processing time, which ultimately results in energy saving. These treatments also eliminate the usage of oil which adds to the processing cost of the conventional oil pre-treatment method. In addition to that, the MW & IR treatment also helps in reducing the cooking time for dehulled dhal by approximately 49.4% & 50.25% which would be helpful in saving cooking energy. In the present study, a minimum dosage of about 2866.86 J/g was found to be the best for getting higher yield with almost a little change in colour of dhal and also having lesser cooking time. Dosage of about 4136.4 J/g was found to be the best for getting higher yield in infrared treatment. Relationships were developed for dehulling yield, dhal yield, dehulling loss, cooking time for the black gram dhal during both treatments. These results are useful for pulse processors as well as in

designing a microwave & infrared assisted continuous type pulse dehulling system. Thus it could be concluded that the modern heat treatments are beneficial for black gram dehulling and also presents an alternative to be commercially adopted. After optimizing the following are the probable best results obtained in the design expert software.

1. Microwave power level of 900 watts at an exposure time of 5.31 minutes give the corresponding best responses which were dehulling time 21.33s, dehulling yield 83.56%, dhal yield 81.12%, dehulling loss 7.64% and a cooking time of 13.11 minutes with a desirability of 0.806.
2. Infrared power level of 900 watts at an exposure time of 7.66 minutes give best responses which were dehulling time 20.61s, dehulling yield 84.74%, dhal yield 79.22%, dehulling loss 5.093% and a cooking time of 11.092 minutes with a desirability of 0.755.

CHAPTER VI

REFERENCES

- Adewumi, B. A. and Igbeka, J. C. 1993. The effect of steaming on the physical and dehulling characteristics of locust bean (*parkia biglobosa*). *Tropical Agriculture* **70**: 380-382.
- Algan, G. and Buyukkartal, H. N. 2000. Ultrastructure of seed coat development in the natural tetraploid *Trifolium pratense* L. *Journal of Agronomy and Crop Science* **184**: 205-213.
- Aliya, S. and Geervani, P. 1981. An assessment of the protein quality and vitamin B content of commonly used fermented products of legumes and millets. *Journal of the Science of Food and Agriculture* **32**: 837-842.
- Alizadeh, M. R. and Bagheri, I. 2009. Field performance evaluation of different rice threshing methods. *International Journal of Natural and Engineering Sciences* **3**: 139-143.
- American Association of Cereal Chemists. 1995. Experimental (test) milling AACC Method 26-95 Test Milling: temper table. In American Association of Cereal Chemists Approved Methods, 1-9. St. Paul, MN: American Association of Cereal Chemists Inc.
- Anton, A.A.; Ross, K.A.; Beta, T.; Fulcher, R.G. and Arntfield, S.D. 2008. Effect of pre-dehulling treatments on some nutritional and physical properties of navy and pinto beans (*Phaseolus vulgaris* L.). *LWT-Food Science and Technology* **41**: 771-778.
- ASAE Standards. 2003. Moisture measurement-unground grain and seeds. *St. Joseph, Mich* **36**: 79-90.
- Aydin, C. and Konak, M. 2002. PH-Postharvest Technology: Some Physical Properties of Turkish Mahaleb. *Biosystems Engineering* **82**: 231-234.
- Barriga, C. 1961. Effects of mechanical abuse of navy bean seed at various moisture levels. *Agronomy Journal* **53**: 250-251.
- Bate-Smith, E. C. 1958. The contribution of phenolic substances to quality in plant products. *Qualitas Plantarum et Materiae Vegetabiles*, **3**: 440-455.
- Bellido, G.; Arntfield, S.D.; Cenkowski, S. and Scanlon, M. 2006. Effects of micronization pretreatments on the physicochemical properties of navy and black beans (*Phaseolus vulgaris* L.). *LWT-Food Science and Technology* **39**: 779-787.

