REVIEW

J. Food Sci. Technol., 1995, Vol. 32, No. 2, 81-93

Methods for Dehulling of Pulses : A Critical Appraisal

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Pulses, the edible seeds of legumes, are dehulled into *dhal* (decorticated dry split cotyledons) for use as human food. Not only does dehulling reduce cooking time and antinutrients, it also improves protein quality, palatability, and digestibility of pulses. An efficient and improved dehulling of pulses is of vital importance in reducing dehulling losses and thus increasing the availability of *dhal* in the daily diets of the people. In spite of several advances in dehulling methodology of pulses, *dhal* millers and villagers are still using the age-old traditional practices of dehulling, consequently incurring significant quantitative and qualitative losses. *Dhal* yield, which is a function of dehulling efficiency, is highest in chickpea and lowest in pigeonpea in case of both small scale (stone *chakki*) and large scale (*dhal* mill) operations. Mean dehulling loss is nearly 33% in stone *chakki* and 25% in *dhal* mills. Of the various pre-treatments, heating of seed before dehulling appears to improve the *dhal* yield in pulses, particularly in pigeonpea. Pulse varieties with uniform and round seeds are preferred for higher *dhal* yields. Genotypic differences exist in the dehulling characteristics of different pulses, as evaluated by using laboratory method. This paper reviews in-depth, several aspects of dehulling, such as methodology, pre-treatments, physical, morphological and chemical nature of seed, with respect to dehulling characteristics, nutrient losses and varietal, differences in dehulling quality.

Keywords : Pulses, Traditional and modern methods of dehulling, Pre-treatments, Seed characteristics, Varietal differences, Nutrient losses.

As a matter of convenience, grain legumes, such as chickpea (*Cicer arietinum* L.), pigeonpea (*Cajanus cajan* L.), mung bean (*Vigna radiata* L.), urd bean (*Vigna mungo* L.) and lentils (*Lens esculenta* L.), are commonly referred to as pulses in the Indian sub-continent. Chickpea and pigeonpea are very important pulse crops in India, as they occupy nearly 45% of the total pulse area and contribute about 60% of the total pulse production in the country. Approximately 75% of the total world yield of pulse is produced in the developing countries and India accounts for about 70% and 85% of the total world production of chickpea and pigeonpea (Singh and Singh 1992). India produces over 12 million tonnes of pulses annually and this figure has almost remained static for the last three decades (Sharma 1994). It is not surprising that per capita availability of pulses has fallen significantly, as the population is expanding at the rate of 2.1% per annum in India (World Bank 1991). Further, the pulse production is stagnant and imports are negligible, until recently. The low production and productivity of pulses are because of the fact that these energy-rich crops are grown under the condition of energy deprivation, i.e., low input management practices (Jeswani and Saini 1981). Over 90% of the area under pulse cultivation is confined to un-irrigated lands, and in the foreseeable future, this situation is unlikely to change. In addition, pulses also suffer considerable quantitative and qualitative losses during transportation, post-harvest handling, dehulling, and storage (Singh and Jambunathan 1990).

Dehulling process, also called primary processing, converts the whole seed of pulses into *dhal* (decorticated dry split cotyledons), which is consumed in various forms. Dehulling is the most important operation of post-harvest handling of pulses, and hence plays an important role in processing and utilization of pulses in the daily diets of the people. Although the exact figures are not available for different pulses, currently it is estimated that over 75% of chickpea and 85% of pigeonpea produced in India are dehulled to produce *dhal*. Earlier, about 80% of the grain legumes produced in India were dehulled and milled to produce splits (*dhal*), before consumption (Parpia 1973). There are several thousands of dehulling units of varying capacities for processing the annual total production of pulses in India (Kurien 1981). Although it will depend on the methods and machinery used for dehulling, several factors such as environment, agronomic practices, genotypes, and pre-treatments influence the dehulling process and consequently, the *dhal* yield (Singh and Jambunathan 1981; Ramakrishnaiah and Kurien 1983; Reichert et al. 1984). In recent years, the processing of pulses has become more attractive, and there are continuing efforts to improve the *dhal* yield of pulses either through better processing techniques or availability of more suitable genotypes or both (Kurien 1984; Ehiwe and Reichert 1987; Singh et al. 1992a; Saxena et al. 1993; Williams

Submitted as JA # 1717 by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)

et al. 1993). In view of this, an attempt is made in this paper to present a comprehensive review on dehulling of pulses in India and suggest future research needs.

