2.1. Origin

The pigeon pea (*Cajanus cajan* L.) is a perennial legume from the family Fabaceae. Since its domestication in South Asia at least 3,500 years ago, its seeds have become a common food grain in Asia, Africa, and Latin America.

**Scientific Classification**

- **Kingdom:** Plantae
- **Division:** Magnoliophyta
- **Class:** Magnoliopsida
- **Order:** Fabales
- **Family:** Fabaceae
- **Genus:** Cajanus
- **Species:** C. cajan
- **Binomial Name:** *Cajanus cajan* (L). Millsp. Anon. (2010)

2.2 Composition

Tookey and Jones (1965) reported that there is a gum layer in between seed coat and cotyledons in different legumes. The pigeon pea grain contains 6.3 % gum in layer between the seed coat and the cotyledons. Muller (1967) also reported the presence of thin gum layer in pigeon pea grains. Adherence of the husk to the cotyledons was possible due to the high lignin/gum content between the seed coat and cell walls of the cotyledons which acted as a binding substance. The husk of the pulses is attached to the cotyledons though a layer of gums (Kurien and Parpia, 1968; Siegel and Fawcett, 1976), while the stickiness is due to the presence of calactomonos disaccharide, glucoronaic acid and glycol-protein of which the presence of these chemicals makes the dehulling of pigeon pea a difficult process. Rachie and Roberts (1974) reported that the pigeon pea grain has a hard seed coat with slightly acrid taste.

Smartt (1976) stated that the pigeon pea is rich source of protein for animal and human consumption. It also supplies significant amount of minerals and vitamins. The pigeon pea grain contains about 19.2 % protein, 57.3 % carbohydrates, 1.5 % fat,
8.1 % fibre and 3.8 % ash. The chemical nature, quantity and level of hydration of gums affected the adherence and milling property of pigeon pea grains. Saxena (1985) reported that the testa contained cellulose, hemicelluloses, lipid, pectin and lignin that play an important role in adherence of seed coat to cotyledons.

Ramakrishnaiah and Kurien (1983) reported that pigeon pea grain contains about 11-14 % seed coat (hull), 2-5 % germ and the remainder is the cotyledon. The seed coat of pigeon pea grain is firmly attached to the cotyledons owing to uronic acid in the form of calcium pectate and compound structure of gums and mucilage in the pillar cells.

Narasimha (1984) found that the outermost layers (about 5 %) of the cotyledon in pigeon pea are very rich in calcium (about 240 mg/100 g) and protein (nearly 40 %). Scouring of 2-3 % of this outer layer resulted significant loss of calcium and protein.

Swami et al. (1991) stated that the cotyledon was rich in starch and protein and contained a water soluble polysaccharide mainly of arabinan type. The intermediate fraction had low starch than that in the cotyledon but it was rich in free sugars. Arabinogalactan type polysaccharides were found in the intermediate fraction which was gummy and hygroscopic. The alkali insoluble residue in the intermediate fraction was a complex of cellulose and non-cellulosic polysaccharides. The pectin content of intermediate fraction was greater in the difficult milling cultivar. The husk was rich in non-starchy polysaccharides with varying amount arabinose and xylose. Both glucuronic acid and galacturonic acid were present in the husk whereas the cotyledon and intermediate fractions contained galacturonic acid only.

Singh and Diwakar (1993) reported that the pigeon pea contained considerable amount of several anti-nutritional factors, namely, protein inhibitors, amylase inhibitors, flab causing sugar and phytic acid. Pigeon pea contains some amount of polyphenolic compounds (tannins) that inhibit the digestive enzymes like trypsin, chymotrypsin and amylase. These are especially present in dark seed coated pigeon pea. These compounds create problems when pigeon pea is consumed in large quantities. However, the anti-nutritional factors in pigeon pea are less than that in soybean, pea and common bean. Pigeon pea also contains some unavailable carbohydrates that reduce the bioavailability of other nutrients.
Oshodi et al. (1993) assessed amino acids, fatty acids and mineral contents in pigeon pea. Amino acids analysis showed that the protein contained nutritionally quantities of most of the essential amino acids but was deficient in sulphur containing amino acids. The total essential amino acids in the pigeon pea are 43.61 %. Linoleic and palmitic acids were predominant fatty acids with quantities as high as of 54.8 and 21.4 %, respectively in the oil sample of pigeon pea. Caprylic, lauric, oleic and eicosenoic acids were present only in small quantities. The results also showed that pigeon pea is rich in potassium, magnesium and calcium while it was deficient in sodium.