- Berrios, J.D.J.; Swanson, B.G. and Cheong, W.A. 1999. Physio-chemical characterization of stored black beans. (*Phaseolus Vulgaris L.*) *Food Research International* **32**: 669-676.
- Bhattacharya, K. R. and Swamy, Y. I. 1967. Conditions of drying parboiled paddy for optimum milling quality. *Cereal chemistry* **44**: 592-600.
- Bhattacharya, S. 1996. Kinetics on colour changes in rice due to parboiling. *Journal of Food Engineering* **29**: 99-106.
- Black, R. G.; Singh, U. and Meares, C. 1998. Effect of genotype and pretreatment of field peas (*Pisum sativum*) on their dehulling and cooking quality. *Journal of the Science of Food and Agriculture* **77**: 251-258.
- Burridge, P.; Hensing, A. and Petterson, D. 2001. Australian pulse quality laboratory manual. *SARDI Grain Laboratory for GRDC, Urrabrae* pp: 231-243
- Carman, K. 1996. Some physical properties of lentil seeds. *Journal of Agricultural Engineering Research* **63**: 87-92.
- Chakraverty, A. 1994. Post-harvest technology of cereals, pulses and oil seeds, Oxford and IBH Publishing Co. Pvt. Ltd.
- Chua, K. J. and Chou, S. K. 2005. A comparative study between intermittent microwave and infrared drying of bio-products. *International Journal of Food Science & Technology* **40**: 23-39.
- CRN India, 2011. Urad. CRN India. Available from: <http://www.crnindia.com/commodity/urad.html>.
- Daniella, A. L. 2010. Effect of storage pre-treatments and conditions on the dehulling efficiency and cooking quality of red lentils (<http://hdl.handle.net/1993/3986>, (2010/5/7)).
- DeMan, J. M.; Banigo, E. O. I.; Rasper, V.; Gade, H. and Slinger, S. J. 1973. Dehulling of sorghum and millet with the palyi compact milling system. *Canadian Institute of Food Technology journal* **6**: 188-193.
- Deshpande, S. D.; Balasubramanya, R. H.; Khan, S. and Bhatt, D. K. 2007. Influence of premilling treatments on dal recovery and cooking characteristics of pigeon pea. *Journal of Agricultural Engineering* **44**: 53-56.
- Deshpande, S.D.; Salokhe, V.M. and Soni, P. 2009. Enhancing dal recovery by application of soy-oil-water and sodium bicarbonate premilling treatments. *Asian Association for Agricultural Engineering* **26**: 79-93.

- Dickson, M. H.; Duczmal, K. and Shannon, S. 1973. Imbibition rate and seed composition as factors affecting transverse cotyledon cracking in bean (*Phaseolus vulgaris* L.) seed. *Journal of American Soc. Horticultural Sciences* **98**: 509-513.
- Dorrell, D. G. 1968. Seed coat damage in navy beans, (*Phaseolus Vulgaris* (L.)), induced by mechanical abuse **6**: 79-90.
- Dronachari, M. and Yadav, B.K. 2015. Application of Microwave Heat Treatment in Processing of Pulses. *Journal of Academia and Industrial Research* **3**: 401.
- Dutta, S. K.; Nema, V. K. and Bhardwaj, R. K. 1988. Thermal properties of gram. *Journal of Agricultural Engineering Research* **39**: 269-275.
- Ehiwe, A. O. F. and Reichert, R. D. 1987. Variability in dehulling quality of cowpea, pigeon pea, and mung bean cultivars determined with the tangential abrasive dehulling device. *Cereal chemistry* **36**: 65-90.
- Ehiwe, A. O. F.; Reichert, R. D.; Humbert, E. S. and Mazza, G. 1986. Genotypic and Environmental Factors Affecting Seed Coat Durability of Field Peas. *Canadian Institute of Food Science and Technology Journal* **19**: 272-286.
- Ehiwe, A. O. F.; Reichert, R. D.; Schwab, D. J.; Humbert, E. S. and Mazza, G. 1987. Effect of seed moisture content and temperature on the seed coat durability of field pea. *Cereal chemistry* **3**: 146-149
- Erskine, W.; Williams, P. C. and Nakkoul, H. 1985. Genetic and environmental variation in the seed size, protein, yield, and cooking quality of lentils. *Field Crops Research* **12**: 153-161.
- Erskine, W.; Williams, P. C. and Nakkoul, H. 1991. Splitting and dehulling lentil (*Lens culinaris*): effects of seed size and different pretreatments. *Journal of the Science of Food and Agriculture* **57**: 77-84.
- Fasina, O.; Tyler, B.; Pickard, M.; Zheng, G.H. and Wang, N. 2001. Effect of infrared heating on the properties of legume seeds. *International Journal of Food Science & Technology* **36**: 79-90.
- Gallardo, F., Araya, H., Pak, N. and Tagle, M. A. 1974. Toxic factors in Chilean legumes II. Trypsin inhibitor activity. *Archivos Latinoamericanos de Nutrición* **24**: 183-189.
- Gopalan, C.; Sastri, R.B.V. and Balasubramanian, S.C. 1989. Nutritive Value of Indian Foods. *National Institute of Nutrition, ICMR, Hyderabad* 59-93.
- Gowen, A.A.; Abu-Ghannam, N.; Frias J. and Oliveira, J. 2008. Modelling dehydration and rehydration of cooked soyabean subjected to combined microwave and hot air drying. *Innovative Food Science & Emerging Technologies* **29**: 207-214.