Advantage of dehulling

Dry whole seeds of pulses possess a fibrous seed coat, or testa (husk, hull, or skin). The seed coat is often indigestible and sometimes causes a bitter taste (Singh and Singh 1992). Therefore, pulses are mostly consumed after dehusking to improve their palatability and taste. The most beneficial effect of dehulling is the reduction of cooking time in terms of removing the impermeable seed coat of pulses, which hinder water uptake during cooking (Williams et al. 1993). The polyphenols, also called tannins, which are considered to be the potential antinutritional factors are mostly present in the seed coat. In case of pulses, seed coats account for 80-90% of the total seed polyphenols (Rao and Deosthale 1982; Singh 1993), which are significantly reduced by dehulling (Rao and Deosthale 1982; Singh 1984, 1993). Removal of hull facilitates a reduction of fibre and tannin contents and improvement in the appearance, texture, cooking quality, palatability and digestibility of the grain legumes (Kon et al. 1973; Deshpande et al. 1982). Dehulling improves the protein quality in pulses. For example, the true protein digestibility and net protein utilization of *dhal* components were significantly higher than those of the whole seed of pigeonpea, indicating the beneficial effects of removal of seed coat (Singh 1993).

Fig. 1. Traditional method of dehulling pulses using pestle and mortar.

Fig. 2. Traditional method of dehulling pulses using stone *chakki*

Methods of dehulling

Historically, the processing of food legumes in developing countries has been done in the home by women, as part of the meal preparation. The conversion of pulses into *dhal* is an age old method, practised in the homes and slowly adopted by the agro-processing industry, in the form of commercial *dhal* mills. Both small and large scale industries have evolved to some extent from these traditional food processing methods. *Dhal* milling is an important industry, comparable with rice milling and flour milling industries, in terms of capital investment. The dehulling methods can be broadly classified into two categories :

1. Traditional methods of dehulling : a) Small scale processing generally adopted by the households in villages and b) Large scale processing adopted by the commercial *dhal* mills in urban areas.

2. *Modern methods of dehulling :* a) Laboratory-type dehullers and b) Mini-*dhal* mills.

Traditional methods

Small scale processing : Since ages, the dehulling of pulses has been practised in traditional ways in India. In the early days, dehulling of pulses was accomplished traditionally with a mortar and pestle (Fig.1). In some African countries, dehulling of legumes is still carried out with a mortar and pestle (Dovlo et al. 1976). The traditional dehulling of pulses is often laborious, time-consuming and inefficient (Singh et al. 1992b).

Method 1 (Uttar Pradesh, Madhya Pradesh, and Karnataka)	Method 2 (Andhra Pradesh and Maharashtra)	Method 3 (Maharashtra and Madhya Pradesh)	Method 4 (Uttar Pradesh and Madhya Pradesh)
↓ Seed material	↓ Seed material	↓ Seed material	↓ Seed material
↓ Cleaning	↓ Cleaning	↓ Cleaning	↓ Cleaning
↓ Tempering	↓ Tempering	↓ Soaking in water (8-14 h)	↓ Boiling in water (15-20 min)
↓ Oil treatment	↓ Oil and turmeric powder treatment	↓ Sun-drying (1 or 2 days)	↓ Sun-drying (1 or 2 days)
↓ Soaking in water (2-5 h)	↓ Store (30-45 days)	↓ Primary milling (cotyledons separate)	↓ Dehulling in stone *chakki* (removes seed coat)
↓ Sun-drying (1 or 2 days)	↓ Dehulling in stone *chakki* (removes seed coat)	↓ Oil/water treatment	↓ *Dhal*
↓ Dehulling in stone *chakki* (removes seed coat)	↓ *Dhal*	↓ Sun-drying (1 or 2 days)	
↓ *Dhal*		↓ Dehulling in stone *chakki* (removes seed coat)	
		↓ *Dhal*	

Fig. 3. Traditional methods of dehulling pigeonpea followed in various Indian States.

In case of small scale dehulling, which is generally practised by the villagers, the basic unit is a stone *chakki* (Fig. 2). The *chakki* is a quern, consisting of two grinding stones, the lower one being immovable and the upper one rotating. It is operated manually and used mainly to dehull small quantities of pulses for domestic consumption. The stone pieces generally vary from 30 to 40 cm diam and 4 to 6 cm thickness (Singh et al. 1992b). The pre-treatments given before dehulling in a *chakki* vary from region to region as shown in Fig. 3. The grains of pre-treated pulses are slowly and uniformly added through a central hole in the upper stone of the *chakki*, which is gently and continuously rotated manually until the material is processed. Depending on the seed size and different species of pulses, the gap between the upper and lower stones could be adjusted by a wooden structure supported at the bottom. After the operation, the upper stone is removed and the processed material is collected for separation into *dhal*, brokens, powder and husk fractions by winnowing.