Morake et al. (2002) investigated the composition of pigeon peas. The raw seeds of six varieties were analysed for dry matter, crude fat, protein, fibre, and ash. Major minerals, Ca, K, P, Mg, Na and trace minerals, Cu, Fe and Zn were also assessed. The ranges of nutrient contents were obtained: dry matter 86.6-88.0 %, crude protein 19.0-21.7 %, crude fat 1.2-1.3 %, crude fibre 9.8-13.2 % and ash 3.9 - 4.3 %. Minerals ranges (mg/100 g dry matter) were: K 1845-1941, P 163-293, Ca 120-167, Mg 113-127, Na 11.3-12.0, Zn 7.2-8.2, Fe 2.5-4.7 and Cu 1.6-1.8. There were no significant differences in Na among the six varieties. The values obtained for the dry matter, crude protein, fat, ash, Ca, Cu, Fe, and Mg were similar to those in pigeon peas grown elsewhere, while those for crude fibre and Zn were higher.

Padmanabhan et al. (2009) evaluated the nutritional quality of dehusked whole grains (gota) and dehusked splits (dhal) in red and white varieties of pigeon pea regarding proximate composition and certain lipid soluble bioactive components. A decrease in fat and crude fibre was noticed when gota was converted to dhal. The lipid profile of gota and dhal from red and white husk pigeon pea types indicated that essential fatty acids were more in gota than in their respective dhal. Gota from white husk variety contained more tocopherols than in the red variety. Dhal contained less tocopherols than gota. Cooking time and dispersed solids on cooking indicated good cooking quality of gota. The results indicated the nutritional superiority of gota over dhal and its similarity with dhal in cooking characteristics.

Pawar et al. (2009) determined the proximate compositions of pigeon pea grains, viz., moisture, carbohydrate, protein, fat, crude fibre and ash on dry weight basis as shown in Table 2.1.
Table 2.1 Proximate compositions of pigeon pea grains

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Proportions (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture, (w.b.)</td>
<td>9.94</td>
</tr>
<tr>
<td>Carbohydrate</td>
<td>54.05</td>
</tr>
<tr>
<td>Protein</td>
<td>21.28</td>
</tr>
<tr>
<td>Fat</td>
<td>2.15</td>
</tr>
<tr>
<td>Crude fibre</td>
<td>8.44</td>
</tr>
<tr>
<td>Ash</td>
<td>4.13</td>
</tr>
</tbody>
</table>

(Source: Pawar et al., 2009)

Ali et al. (2010) investigated chemical composition of pigeon pea. Moisture (8 %), crude protein (21 %), crude fat (1.7 %), ash (3.2 %) and fibre content (2.5 %) was found during proximate analysis of pigeon pea.

Saxena et al. (2010) evaluated protein mal-nutrition is widespread among poor of developing and under developed countries. Pigeon pea is rich in starch, protein, calcium, manganese, crude fibre, fat, trace elements and minerals as shown in following Table 2.2.

Table 2.2 : The dietary nutrients of pigeon pea.

<table>
<thead>
<tr>
<th>Constituents</th>
<th>Dry seed</th>
<th>Dhal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protein (%)</td>
<td>21.7</td>
<td>24.6</td>
</tr>
<tr>
<td>Protein digestibility (%)</td>
<td>58.8</td>
<td>60.5</td>
</tr>
<tr>
<td>Trypsin inhibitor (units mg⁻¹)</td>
<td>9.9</td>
<td>13.5</td>
</tr>
<tr>
<td>Starch (%)</td>
<td>53.0</td>
<td>57.6</td>
</tr>
<tr>
<td>Starch digestibility (%)</td>
<td>36.2</td>
<td>-</td>
</tr>
<tr>
<td>Amylase inhibitor (units mg⁻¹)</td>
<td>26.9</td>
<td>-</td>
</tr>
<tr>
<td>Soluble sugar (%)</td>
<td>3.1</td>
<td>5.2</td>
</tr>
<tr>
<td>Crude fibre (%)</td>
<td>6.6</td>
<td>1.2</td>
</tr>
<tr>
<td>Flatulence factors (g 100 g⁻¹ soluble sugar)</td>
<td>53.5</td>
<td>-</td>
</tr>
</tbody>
</table>
2.3 Quality Parameter of Whole Grain during Cooking

Fasoyiro et al. (2005) evaluated physical characteristics, cooking and sensory characteristics of three varieties of pigeon pea. Swelling capacity and cooking time ranged between 45.7 to 54.7 % and 170-210 min, respectively. The red brown coloured variety was most acceptable amongst three varieties by sensory analysis. Soaking and cooking method reduced cooking time but most of the processing methods reduced protein and mineral contents of pigeon pea. Roasted and fried grains had higher protein, fat and ash contents than from other processing methods.