- Goyal, R. K.; Vishwakarma, R. K. and Wanjari, O. D. 2008. Optimisation of the pigeon pea dehulling process. *Biosystems Engineering* **99**: 56-61.
- Goyal, R. K.; Vishwakarma, R. K. and Wanjari, O. D. 2009. Optimization of process parameters and mathematical modelling for dehulling of pigeonpea. *International Journal of Food Science & Technology* **44**: 36-41.
- Goyal, R. K.; Vishwakarma, R. K. and Wanjari, O. D. 2010. Effect of Moisture Content on Pitting and Milling Efficiency of Pigeon Pea Grain. *Food and Bioprocess Technology* **3**: 146-149.
- Henderson, S. M.; Perry, R. L. and Young, J. H. 1997. Principles of process engineering (Ed. 4). Kenya Agricultural Research Institute (KARI).
- Hiregoudar, S.; Sandeep, T.N.; Nidoni, U.; Shrestha, B. and Meda, V. 2014. Studies on dhal recovery from pre-treated pigeon pea (*Cajanus cajan L.*) cultivars. *Journal of Food Science and Technology* **51**: 922-928.
- <https://www.grainscanada.gc.ca/index-eng.htm>
- Hu, F. B. 2003. Plant-based foods and prevention of cardiovascular disease: an overview. *The American Journal of Clinical Nutrition* **78**: 544S-551S.
- Ikebudu, J. A.; Sokhansanj, S.; Tyler, R. T.; Milne, B. J. and Thakor, N. S. 2000. Grain conditioning for dehulling of canola. *Canadian Agricultural Engineering* **42**: 27-32.
- Isik, E. 2007. Some physical and mechanical properties of round red lentil grains. *Applied Engineering in Agriculture* **23**: 503-509.
- Iyer, L.; Flinn, P. C.; Black, R. G.; Brouwer, J. B. and Meares, C. 1998. Estimating the food processing characteristics of pulses by near infrared spectroscopy, using ground or whole samples. *Journal of Near Infrared Spectroscopy* **6**: 213-220.
- Jacobs Jr, D. R. and Gallaher, D. D. 2004. Whole grain intake and cardiovascular disease: a review. *Current Atherosclerosis Reports* **6**: 415-423.
- Jaynes, J.; Ding, X.; Xu, H.; Wong, W. K. and Ho, C. M. 2013. Application of fractional factorial designs to study drug combinations. *Statistics in Medicine* **32**: 307-318.
- Joyner, J.J. and Yadav, B.K. 2013. Microwave assisted dehulling of black gram (*Vignamungo L.*). *Journal of Food Science and Technology* **52**: 2003-2012.
- Kakade, M. L. and Evans, R. J. 1966. Effect of soaking and germinating on the nutritive value of navy beans. *Journal of Food Science* **31**: 781-783.
- Kakati, P.; Deka, S. C.; Kotoki, D. and Saikia, S. 2010. Effect of traditional methods of processing on the nutrient contents and some anti-nutritional factors in newly