Large scale processing : According to the dehulling procedure that is commonly used for large scale processing of pulses, commercial *dhal* mill is a basic dehulling unit for processing large quantities of pulses in urban areas of the country. Eventhough the basic approach is similar, details of dehulling procedures vary widely from one *dhal* mill to another *dhal* mill and one region to another region. The use of an emery-coated roller is a common practice in commercial *dhal* mills (Kurien 1981). The emery-coating, also called as carborundum, is made of silicon carbide (carbon + crystallized alumina) and used for abrasive or refractory action. Some millers use a roller (Fig. 4) for both dehusking and splitting, while others use a roller and disc sheller alternatively for this purpose. The disc sheller is generally used for wet-processing and works on the principles of attrition, which removes the husk and splits the cotyledons simultaneously (Kurien 1981). However, its functioning mechanism is not properly understood and excessive breakage in this machine is common, especially when the grains are not size-graded (Kurien 1981). The disc-shellers are generally used for dehusking rice (Kurien 1981). The roller machine, which is most commonly employed for dehulling pulses in India, is used in dry method of processing

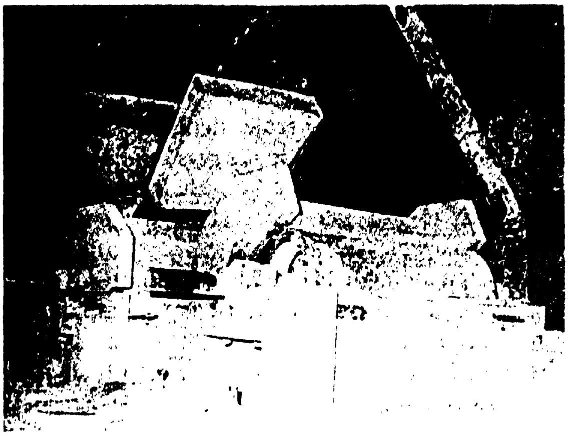

Fig.4. A commercial method of dehulling pulses using a roller machine in a *dhal* mill

and it works on the principle of abrasive action (Singh and Jambunathan 1990).

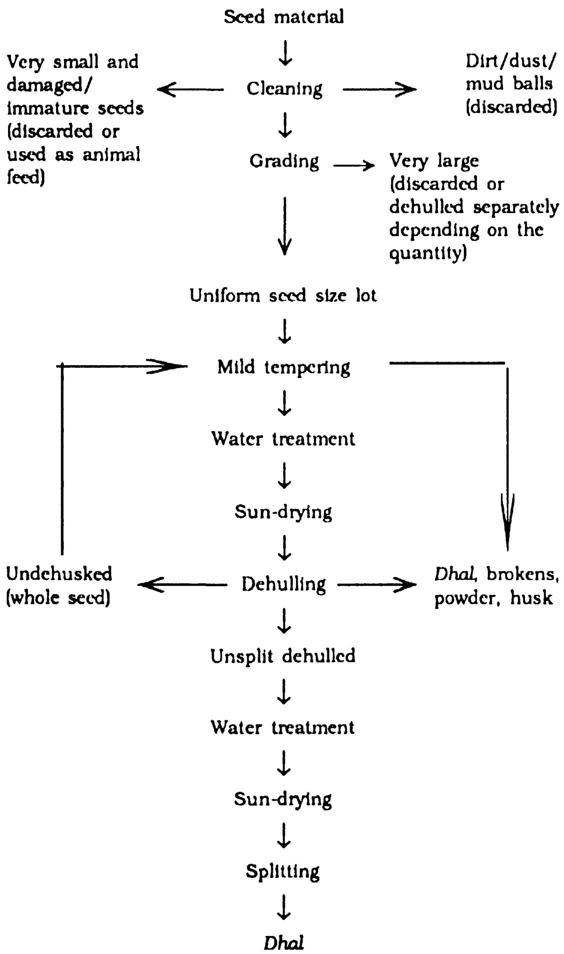

Fig.5. Chickpea dehulling procedure followed in Indian *dhal* mills

As shown in Fig. 5, there are several steps involved in the large scale processing of the pulses. The flow diagram described for chickpea (Fig. 5) is generally applicable for other pulses, excepting pigeonpea, which is processed in a different way (Fig. 6). In large scale processing of pulses, foreign material is first removed by sieving and exposure to fans. This removes soil, straw, pods, weed, and very small immature seeds (Singh and Jambunathan 1981). Then, seed material is graded into different sizes depending on the species. At least, seed lots are graded into two sizes, i.e., average and uniform seed size lots, which are processed, while very bold seed size lots are generally discarded or separately dehulled (Singh and Jambunathan 1981). After grading, the seed lots are passed through a roller machine, which causes a mild abrasion- the tempering operation. This tempering causes slight scratches on the seed coat, testa, and enhances their oil- and water-absorbing efficiency. The oil/ water treatment (Fig. 6) is commonly employed in