Sethi et al. (2008) developed inter-relationship between cooking time and some physicochemical characteristics in pigeon pea genotypes. They reported that the cooking time of whole pigeon pea pulse ranged between 51 and 63 min. indicating a large variation. However, the cooking time of pigeon pea dhal ranged between 19 to 31 min. Correlation coefficient between grain weight and hydration capacity (0.77), grain volume and grain weight (-0.86) and that of swelling capacity and swelling index (0.90) were found to be significant at 1 % level.

2.4 Wet Milling Treatment

Vijyakumari et al. (1997) reported that pigeon pea dhal prepared by wet method had poor cooking quality. This was especially true in case of the pigeon pea for which cooking time increased with duration of soaking. However, such dhal had an attractive appearance and a more desirable flavour.
2.5 Dry Milling Treatment

Kurien and Parpia (1968) reviewed pulse milling method in India. The pitted grains were mixed with about 1 % oil and spread in thick layer for sun drying for 2 to 5 days. Grains were heaped during the night to preserve the heat. About 2 to 3 % of water was added to the grains which were subsequently passed though the roller for dehusking. In this process about 40 to 50 % of the grains were dehusked.

Ramakrishnaiah and Kurien (1983) optimized moisture content for dehulling of pigeon pea. They reported that the dehulling efficiency decreased with increase in moisture content. This reduction was not significant up to 10 % moisture content (w.b.). Ehiwe and Reichert (1987) reported that the moisture content of grain played an important role in dehulling. They observed coat breaking of field peas was affected by grain moisture followed by temperature and cultivars.

Saxena (1985) reported that proteins of the lipid membrane either lie on the periphery of the lipid bi-layer or impregnated within it. Entry of oil may displace the proteins from the surface of the bi-layer causing the loosening of the membrane. This will loosen the binding force between husk and cotyledon. Polar group of oils may interact with the caption present in the vicinity of the membrane and cause loosening of the husk. Drying of oil-water treated grain may cause the formation of the cavity between husk and cotyledon.

Makhoha (1992) studied processing of pigeon pea. Cleaned and graded grains were treated with addition of edible oil at 0.35 % by weight. The grains were then sun dried for 8 to 9 h followed by preliminary dehulling using a dehuller. The grains were then tempered with addition of water at 8 % by mass, equilibrated in a heap for 3 h and dried in the sun for 4 h. The tempered grains were dehulled that gave 70 % recovery as dhal.

Singh and Diwakar (1993) reported that cleaned and graded pigeon pea is passed though an emery coated roller for pitting. The pitted grains were manually mixed with warm oil (about 1 % linseed or mustard oil) followed by sun drying for 2 - 5 days. On penultimate day of sun drying, 2-5 % water was sprinkled on the grains and it is thoroughly mixed and heaped overnight for tempering.

Patel et al. (2001) reported the status of pigeon pea milling industries in Gujarat. The major change was found in the presently followed system and the
traditional method was the drying step after pitting and oil treatment. In the old method, after every pitting operation edible oil treatment was given and the grains were exposed to sun drying for one day. Then next day pitting continued till all the grains got dehusked. On the other hand, in the new process, the sun drying was not carried out after pitting and oil treatment. But after mustard oil treatment, the grains were stored in bin for about 36 h which lead to loosening of husk. Then next day further pitting was carried out.

Deshpande (2003) studied the effect of pre-milling on recovery of dhal. The pigeon pea grains (10 kg) were treated with 20, 30 and 40 g oil with 3, 4 and 5 % water application without scratching operation. This gave dhal recovery of about 17 to 29 %, whereas the scratched and treated sample gave the dhal recovery of 58 to 67 %.

Deshpande et al. (2007) determined the influence of pre-milling treatments on dhal recovery and cooking characteristics of pigeon pea. The grains were scratched followed by mixing soy oil @ 3 kg/tonne. Oil mixed grains was then held for 8-10 h. After that, grains were kept for 3-4 h for equilibration. Then water was mixed (4 %) and grains were heaped overnight. Next day grains were dried in the sun or by mechanical dryer to bring down moisture content to 10 % (w.b.). Soy oil-water treatment showed dhal recovery of 67.61 to 70.39 %.