- developed cultivars of green gram [*Vigna radiata* (L.)] and black gram [*Vigna mungo* (L.) Hepper] of Assam, India. *International Food Research Journal* **17**: 377-384.
- Kannenbergh, L. W. and Allard, R. W. 1964. An association between pigment and lignin formation in the seed coat of the lima bean. *Crop Science* **4**: 621-622.
- Khamgaonkar, S. G.; Singh, A.; Chand, K.; Shahi, N. C. and Lohani, U. C. 2013. Processing technologies of Uttarakhand for lesser known crops: An overview. *Journal of Academic Industrial Resources* **1**: 447-452.
- Kimura, T. 1993. Discoloration characteristics of rice during parboiling: Effect of processing conditions on the colour intensity of parboiled rice. *Journal of Japanese Society of Agricultural Structures* **24**: 23-30.
- Krishnamurthy, K.; Girish, R.K.; Ramasivan, T.; Bose, S.K.; Singh, K. and Tomar, R.S.D. 1972. A new process for the removal of husk from red gram using sirka. *Bulletin of Grain Technology* **10**: 181-186.
- Kurien, P. P. 1980, December. Advances in milling technology of pigeonpea. *International Workshop on Pigeonpeas* Vol. 1, pp. 321-328.
- Kurien, P. P. 1981. Processing of pulses. In *Grain Legumes: Agronomy and Crop Improvement, Processing and Storage, Marketing, and Nutrition* **37**: 527-537
- Kurien, P. P. 1984. Dehulling technology of pulses. *Research and Industry* **29**: 207-214.
- Kurien, P. P. and Parpia, H. A. B. 1968. Pulse milling in India. I-Processing and milling of Tur, Arhar (*Cajanus cajan* Linn). *Journal of Food Science and Technology (Mysore)* **5**: 203-207.
- Lal, R.R. and Prason Verma. 2007. *Technical Bulletin*, Indian Institute of Pulse Research.
- Liener, I. E. 1962. Toxic factors in edible legumes and their elimination. *The American Journal of Clinical Nutrition*, **11**: 281-298.
- Mangaraj, S. 2011. Milling study of multiple pulses using CIAE dhal mill for optimal responses. *Journal of Food Processing & Technology* **2**:110.
- Mangaraj, S. and Kapur, T. 2005. Milling Studies of Pulses using Different Pre-Milling Treatments and Abrasive Roller Assembly. *Agricultural Engineering Today* **29**:64-70.
- Mangaraj, S. and Singh, K. 2009. Optimization of machine parameters for milling of pigeon pea using RSM. *Food and Bioprocess Technoogy* **10**: 181-186

- Mangaraj, S.; Agrawal, S.; Kapoor, T. and Kulkarni, S. D. 2004. Effect of Pre-milling Treatment and Abrasive Roller on Milling of pulses. *Journal of Agricultural Engineering*, **41**: 10-15.
- Mazza, G. and Campbell, C. G. 1985. Influence of water activity and temperature on dehulling of buckwheat. *Cereal Chemistry* **7**: 203-207
- McEwen, T. J.; Dronzek, B. L. and Bushuk, W. 1974. Scanning electron microscope study of fababean seed. *Cereal Chemistry* **16**: 43-52
- Miah, M. A.; Haque, A.; Douglass, M. P. and Clarke, B. 2002. Parboiling of rice. Part I: Effect of hot soaking time on quality of milled rice. *International Journal of Food Science & Technology* **37**: 527-537.
- Mirasgedis, S.; Makatsoris, J.; Assimacopoulos, D.; Papagiannakis, L. and Zervos, A. 1996. Energy conservation and CO₂-emission abatement potential in the Greek residential services sector. *Energy* **21**: 871-878.
- Mohapatra, D. and Bal, S. 2007. Effect of degree of milling on specific energy consumption, optical measurements and cooking quality of rice. *Journal of Food Engineering* **80**: 119-125.
- Mohoric, A.; Vergeldt, F.; Gerkema, E.; Van Dalen, G.; Van den Doel, L. R.; Van Vliet, L. J. and Van Duynhoven, J. 2009. The effect of rice kernel microstructure on cooking behaviour: A combined μ -CT and MRI study. *Food Chemistry* **115**: 1491-1499.
- Moise, J. A.; Han, S.; Gudynaitė-Savitch, L.; Johnson, D. A. and Miki, B. L. 2005. Seed coats: structure, development, composition, and biotechnology. *In Vitro Cellular & Developmental Biology-Plant* **41**: 620-644.
- Mpagalile, J. J.; Laswai, H. S.; Ballegu, W. R. and Silayo, V. C. 2008. The effectiveness of a novel steaming method in improving small scale soybean dehulling. *African Journal of Food, Agriculture, Nutrition and Development* **8**: 304-318.
- Mugendi, J.B.; Njagi, E.N.M.; Kuria, E.N.; Mwasaru, M.A.; Mureithi, J.G. and Apostolides, Z. 2010. Effects of processing technique on the nutritional composition and anti-nutrient content of mucuna bean (*Mucuna pruriens L.*). *African Journal of Food Science* **4**: 155-166.
- Mwangwela, A.M.; Waniska, R.D. and Minnaar, A. 2006. Hydrothermal treatments of two cowpea (*Vigna unguiculata L.*) varieties: Effect of micronisation on physicochemical and structural characteristics. *Journal of the Science of Food and Agriculture* **86**:35-45.