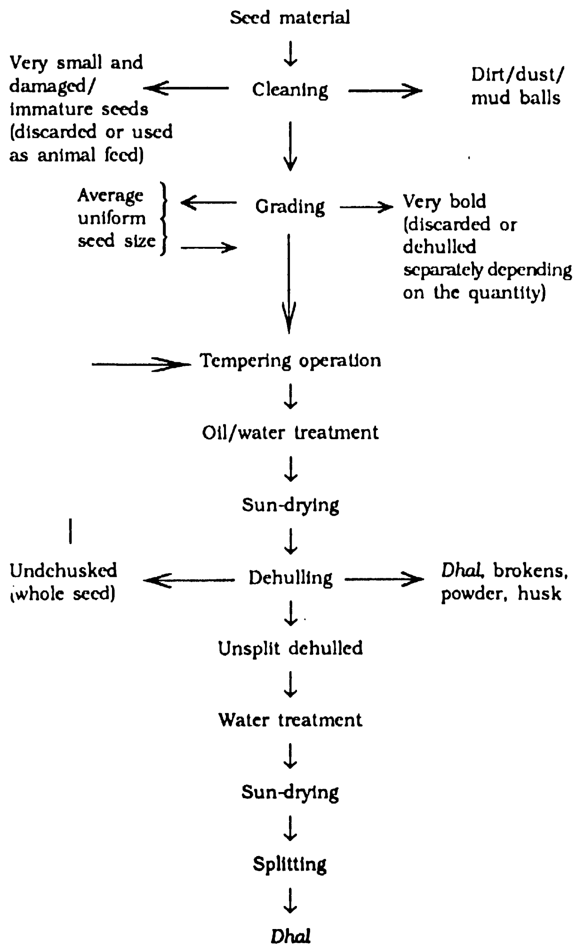

Fig.6. Pigeonpea dehulling procedure followed in Indian *dhal* mills

case of pigeonpea, whereas water treatment (soaking or moistening) is followed (Fig. 5) in case of other pulses, including chickpea (Singh and Jambunathan 1981). The material is then treated with oil and water and processed. After pre-treatments, pulses are dehusked in a similar way with a roller machine, and different fractions of dehulling are separated and collected.

Modern methods of dehulling : In recent years, efforts have been made to develop improved methods and machinery to process pulses more efficiently (Reichert et al. 1986) and economically as the traditional methods are laborious, time consuming, and incur heavy losses during dehulling (Singh and Jambunathan 1990). A new technology and machinery for dehulling pulses was developed at the Central Food Technological Research Institute, Mysore, India (Kurien 1981). According to this technique, loosening of the husk is achieved by an incipient toasting of the grain in a current of hot air, followed by tempering, when the seed coat is loosened (Kurien 1981). This technique is reported to be more suitable for dehulling pigeonpea, but can be used for other pulses also (Kurien 1981). However, the technique was not adopted by the commercial *dhal* millers because of its high cost of operation (Singh and Jambunathan 1990). Several machines developed for processing cereal grains can be used for dehulling pulses (Reichert et al. 1984). Although the attrition-type dehullers (*dhal* mills) are mostly suitable for dehulling coarse grain cereals, these can be conveniently used for dehulling some grain legumes (DeMan et al. 1973). The roller mills are more suitable for dehulling pulses (Singh and Sokhansanj 1984; Kurien 1984). Attrition-type dehullers and roller mills are particularly suitable for dehulling and splitting pulses with loose seed coats (Reichert et al. 1984), whereas abrasive type dehullers are more suitable for dehulling pulses with more tightly adhering seed coats (Reichert and Young 1976). Of late, efforts have been made to develop laboratory methods for dehulling and to identify genotypes with improved yield (Reichert et al. 1984; Ehiwe and Reichert 1987).