Goyal et al. (2008) studied the effect of dehulling time, moisture content and the mustard oil (as pre-milling treatments) on dehulling efficiency and losses. They optimized this parameters using response surface methodology. A quadratic model satisfactorily described the dehulling efficiency with high coefficient of determination $R^2 (0.95)$. It predicted a maximum dehulling efficiency of 83.2 % at 10.1 % moisture content, 12.3 sec dehulling time and 0.3 % mustard oil treatment. Moisture content and dehulling time affected dehulling loss significantly whereas the effect of mustard oil treatment was non-significant. Dehulling loss of 2.5 % was predicted at optimum conditions. Dehulling efficiency and loss at optimum conditions were observed to be 82.4±0.8 % and 3.1±0.4 %, respectively and these values were close to the predicted values.

Goyal et al. (2009) studied the effect of grain moisture content on pitting. Pitting of the grain was done at 6, 8, 10, 12 and 16 % moisture content using dhal mill developed by central Institute of Agricultural Engineering, Bhopal (India). Grains
having a cracked hull or partly dehulled varied from 35.3 to 85.3 % during pitting with maximum value at 10 % moisture content and reduced with an increase in moisture content.

Mangaraj and Singh (2011) determined effect of pre-milling treatment and abrasive roller on milling of pulses. The experiment was carried out by using different carborundum grade rollers (8, 16, 24, 32, 40) and pre-treatments (conventional, CIAE, millers practice) for thee pulses-pigeon pea, chickpea and green gram. Moisture content of sample was kept at 9 % (d.b.) for milling studies using CIAE dhal mill. The head dhal recovery of 81 % for pigeon pea and 79 % for chick pea was obtained using 32 grades for roller and CIAE milling method and 81 % for green gram using 40 grades for roller and millers practice method. The milling efficiency for pigeon pea, chickpea and green gram was found to be 83.16 %, 81 % and 88 %, respectively using millers practice.

Ramasamy and Verma (2015) investigated the effect of moisture content (10, 15, 20, 25 %, d.b.) on dehulling efficiency and dhal recovery of pigeon pea. The milling of pre-treated pigeon pea was done on abrasive dehuller and CIAE dhal mill. The milling products were fractionated into unhusked whole grain, dehusked whole grain, unhusked dhal, dehusked dhal, broken and powder. The results were analyzed to find out the best level of moisture content for obtaining maximum percentage of finished product, dhal recovery and highest hulling efficiency. The maximum dhal recovery and hulling efficiency were obtained at 10 % moisture content of pigeon pea grain and milled by using abrasive dehuller.

2.6 Chemical treatment

Saxena et al. (2007) reported that the soaking pigeon pea grains in 6 % sodium bicarbonate solution for 1 h, followed by oven drying to 10 % moisture. The pre-milling treatment resulted into 94 % yield of dhal. Treatment reduced gum and pectin content, increased enzyme activity, but caused losses in protein and starch content of the dhal.

Nayak and Samuel (2011) optimized the process for instant pigeon pea dhal. Sodium bicarbonate was used in the soaking treatment for preparation of instant pigeon pea dhal. The combination of three factors, salt concentration (0.5-1.0 %),
cooking time (8-12 min) and flaking thickness (0.5 mm-1.0 mm) were used for the product development. Four sensory parameters; colour, odour, taste and overall acceptability and two instantiation parameters namely reconstitution time and rehydration ratio were evaluated. A combination of salt concentration of 0.80 %, cooking time of 10 min and flaking thickness of 1.0 mm was found to be the optimum combination for the developed product.

Nayak and Samuel (2014) optimized the process for pigeon pea dhal using sodium chloride. Four sensory parameters viz., colour, odour, taste and overall acceptability and two instantiation parameters namely reconstitution time and rehydration ratio were evaluated. The optimum combination of three factors, salt concentration (0.5-1.0 %), cooking time (8-12 min) and flaking thickness (0.5-1.0 mm) was obtained. A combination of salt concentration of 0.75 %, cooking time of 12 min and flaking thickness of 0.75 mm was found to be the optimum combination for the desired product.