- Mwangwela, A.M.; Waniska, R.D.; McDonough, C. and Minnaar, A. 2007. Cowpea cooking characteristics as affected by micronisation temperature: a study of the physicochemical and functional properties of starch. *Journal of the Science of Food and Agriculture* **87**:399-410.
- Myers, R. H.; Montgomery, D. C. and Anderson-Cook, C. M. 2016. Response Surface Methodology: Process and Product Optimization using designed experiments **4**: 547-556
- Narasimha, H. V. and Desikachar, H. S. R. 1978. Objective methods for studying cookability of tur pulse (*Cajanus cajan*) and factors affecting varietal differences in cooking. *Journal of Food Science and Technology* **15**: 47-50.
- Narasimha, H. V.; Ramakrishnaiah, N. and Pratape, V. M. 2003. Conditioning and Dehulling of Pigeon Peas and Mung Beans. Presentation at the CSAE/SCGR 2003 Meeting, Montreal, Quebec. Paper No. **03**: 347-452.
- Nevena, M. M.; Koprivica, G. B. and Pezo, L. L. 2012. Optimization of the osmotic dehydration of carrot cubes in sugar beet molasses. *Thermal science* **16**: 43-52.
- Oomah, B. D.; Kotzeva, L.; Allen, M. and Bassinello, P. Z. 2014. Microwave and micronization treatments affect dehulling characteristics and bioactive contents of dry beans (*Phaseolus vulgaris* L.). *Journal of the Science of Food and Agriculture* **94**: 1349-1358.
- Opoku, A.; Tabil, L. G.; Sundaram, J.; Crerar, B. J. and Park, S. J. 2003. Conditioning and dehulling of pigeon peas and mung beans **4**: 03- 347.
- Padhye, V. W. and Salunkhe, D. K. 1978. Biochemical studies on black gram (*Phaseolus mungo* L.). Fermentation of the black gram and rice blend and its influence on the in vitro digestibility of the proteins. *Journal of Food Biochemistry* **2**: 327-347.
- Phirke, P. S. and Bhole, N. G. 1999. The effect of pre-treatment on the strength and dehulling properties of pigeonpea grain. *International Journal of Food Science & Technology* **34**: 107-113.
- Phirke, P. S.; Bhole, N. G. and Adhoo, S. H. 1994. Effect of pretreatment on strength properties of pigeon pea grain for dehulling. *Indian Journal of Nutritional Diet* **31**: 265-272.
- Phirke, P. S.; Bhole, N. G. and Adhoo, S. H. 1996. Response surface modelling and optimization for dehulling of pigeonpea with different pretreatments and conditions. *Journal of Food Science and Technology* **33**: 47-52.