As shown in Fig. 7, an intermediate-sized, batch dehuller, capable of processing 2-8 kg of a wide variety of cereal and legume grains has been developed (Reichert et al. 1984). According to this technique, grains are dehulled by abrasion, provided by abrasive wheels (25 cm diam) mounted on a horizontal shaft. The tangential abrasive dehulling device (TADD) was reported to be suitable for studying variability in dehulling quality of cowpea,

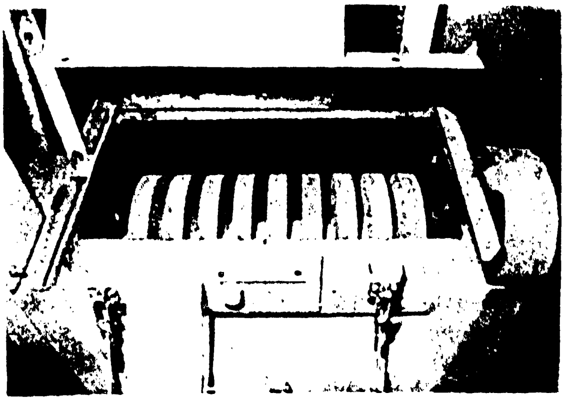

Fig. 7. New method of dehulling pulses using an intermediate-sized, batch dehuller.

pigeonpea and *mung* bean cultivars (Ehiwe and Reichert 1987). More recently, Singh et al (1992b) compared the suitability of two laboratory methods, namely, barley pearler and the tangential abrasive dehulling device (TADD), to evaluate genotypic differences in dehulling quality of pigeonpea and both methods were found highly comparable and reliable.

Dehulling pre-treatments

In both small scale and large scale processing of pulses, two major operations are involved : a) loosening the seed coat from cotyledons, and b) removing the seed coat and splitting the cotyledons. The pre-treatments are generally employed to loosen the seed coats and these can be grouped into two categories : a) wet-treatments and b) dry-treatments.

Wet-treatment : This method of dehulling generally involves water soaking and sun-drying, and is common in many parts of India (Singh and Jambunathan 1981). According to this method, soaking and drying are considered as effective techniques to loosen the husk. The wet-method has the advantage of facilitating good dehusking and splitting of the cotyledons, giving less breakage, though it may adversely affect the cooking quality. The method is also labour intensive, and is completely dependent upon climatic conditions for drying the soaked seeds. The entire process usually takes about 5-6 days, and only limited quantities can be processed at any given time. *Dhal* produced by the wet-method tastes better, but takes longer time to cook (Kurien and Parpia 1968).

Soaking in water : A survey, conducted some time ago, indicated different types of soaking-pre-treatments for different pulses processed in different regions of India (Singh and Jambunathan 1981).

For chickpea, soaking in water is a common practice only in case of large scale processing i.e., *dhal* mills. This is commonly followed in the States of Punjab, Haryana, Rajasthan, and certain parts of Uttar Pradesh. For small scale dehulling of pigeonpea, different pre-treatments employed in different States are summarized in Fig. 3. The soaking of pigeonpea in water ranging from 2 to 14 h is a common practice in Maharashtra, Uttar Pradesh, and Madhya Pradesh. Soaking for longer period is preferred in certain regions, when pulses are processed in summer season. According to Kurien (1981), dehulling can be rendered more easy by prolonged soaking in water for 12 h or more, but the *dhal* remains uncooked and tough even on prolonged boiling. In some households, pigeonpea is first split using a *chakki*, then treated with water and finally hand-pounded to remove seed coat (Singh and Jambunathan 1981). Soaking in water, followed by coating with red earth slurry and sun-drying for several hours is a household practice for dehulling pigeonpea in some Southern States of India. Treatment with red earth is said to impart a good yellow colour to the finished product, possibly by preserving its natural colour.

Chemical treatment : The use of chemicals as pre-treatment to loosen the seed coats of pigeonpea has been reported. Reddy (1981) used sodium bicarbonate (5% solution), and reported an increase in *dhal* yield (75%). Krishnamurthy et al (1972) substituted *sirka* (vinegar) for vegetable oil in the dry milling process. These authors also tried sodium bicarbonate, sodium hydroxide, acetic acid, and ammonia as a replacement for vegetable oil in the traditional process and reported a considerable improvement in *dhal* yield, when sodium bicarbonate was used. Saxena et al (1981) treated pigeonpea grains with aqueous solutions of calcium hydroxide, sodium hydroxide, sodium bicarbonate, sodium carbonate or sodium chloride of different normalities. Normal sodium bicarbonate solution was reported to be the most effective, resulting in a *dhal* yield of 78%. These authors also recommended the use of sodium bicarbonate not only to loosen the husk, but also to reduce the cooking time of *dhal*. Srivastava et al (1988) have also reported high dehusking efficiency, when sodium bicarbonate was used as a soaking solution (Table 1).