2.7 Enzymatic treatment

Verma (1991) investigated the effect of enzyme hydrolysis on the milling of pigeon pea. Pigeon pea grains were treated with enzyme, obtained from Aspergillus fumigante. The hydrolysis parameters were (i) temperature during hydrolysis (32.7, 40, 45, 50 and 53.7 °C) (ii) incubation period (4.6, 9, 12, 15 and 19.4 h) and (iii) moisture content during hydrolysis (12.7, 20, 25, 30 and 37.3 % w.b.). It was observed that hulling efficiency of treated grains increased by 18.86 % and 13.08 % as compared to untreated and water treated grains, respectively, both at milling moisture content of 10 % (d.b.). It was concluded that the maximum hulling efficiency (88.9 %) could be obtained at 26.6 % (w.b.) moisture content of grain during hydrolysis, 0.08: 260 enzyme protein grain ratio and 46.7 °C incubation temperature for the period of 12.7 h.

Saxena et al. (1993) used food grade mixed activity enzyme (i.e. xylanase and cellulase) as husk loosening agent. He reported a maximum hulling efficiency of 88.93 % at an enzyme concentration of 0.08 g protein per 260 g pigeon pea grain. Grains were treated with the enzyme and allowed to incubate. During this period of incubation, enzymatic hydrolysis took place which brought about the biodegradation of complex molecules of the grain. The complex gums were degraded which resulted
in easy dehusking. It established that a lesser force was required to bring about the dehusking of enzyme treated grain. The action of enzyme also disturbed the microstructure of the grain affecting its strength. They further reported an increase in the protein digestibility and 37.03 % reduction in cooking time. Further, this dhal was reported to cause less gastritis due to fermentation which broke down the polysaccharides responsible for causing gastritis in many people.

Zambre (1994) reported a decrease in gum content after enzyme treatment. The protein digestibility of the treated dhal was more than that of untreated dhal. He also reported that enzyme treatment caused grain to split at a lesser force and deformation. This was due to change in microstructure which affected the strength of the grain.

Benamrouche et al. (2002) determined the effect of (1→4)-β-endo-xylanase treatment on wheat bran. By using UV fluorescence microscopy, this study confirmed the degradation of the aleurone cell wall after (1→4)-β-endo-xylanase treatment. After 24 h incubation, the aleurone layer was completely lost. However, the tissues in the outermost layer of the bran retained their integrity during xylanase treatment. They also reported that 80 % and 51.8 % of the total carbohydrate was liberated by the hydrolysis of aleurone and inner bran respectively, whereas no carbohydrate was released by (1→4)-β-endo-xylanase treatment.

Bharodia (2004) studied on enzymatic pre-treatments for loosening of seed coat of pigeon pea grains. The enzyme solution soaking treatment having 1000 ml soaking volume, 0.05 g enzyme concentration for 2 kg pigeon pea with 7 h soaking time was found the most effective considering the quality of dhal. The amount of husk removed was to the tune of 76.24 %.

Arora et al. (2007) optimized process parameters for milling of enzymatically pre-treated rice. To obtain a higher quality of finished product (polished white rice), three process parameters (enzyme concentration 0.0015 g/ml-0.0055 g/ml, incubation time 1-3 min and incubation temperature 27-47 °C) were examined and optimized for developing an efficient milling system. The data analysed according to response surface methodology (RSM) showed that with enzymatic pre-treatment, the rice bran layer softened up and removed easily in the mechanical polisher. Optimum process parameters for minimum percentage of broken and good cooking quality were found
as 0.0015 g/ml of enzyme concentration, 40 °C of pre-treatment temperature and 2 min of pre-treatment time.

Sreerama et al. (2009) evaluated the 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) had facilitated the easy dehulling of green gram, black gram and horse gram. Xylanase pre-treatment of horse gram resulted in 84.4 % dehulled grains, whereas 78.4 % and 75.7 % dehulled grains were produced in green gram and black gram, respectively. However, protease pre-treatment was more efficient in improving the dehulling properties of green gram and black gram in addition to red gram with higher amount of dehulled grains (>78 %) and lower amount of fines. Selective improvements in the degree of dehulling, dehulling index and dehulling efficiency were observed in enzyme treatments compared to buffer and oil treated controls.

Yoo et al. (2009) examined the effect of cell wall degrading enzymes added to temper water on wheat milling performance and flour quality. An enzyme cocktail consisting of cellulase, xylanase and pectinase and five independent variables (enzyme concentration, incubation time, incubation temperature, tempered wheat moisture content and tempering water pH) were manipulated in a response surface methodology (RSM) central composite design. A single pure cultivar of hard red winter wheat was tempered under defined conditions and milled on a Ross experimental laboratory mill. Some treatment combinations affected flour yield from the break rolls more than that from the reduction rolls. However, a maximum flour yield was not found in the range of parameters studied. Though, treatments did not affect the optimum water absorption for bread making, enzyme-treated flours produced dough exhibiting shorter mixing times and slack and sticky textures compared with the control. Regardless of differences in mixing times, specific loaf volumes were not significantly different among treatments. Crumb firmness of bread baked with flour milled from enzyme treated wheat was comparable to the control after 1 day but became firmer during storage up to 5 days.