- Phirke, P. S.; Umbarkar, S. P. and Tapre, A. B. 1992. Evaluation of chemical pretreatment of pigeon pea grains for milling. *Indian Journal of Agricultural Engineering* **2**: 141-142.
- Phirke, P. S. and Bhole, N. G. 2000. Pretreatment of pigeon pea grain for improvement of dehulling characteristics. *International Journal of Food Science & Technology* **35**: 305-313.
- Pihlanto, A. and Korhonen, H. 2000. Bioactive peptides and proteins. *Advances in Food and Nutrition Research* **47**: 175-276.
- Pillaiyar, P. and Mohandoss, R. 1981. Hardness and colour in parboiled rices produced at low and high temperatures. *Journal of Food Science and Technology* **105**: 235-238.
- Purohit, P.; Jayas, D. S.; Chelladurai, V. and Yadav, B. K. 2013. Microwave treatment of mung bean (*Vignaradiata*) for reducing the cooking time. *Applied Engineering in Agriculture* **4**: 547-556.
- Ramakrishnaiah, N. and Kurien, P. P. 1983. Variabilities in the dehulling characteristics of pigeon pea (*Cajanus cajan L.*) cultivars. *Journal of food science and technology*, **20**: 287-291.
- Ranghino, F. (1996). Evaluation of rice resistance to cooking based on the gelatinization time of kernels **12**: 117-127.
- Reddy, A. A. 2013. Strategies for reducing mismatch between demand and supply of grain legumes. *Indian Journal of Agricultural Sciences*, **83**:243-59.
- Reddy, K. S.; Rao, D. S.; Rao, Z. P. and Prasad, J. R. 2000. Effect of inclusion of varying levels of urad (*Phaseolus mungo*) chuni in concentrate mixtures on the nutrient utilization in native male buffaloes. *Buffalo Bull* **19**:43-47.
- Reddy, N. R.; Pierson, M. D.; Sathe, S. K. and Salunkhe, D. K. 1985. Dry bean tannins: a review of nutritional implications. *Journal of the American Oil Chemists Society* **62**: 541-549.
- Reichert, R. D. and Ehiwe, A. O. F. 1987. Variability, heritability and physiochemical studies of seed coat durability in field pea. *Canadian Journal of Plant Science* **67**: 667-674.
- Reichert, R. D. and Youngs, C. G. 1976. Dehulling cereal grains and grain legumes for developing countries. Quantitative comparison between attrition-and abrasive-type mills. *Cereal Chemistry* **53**: 829-838.

- Reichert, R. D.; Oomah, B. D. and Youngs, C. G. 1984. Factors Affecting the Efficiency of Abrasive-Type Dehulling of Grain Legumes Investigated with a New Intermediate-Sized, Batch Dehuller. *Journal of Food Science* **49**: 267-272.
- Rout, B.; Sahoo, S. and Senapati, P.K. 2007. Effect of pre milling treatment on protein and carbohydrate content in tribal pulses. *Indian Journal of Traditional Knowledge* **6**: 69-71.
- Roy, P.; Shimizu, N. and Kimura, T. 2004. Energy conservation in cooking of milled raw and parboiled rice. *Food science and technology research* **10**:121-126.
- Sahay, K. M. and Bisht, B. S. 1988. Development of a small abrasive cylindrical mill for milling pulses. *International Journal of Food Science & Technology* **23**: 17-22.
- Sahay, K. M.; Agrawal, S. P., and Bisht, B. S. 1985. Optimization of emery/carborundum grade for pulse dehulling for 100 kg/h capacity. *RPF-III, project, (111)* **56**: 379-386.
- Sahay, K.M. and Singh, K.K. 2001. Unit operations in agricultural processing, Vikas Publishing House Pvt. Ltd.
- Salve, V.A.; Phirke, P.S.; Turbatmath, P.A. and Rane, S.V. 2008. Thermo-chemical pretreatment for dehulling of pigeon pea grain. *International Journal of Agricultural Engineering* **1**: 65-70.
- Sareepuang, K.; Siriamornpun, S.; Wiset, L. and Meeso, N. 2008. Effect of soaking temperature on physical, chemical and cooking properties of parboiled fragrant rice. *World Journal of Agricultural Sciences* **4**: 409-415.
- Saxena, R. P. 1985. Milling of pigeon pea (*Cajanus cajan*) and associated aspects **23**: 17-22.
- Saxena, R. P.; Singh, B. P. N.; Salokhe, V. M. and Ilangantileke, S. G. 1990. Electronmicroscopic studies of sodium bicarbonate treated pigeonpea grain (*Cajanus Cajan L.*) for making dhal. *Asian Institute of Technology* (pp. 751-760) **32**: 81-93
- Sefa-Dedeh, S. and Stanley, D. W. 1979. The relationship of microstructure of cowpeas to water absorption and dehulling properties. *Cereal Chemistry* **56**: 379-386.
- Siddique, M. A. and Goodwin, P. B. 1980. Maturation temperature influences on seed quality and resistance to mechanical injury of some snap bean genotypes. *Journal of the American Society for Horticultural Science* **105**: 235-238.