Dry-treatment : This method of dehulling is more applicable for chickpea dehulling by stone *chakki* and for pigeonpea dehulling by *dhal* mill. Dry-method of dehulling is said to produce *dhal* that cooks faster than the *dhal* produced by the wet-method (Kurien and Parpia 1968). The major disadvantage of the dry-method is the high dehulling losses due to breakage and powdering. In the dry method, oil/water application, followed by sun-drying, are the important steps, which are involved in processing of pulses.

TABLE 1. EFFECT OF SOAKING ON DEHULLING EFFICIENCY (%) ON PIGEONPEA SEEDS[a]

Cultivar	Control	Pre-soaking treatment			
		Water	$NaHCO_3$, % 4	6	8
'UPAS'	65.4	66.3	71.1	81.3	77.2
'T 21'	70.4	71.2	87.2	80.5	80.3
'Pant A 3'	69.1	72.3	80.8	74.2	82.5
'Pant 10'	74.6	77.8	87.2	88.1	85.3

a. Seeds were soaked in water or sodium bicarbonate solution for 1 h at room temperature, and oven-dried at 65°C for 150 min to obtain 10% moisture content. Source : Srivastava et al (1988)

Oil-treatment : The application of edible oil, as a pre-treatment, is mostly confined to pigeonpea, where seed coat is more tightly bound to the cotyledons, as compared to other pulses. This treatment is generally followed in case of large scale dehulling of pigeonpea by the commercial *dhal* mills. After tempering operation, grains are thoroughly mixed with about 1% oil (preferably linseed), either manually or in a worm mixer, and the oiled-grains are then sun-dried for 2-3 days. Oil appears to penetrate through the husk to the cotyledons and releases its binding under the mild heat of the sun. This loosening process may be slow, but the husk can be totally loosened, if the treatment is extended to several days. In certain parts of India, oil and turmeric powder as a pre-treatment are also given in case of small scale dehulling of pigeonpea.

Heat-treatment : It was reported that pre-treatment of pigeonpea seed with hot air at 120-180°C was quite effective in loosening the seed coat (Kurien 1981). This could be achieved in conditioning chambers, where the grain temperatures are 70-95°C, depending on the cultivar. In some parts of Uttar Pradesh, villagers use sand roasting at 100-125°C for 5-10 min, as a pre-treatment to improve the *dhal* yield in pigeonpea (Singh and Jambunathan 1981). The heating of pigeonpea seed in a pan (150°-200°C for 2-3 min), with or without sand before dehulling in stone *chakki*, is also followed in certain parts of Uttar Pradesh.

Seed characteristics that affect dehulling

Several seed characteristics affect the dehulling efficiency in terms of loosening the seed coat, and

TABLE 2. VARIABILITY IN SEED COAT CONTENT OF DIFFERENT PULSES

Pulse	Number of genotypes	Range	Mean	Reference
Chickpea, *desi*	21	9.7 - 17.3	14.2	Kumar and Singh (1989)
Chickpea, *kabuli*	19	3.7 - 7.0	4.9	Kumar and Singh (1989)
Pigeonpea	22	12.6 - 17.2	14.4	Sharma et al (1987)
Mung bean	24	7.4 - 11.4	8.8	Ehiwe and Reichert (1987)
Urd bean	5	8.9 - 11.6	10.4	Uma (1993)
Lentil	6	7.0 - 8.0	7.2	Williams et al (1992)

govern the *dhal* yield and nutrient losses in different pulses. In this context, interaction of pre-treatments of dehulling and the seed characteristics play an important role in determining the dehulling quality.

Nature of seed coat : Generally, it is expected that *dhal* yield would depend on the seed coat content - higher the seed coat, lower will be the *dhal* yield. As shown in Table 2, mean seed coat ranges between 4.9 and 14.4% for different pulses, indicating a large variability. This would significantly affect the expected *dhal* yields. The theoretical yields of dehulled grain, primarily determined by subtracting the seed coat content from the seed mass, are generally higher than those obtained by the mechanical methods (Table 3). However, there was no correlation between the theoretical *dhal* yield and the *dhal* yields obtained by mechanical methods in pigeonpea, thereby implying that dehulling machinery and methodology would play a greater role in determining the *dhal* yields (Singh et al. 1992).