Sangani et al. (2014a) evaluated cooking quality of pigeon pea dhal as influenced by the enzymatic hydrolysis. The effects of four enzymatic hydrolysis parameters, i.e., enzyme concentration (20-60 mg/100 g dry matter), incubation time
(3-15 h), incubation temperature (40-60 °C) and tempering water pH (4.0-6.0) on cooking time of pigeon pea dhal were optimized using response surface methodology. Three kinds of enzymes, i.e., xylanase, pectinase, and cellulase were used in combination for enzymatic pre-treatment. A quadratic model satisfactorily described the dehulling efficiency with high value for the coefficient of determination R² (0.9062). It predicted a minimum cooking time of 21.91 min at enzyme concentration of 37.8 mg/100 g dry matter, incubation time 8.69 min, incubation temperature 48.5 °C and pH 5.49 of tempering water. Cooking time at optimum condition was observed to be 21.50 min and the predicted value of cooking time showed 2.19 % deviation from the experimental values. Results of the study revealed that cooking time of enzyme treated dhal could be decreased by 19.77 % compared to the oil treated dhal.

Sangani et al. (2014b) optimized the enzymatic hydrolysis of pigeon pea for better recovery of dhal. The effect of four enzymatic hydrolysis parameters viz., enzyme concentration (20–60 mg/100 g dry matter), incubation time (3-15 h), incubation temperature (40-60 °C) and tempering water pH (4.0-6.0) on hulling efficiency, protein content and cooking time were optimized using response surface methodology. Three enzymes, i.e., xylanase, pectinase and cellulase were used in combination for enzymatic pre-treatment. It predicted a maximum dehulling efficiency 88.37 % at enzyme concentration 37.80 mg/100 g dry matter, incubation time 8.69 min, incubation temperature 48.48 °C and tempering water pH 5.49. Dehulling efficiency, protein content and cooking time at optimum condition was observed to be 88.12 % showed 0.28 % deviation from the predicted value. Results of the study revealed that dehulling efficiency of enzyme treated dhal could be increased 13.81 % compared to the control, i.e., the oil treated sample.

Khodke et al. (2016) studied the improvement of dehulling properties of enzyme pre-treatment of pigeon pea which can be definitely use full to pulse milling processors in terms of recovery of good quality of dhal, time and money saving, energy consumption and labour cost. Xylanase and protease enzyme pre-treatments were used to evaluate the dehulling properties of pigeon pea. Better recovery and quality of pigeon pea dhal was obtained from Protease enzyme pre-milling treatment. Optimum process parameter with 2 units/g concentration and 3 h conditioning period produce maximum dehulling efficiency of 77.133 % and cooking time of 31 min as
compared to xylanase enzyme and oil pre-milling treatment of pigeon pea. It was observed that protease pre-milling treatment produced dhal recovery of around 78-79%. Moreover minimum breakage of dhal was observed as compared to traditional method of oil treatment followed in the dhal milling industry. The cost for processing of oil pre-treated pigeon pea dhal per quintal for effective milling operation was estimated to be Rs. 142.33. Oil treatment of pigeon pea was time consuming and labour intensive. Oil treatment requires 5 days to complete process for 200 quintal/day capacity plant. The cost for processing of enzymes pre-treated pigeon pea dhal per quintal for effective milling operation was estimated to be Rs. 93.88. Protease enzyme treatment requires 2 days to complete process for 200 quintal/day capacity plant. The cost for processing of enzyme pre-treated pigeon pea dhal was observed less as compared to oil pre-treatment of pigeon pea. This protease enzyme treatment save time, energy, labour cost and it is economical low cost as compared to oil treatment.

2.8 Culture extract

Bhowmik et al. (2014) determined the effect of some culture extracts of Aspergillus oryzae on dehulling properties of pigeon pea. They reported that yield percent of dehulled grains and dehulling efficiency increased concurrently with increase of incubation period of culture extract. Maximum dehulled grains were achieved by 12 day old culture extract to the tune of 73% with least amount of undeihulled kernels (6.6%) and fines (6.5%). Pre-dehulling trials conducted on pigeon pea grain employing wheat bran and pigeon pea husk based culture extracts of A. Oryzae showed dehulling efficiency of 73% for wheat bran (12 day incubation period) and pigeon pea husk (9 day incubation period) in comparison with uninoculated extract (control) in the range 62.2-64.4%. Based on the results obtained, dehulling properties affected by pigeon pea husk based culture extract proved better than wheat bran culture extract.