- Singh, D. and Sokhansanj, S. 1984. Cylinder concave mechanism and chemical treatment for dehulling pigeon peas. *AMA, Agricultural Mechanization in Asia, Africa and Latin America* **92**: 389-395
- Singh, R.; Singh, K.K. and Kotwaliwale, N. 2012. Study on disinfestation of pulses using microwave technique. *Journal of Food Science and Technology* **49**: 505-509.
- Singh, U. 1995. Methods for dehulling of pulses: a critical appraisal. *Journal of Food Science and Technology* **32**: 81-93.
- Singh, U.; Santosa, B. A. S. and Rao, P. V. 1992. Effect of dehulling methods and physical characteristics of grains on dhal yield of pigeonpea (*Cajanus-Cajan L.*) genotypes. *Journal of Food Science and Technology* **29**: 350-353.
- Sokhansanj, and Patil, R. T. 2003. Dehulling and splitting pulses. *Handbook of postharvest technology: cereals, fruits, vegetables, tea, and spices* **93**: 397.
- Sreenarayanan, V. V. and Devadas, C. T. 2000. Status of pulse milling techniques. *Pulses Production Strategies in India* **43**: 1458-1463
- Sreerama, Y. N.; Sashikala, V. B. and Pratape, V. M. 2009. Effect of enzyme pre-dehulling treatments on dehulling and cooking properties of legumes. *Journal of food engineering* **92**: 389-395.
- Sreerama, Y. N.; Sasikala, V. B. and Pratape, V. M. 2008. Nutritional implications and flour functionality of popped/expanded horse gram. *Food chemistry* **108**: 891-899.
- Srivastava, A. K.; Goering, C. E.; Rohrbach, R. P. and Buckmaster, D. R. 2006. Engineering Principles of Agricultural Machines. *American Society of Agricultural and Biological Engineers* **25**: 733-741
- Srivastava, V.; Mishra, D. P.; Chand, L.; Gupta, R. K. and Singh, B. P. N. 1988. Influence of soaking on various biochemical changes and dehusking efficiency in pigeon pea (*Cajanus cajan L.*) seeds. *Journal of Food Science and Technology* **25**: 267-271.
- Stanley, D. W. 1992. A possible role for condensed tannins in bean hardening. *Food Research International* **43**: 1458-1463.
- Susheelamma, N. S. and Rao, M. V. L. 1979. Effect of simple processing on the properties of protein and polysaccharide from black gram. *International Journal of Food Science & Technology* **14**:463-472.
- Tang, G. Y.; Li, X. J. and Zhang, H. Y. 2008. Antidiabetic components contained in vegetables and legumes. *Molecules* **13**: 1189-1194.

- Tavman, S. and Tavman, I. H. 1998. Measurement of effective thermal conductivity of wheat as a function of moisture content. *International Communications in Heat and Mass Transfer* **25**: 733-741.
- Tharanathan, R. N. and Mahadevamma, S. 2003. Grain legumes- a boon to human nutrition. *Trends in Food Science & Technology* **14**: 507-518.
- Thomson, J.R. 1979. An introduction to seed technology. John Wiley and Sons, inc ., Toronto, Ont. pp.252.
- Tiwari, B. K.; Gowen, A. and McKenna, B. (Eds.). 2011. *Pulse foods: Processing, Quality and Nutraceutical Applications* **88**: 108-115.
- Tiwari, B. K.; JaganMohan, R. and Vasani, B. S. 2007. Effect of heat processing on milling of black gram and its end product quality. *Journal of Food Engineering* **78**: 356-360.
- Tiwari, B. K.; JaganMohan, R. and Vasani, B. S. 2008a. Effect of several pre-treatments on the physical characteristics of dehulled fraction of pigeon pea (*Cajanus cajan L.*). *International Journal of Food Science & Technology* **43**: 1458-1463.
- Tiwari, B. K.; JaganMohan, R.; Venkatachalapathy, N.; Anand, M. T.; Surabi, A. and Alagusundaram, K. 2010. Optimisation of hydrothermal treatment for dehulling pigeon pea. *Food Research International* **43**: 496-500.
- Tiwari, B. K.; Mohan, R. J. and Vasani, B. S. 2008b. Effect of different premilling treatments on dehulling of black gram (*Phaseolus mungo L.*). *Journal of Food Processing and Preservation* **32**:610-620.
- Turhan, M. and Sagol, S. 2004. Abrupt changes in the rates of processes occurring during hydrothermal treatment of whole starchy foods around the gelatinization temperature-a review of the literature. *Journal of Food Engineering* **62**: 365-371.
- Urbano, G.; Aranda, P.; Gómez-Villalva, E.; Frejnagel, S.; Porres, J. M., Frias, J. and Lopez-Jurado, M. 2003. Nutritional evaluation of pea (*Pisum sativum L.*) protein diets after mild hydrothermal treatment and with and without added phytase. *Journal of Agricultural and Food Chemistry* **51**: 2415-2420.
- Vadivambal, R.; Jayas, D.S. and White, N.D.G. 2007. Wheat disinfection using microwave energy. *Journal of Stored Products Research* **43**:508-514.
- Vandenberg, A. and Slinkard, A. E. 1990. Genetics of seed coat colour and pattern in lentil. *Journal of Heredity* **81**: 484-488.