Dehulling characteristics are to some extent governed by seed morphology and anatomy, which vary immensely among legumes (Singh et al. 1984, and Reichert et al. 1984). In pulses, cell arrangements of seed coats are very different and these could influence dehulling characteristics. The seed coat in cowpea consists of highly organized palisade cell structure. Sefa-Dedeh and Stanley (1979) suggested that cowpea varieties with thick, smooth seed coats (highly organized palisade cells) dehulled more satisfactorily than those with thin, rough seed coats. In *kabuli* chickpeas, the outermost layer (epidermis) develops into a uniseriate palisade layer without thickening of the cell wall, whereas in *desi* chickpeas, it develops into a multiseriate palisade layer, which later becomes thick-walled sclereids, heavily stainable with toluidine blue (Singh et al. 1984). This would probably explain that dehulling of *desi* varieties (generally smaller seeded and brown seed coat) is easier than *kabuli* varieties. Further, the chemicals associated with the seed coat such as gums and non-starchy polysaccharides, present in the interspace between the husk and cotyledons, have been implicated in the adherence of husk to the cotyledons, thereby making the dehulling operation difficult (Ramakrishnaiah and Kurien 1983).

Physical characteristics of grains : Seed size is the most important factor affecting the dehulling process in pulses (Ehiwe and Reicher 1987; Singh et al. 1992b). Seed size is a varietal characteristic, which can be strongly influenced by growing season and location of pulses (Erksine et al. 1985; Williams and Singh 1987; Ehiwe and Reichert 1987). Seed size affects the efficiency of dehulling and splitting of cotyledons. Dehulling efficiency is negatively and significantly correlated with seed size in *mung* bean and cowpea (Ehiwe and Reichert 1987). As shown in Table 4, pigeonpea *dhal* yield obtained by TADD and barley pearler was negatively correlated with grain volume and seed size, implying that bolder grains would reduce the *dhal* yield (Singh et al. 1992). Although the magnitude of correlations was low, grain hardness was negatively correlated (Singh et al. 1992) with TADD and barley *dhal* yields (Table 4). This implies that hard grain genotypes of pigeonpea would produce lower *dhal* yield. It has been shown that greater than 75% of the variability in dehulling efficiency or *dhal* yield could be accounted for by grain hardness and resistance to splitting of the grain into individual cotyledons (Reichert et al. 1984). Further, swelling capacity and floatation values of pigeonpea genotypes were not correlated with the *dhal* yield obtained by different methods (Singh et al. 1992). The splitting is as important as dehulling for commercial *dhal* mills and household dehulling by stone *chakki* (Singh and Jambunathan 1990). The larger seeds split

TABLE 3. *DHAL* YIELD (%) ACHIEVED BY DIFFERENT PROCESSING METHODS

Pulse	Stone *chakki*[a]	*Dhal* mill[a]	Max (thermetical)[b]
Chickpea	70.8	80.0	85.8
Pigeonpea	61.0	70.1	85.6
Mung bean	65.0	74.0	89.2
Urd bean	70.5	73.5	89.6
Lentils	66.4	75.0	92.8
Mean	66.7	74.5	88.6

[a] Based on survey data of household practices and *dhal* mills.
[b] Calculated by subtracting the values on seed coat percentage as given in Table 2.

TABLE 4. CORRELATION COEFFICIENT BETWEEN PHYSICAL CHARACTERISTICS AND *DHAL* YIELD OF PIGEONPEA GENOTYPES.

	1	2	3	4	5	6	7	8
Moisture	1.00							
100-seed mass	- 0.38	1.00						
Grain volume	- 0.28	0.94**	1.00					
Floatation value	- 0.10	- 0.36	- 0.28	1.00				
Swelling capacity	- 0.17	0.05	- 0.07	0.46	1.00			
Grain hardness	- 0.20	0.81*	- 0.72*	- 0.29	- 0.11	1.00		
Dhal yield[a]	- 0.03	- 0.76*	- 0.82*	0.24	- 0.12	- 0.65	1.00	
Dhal yield[b]	- 0.20	- 0.67	- 0.71*	0.36	- 0.16	- 0.57	0.97**	1.00

[a] *Dhal* yield by TADD, [b] *Dhal* yield by barley pearler. Source : Singh et al (1992b).

more readily than smaller seeds and reduce the requirement for recycling (Williams et al. 1993). On the other hand, if the dehulling equipment, roller machine or stone *chakki*, is not properly set up, large seeds are most likely to incur breakage, resulting in heavy losses during dehulling (Singh and Jambunathan 1981). These workers further suggested that uniform and medium seed size of pigeonpea would improve the efficiency of dehulling. Very small to small seeds are more difficult to dehull and split and require several recycling steps and are, therefore, not generally preferred by *dhal* millers. Williams et al (1993) reported that efficiency of dehulling and splitting of lentil is favoured by large seed size, thin testa, short storage period and correct wetting and drying practices. Further, they reported that very bold seeds are not accepted in *dhal* mills, because heavy losses are incurred due to broken seeds.