2.9 Combination treatment

Singh and Rao (1995) studied on quick cooking dhal of pigeon pea as influenced by salt solution and enzymatic pre-treatment. Quick cooking dhal of pigeon pea was prepared by employing various salt solutions and enzymatic treatments. Sodium bicarbonate was effective in reducing the cooking time but the
quality was affected. Pectinase treatment decreased the cooking time as compared to other enzymes and salt solution. Generally, the acceptability score of dhal was the highest for pectinase treated dhal followed by the control, solution of sodium bicarbonate and salt mixture.

Saxena and Srivastava (1998) evaluated cooking time of dhal obtained with different pre-milling treatments of pigeon pea on a laboratory mill. It was found that the dhal obtained from enzyme treated sample took 3 min less time in cooking over the control. Water soaking method resulted in hard to cook dhal, which nearly took 15 min more time of cooking.

Singh (1999) studied the effect of different pre-treatments on cooking quality of pulses. It was reported that the pre-treatment reduced the cooking time of pulses when soaked in sodium bicarbonate solution, ammonium carbonate, tri-sodium phosphate, enzyme-pectinase, sodium tri-polyphosphate, sodium chloride, sodium carbonate, citric acid and salt mixed with sodium bicarbonate.

Srivastava et al. (1999) assessed the change in protein content both in cotyledon (manually dehulled) and finished product (dhal) obtained by different pre-treatments (water soaking, water spray, oil treatment, sodium bicarbonate treatment and enzyme treatment). All the pre-milling treatments except sodium bicarbonate treatment caused significant loss in protein content in cotyledon over untreated sample. Oil treatment resulted in maximum loss (3.18 %). Protein contents of dhal ranged from 20.71 to 22.45 %. Maximum protein content was observed in enzyme treated sample and minimum in oil treated sample.

Perera (2000) studied the effect of pre-treatments for pigeon pea grains in order to get quality dhal with high recovery rate. Two oil treatments (coconut and sunflower), chemical treatment (1 % aqueous solution of bicarbonate) and control (sun dried) were employed three newly developed varieties (MPG537, MI12, ICPL87 and ICPL90050) and one earlier recommended variety ‘Prasada’ by using FMRC dhal processing machine. Dhal yield of pigeon pea ranges between 59-63 % for sunflower oil, 63-71 % for coconut oil, 56-65 % for 1 % aqueous solution of bicarbonate and 41- 59 % for control. Considering variability in dhal yield (41-71 %) and its quality, it was observed that amongst the different pre-treatments, coconut oil was found to be
the best. Further, the recommended variety ‘Prasada’ gave high quality dhal with favourable characteristics.

Singh et al. (2000) examined the cooking qualities of six pulses, namely, chickpea, pigeon pea, mung bean, urd bean, lentil and field pea as influenced by dehulling, soaking solution and enzyme treatment. The pre-treatments of soaking in sodium bicarbonate solution and pectinase significantly reduced the cooking time in both whole grain and dhal components. Sodium bicarbonate solution was more effective than the enzyme treatment in reducing cooking time in whole grain, whereas the latter was more effective in dhal samples. Effect of pectinase enzyme treatment was most pronounced in pigeon pea followed by field pea and chickpea in dhal samples. Soaking in Sodium bicarbonate solution resulted in the highest reduction of cooking time of chickpea and the lowest in pigeon pea in case of whole grain sample.

Deshpande (2003) determined pre-milling treatment to enhance recovery of dhal. The pigeon pea grains (60 kg) were treated with soy oil (4 %) and enzymes (CIRCOT, 4 %) and mixed thoroughly to achieve uniform application of enzyme to the grains. These samples were then pitted and soaked in water for varying duration, i.e., 45, 60, 75 and 90 min followed by drying to 10 % moisture content. The results indicated the dhal recovery in the range of 81.11 to 84.58 % for 75 min subsequent soaking compared to other soaking treatments.