- Verma, P.; Saxena, R. P.; Sarkar, B. C. and Omre, P. K. 1993. Enzymatic pretreatment of pigeonpea (*Cajanus cajan L.*) grain and its interaction with milling. *Journal of Food Science and Technology (India)*.
- Wang, H. L. and Grusak, M. A. 2005. Structure and development of *Medicago truncatula* pod wall and seed coat. *Annals of botany* **95**: 737-747.
- Wang, N. 2005. Optimization of a Laboratory Dehulling Process for Lentil (*Lens culinaris*) 1. *Cereal Chemistry* **82**: 671-676.
- Wang, N. 2008. Effect of variety and crude protein content on dehulling quality and on the resulting chemical composition of red lentil (*Lens culinaris*). *Journal of the Science of Food and Agriculture* **88**: 885-890.
- Walia, N. K.; Sekhon, K. K.; Cameotra, S. S.; Chaudhary, D. P.; Srivastava, P. and Dutta, A. 2014. Optimization of Fermentation Parameters for Bioconversion of Corn to Ethanol Using Response Surface Methodology. *Journal of Petroleum & Environmental Biotechnology*, 2014.
- Williams, P. C. and Singh, U. 1998. Nutritional quality and the evaluation of quality in breeding programmes. *The chickpea* 329-356.
- Williams, P.; El-Haramein, F. J.; Nakkoul, H. and Rihawi, S. 1988. Crop quality evaluation methods and guidelines. *ICARDA Technical Manual, International Center for Agricultural Research in the Dry Areas, Syria* **14**: Ed. 2.
- Wood, J. A.; Knights, E. J. and Harden, S. 2008. Milling performance in desi-type chickpea (*Cicer arietinum L.*): Effects of genotype, environment and seed size. *Journal of the Science of Food and Agriculture* **88**: 108-115.
- www.fao.org/statistics/en/.
- Yalcin, I. and Ozarslan, C. 2004. *Physical properties of vetch seed. Biosystems Engineering* **88**: 507-512.
- Yalcin, S. and Basman, A. 2015. Effects of infrared treatment on urease, trypsin inhibitor and lipoxigenase activities of soybean samples. *Food Chemistry* **169**: 203-210.
- Yoganandhan, K. and Hameed, A. S. 2000. Evaluation of Red Gram, (*Cajanus cajan*) and Black Gram, (*Vigna mungo*) Husks as Food for Brine Shrimp, *Artemia sp.*, Culture. *Journal of Applied Aquaculture* **10**:79-85.
- Zamfir, C. I. 2009. Study on the authenticity and typicity of red wines obtained from local grape varieties. (Doctoral dissertation, PhD Thesis) (pp. 51-76)

- Zareiforush, H.; Komarizadeh, M. H. and Alizadeh, M. R. 2010. Performance evaluation of a 15.5 cm screw conveyor during handling process of rough rice (*Oriza Sativa L.*) grains. *Nature and Science* **8**: 66-74.
- Zhang, Y.; Tabil, L. G.; Li, X. and Opoku, A. 2008b. Effect of moisture content, postharvest treatment, and storage time on some properties and quality attributes of red lentil.