Deshpande et al. (2007) conducted pre-milling trials on pigeon pea grain employing soy oil water and CIRCOT microbial consortium enzyme treatments. Application of CIRCOT microbial consortium treatment included treating grains with 4 % consortium. The consortium was mixed in water and grain samples were soaked for 3 h. The treated samples were kept for equilibration for 3 h, and then dried to 10 % moisture content. They observed dhal recovery of 67.61 to 70.39 % and 71.39 to 73.85 %, respectively in comparison to dhal recovery of 63.19 to 66.27 % by conventional dhal milling method. Further, the range of variation of solid dispersion during the cooking was observed as 0.24 to 0.80 g/10 g for raw grain, 0.27 to 0.85 g/10 g for soy oil treated grain and 0.45 to 1.75 g/10 g for consortium treated grains. The optimum cooking time was found to be 38 min for soy oil treated grain, 33 min for microbial consortium treated grain as compared to 43 min for raw untreated grain. Based on the results obtained, the microbial consortium pre-milling treatment was observed the most appropriate and promising.
Tiwari et al. (2008) studied the effect of different pre-milling treatments such as dry method, chemical and hydrothermal treatments on dehulling of black gram. It was found that pre-milling treatments with certain chemicals such as sodium bicarbonate, acetic acid and alcohol were found effective in dehulling black gram. Several vegetable oils at varying concentrations (0.2, 0.4, 0.6, 0.8 and 1.0 %) were used; it was found that 0.6 % was optimal, except that sesame oil was effective even at 0.2 %. Chemicals were also effective at relatively high concentrations of approximately 5 %. It was also found that a steaming time of 10-15 min was adequate to loosen the hull, resulting in easy dehulling. It was concluded that hydrothermal treatment could be used for dehulling black gram. However, hydro-thermally pre-treated dhal was not suitable for fermented products, in which case a conventional oil pre-treatment method should be used with sesame oil.

Tiwari et al. (2009) determined the effect of various pre-treatment on physico-chemical, functional, pasting, and cooking properties of dehulled pigeon pea splits and flour. There was no significant difference in protein and carbohydrate content of pre-treated pigeon pea samples except ash content for wet method and lipid content for dry method. Significant differences were observed in some physicochemical properties such as physical dimensions, hydration, and swelling capacity. Water absorption and oil absorption capacity were significantly higher for hydro-thermally pre-treated grain with reduced foaming capacity and stability as compared to other pre-treatments. Pasting profile of hydro-thermally treated pigeon pea showed lower value on peak viscosity (0.90 Pa.s) and breakdown (0.002 Pa.s), with higher pasting temperature (87.5 °C). Hydro-thermally treated pigeon pea splits were found to be superior in terms of cooking properties compared to other pre-treatments.

Sreerama et al. (2009) studied the effect of chemical and enzyme pre-treatments on expansion properties and ultra structure of legumes. Sodium bicarbonate and protease pre-treatments altered the cell wall structure of horse gram and pigeon pea leading to the development of expanded grains. Expansion processing of pre-treated legumes resulted in statistically significant increases in grain size and expansion volume compared to control grains. Highest yield of expanded grains were obtained with sodium bicarbonate pre-treatment (80 grains/100 grains in pigeon pea and 96 grains/100 grains in horse gram), whereas, protease treatment yielded 68 and 94 expanded grains per 100 grains of pigeon pea and horse gram, respectively. Pre-
treated expanded grains had lower bulk densities in the range of 480–510 g/L compared to untreated controls (about 760 g/L). Increased porosity and decreased cell wall thickness in expanded grains resulted in the collapse of cell walls and the appearance of large void spaces within the intercellular matrix. These results suggested the potential utility of under-utilized expanded pigeon pea and horse gram grains or their flours as ingredients in food processing or in legume composite flours.

Sandeep et al. (2014) studied dhal recovery from three popular varieties of North Karnataka using CFTRI mini dhal mill with five different treatments at three different levels. 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 treatment yielded minimum hulling efficiency and finished product recovery for all the varieties.

Ashish and Mohite (2014) evaluated pre-milling treatments for five samples of pigeon pea with different pre-treatments which includes two of oils and two of chemical treatments and one treatment as control. Experimentally trails were carried out on PKV mini dhal mill and the above pre-treatments were carried out before milling. The consortium treatments and open sun dried samples obtained range of dhal recovery of 70.25 to 75.00 % and 71.25 to 77.25 % for tray dried samples. Broken losses were maximum in control samples of both drying methods. Cost incurred for different treatments ranged from Rs. 0.67 to 0.88 for open sun drying method and Rs. 0.68 to 0.90 for tray drying method per kg for each milling process. Based on the results obtained, mustard oil pre-milling treatment was observed to be the most appropriate and promising.