Like seed size, seed shape is a varietal characteristic in pulses (Erskine et al. 1985; William and Singh 1987). This characteristic is generally not affected by growing environment. The rounder the seeds, the better they are for dehulling (Singh and Jambunathan 1990). Very angular seeds lose excessive amounts during the dehulling, because the dehulling process attacks sharper edges preferably and more seed mass is removed from flatter seeds (Williams et al. 1993). As a result, the flatter the seeds, the higher the amount of powder and brokens, i.e., small pieces of cotyledons. In addition, rounder seeds split more readily than flatter seeds, thus improving the efficiency of dehulling/splitting (Kurien 1984). *Dhal* yield is affected by seed size and shape of lentils (Williams et al., 1993). According to these workers, the rounder, (i.e., less lenticular) the seeds, the better they are for dehulling and *dhal* milling.

In addition, several environmental factors may influence the *dhal* yield from pulses. Variations in milling characteristics of pigeonpea, as influenced by variety and agroclimatic conditions, have been reported (Ramakrishnaiah and Kurien 1983). According to a survey report, location and maturation of pigeonpea, which influence seed size, shape and grain hardness would directly affect the *dhal* yield in small and large scale processing operations (Singh and Jambunathan 1981). Further, this report indicates that the farmers feel that pigeonpeas grown on light soils have better dehulling and cooking qualities (Singh and Jambunathan 1981). Some *dhal* mill owners also have preferences in seed colour, favouring white pigeonpea for two reasons : 1) *dhal* yield is better when compared with other pigeonpeas, 2) *dhal* with a lesser degree of dehusking, but less visible white spots of leftover husk, can be sold in the market at a higher price than *dhal* obtained from coloured seeds.

Comparison of dehulling methods

Several methods are used to dehull pulses and numerous factors influence the efficiency of the methods. Although it is difficult, some efforts have been made to compare different methods in the

TABLE 5. *DHAL* YIELD OF PIGEONPEA GENOTYPES OBTAINED BY DIFFERENT METHODS OF DEHULLING

Genotype	*Dhal* yield, % MNM	SNC	BRP	TADD
'C 11'	85.8	45.6	71.8	75.7
'BDN 2'	85.2	49.9	66.9	76.7
'T 15-15'	88.4	51.4	73.2	78.5
'ICPL 87049'	86.4	46.7	55.6	54.1
'ICPL 87052'	86.6	54.0	73.7	80.0
'ICPL 87053'	85.9	42.6	72.5	75.5
'ICPL 87066'	88.2	54.5	57.6	56.6
'ICPL 87075'	87.0	59.0	69.2	73.5
Mean	86.7	50.5	67.6	71.3
SEM	± 0.36	± 1.84	± 0.51	± 0.28

MNM = manual method, SNC = stone *chakki*, BRP = barley pearler, TADD = tangential abrasive dehulling device. Means of three independent determinations. Source : Singh et al (1992b).

TABLE 6. *DHAL* YIELD LOSSES IN CHICKPEA AND PIGEONPEA

Pulse		Large scale processing		Small-scale processing	
		Range	Mean	Range	Mean
Chickpea[a]	*Dhal*	75.0 - 85.0	80.0	50.0 -80.0	70.8
	Brokens	1.0 - 5.0	2.6	5.0 -20.0	8.6
	Powder	5.0 - 10.0	6.7	7.0 -20.0	7.0
	Husk	8.0 - 14.0	11.8	10.0 -20.0	13.5
Pigeonpea[b]	*Dhal*	60.0 - 85.0	70.1	50.0 -80.0	61.0
	Brokens	2.0 - 10.0	4.4	5.0 -20.0	10.6
	Powder	9.0 - 18.0	12.8	7.0 -20.0	12.6
	Husk	8.0 - 25.0	12.9	10.0 -25.0	15.2

[a] Based on 20 respondents in large-scale and 60 respondents in small scale processing in Punjab, Haryana, Rajasthan, and Maharashtra. [b] Based on 46 respondents in large scale and 136 respondents in smallscale processing in Madhya Pradesh, Maharashtra, and Uttar Pradesh. Source : Singh and Jambunathan (1981).

laboratory using the same varieties of pigeonpea (Singh et al. 1992b). Excluding manual method, average *dhal* yield (Table 5) was the highest (71.3%) in TADD, followed by barley pearler (67.6%), and the lowest in stone *chakki* (50.5%). The average *dhal* yield of pigeonpea genotypes analyzed by TADD is comparable with that of the commercial *dhal* mills (70.1% *dhal*) in India (Table 6), but is considerably lower than that of the improved commercial dehulling method developed for dehulling of pigeonpea (Kurien 1981). The value for *dhal* yield was the highest (80.0%) for 'ICPL 87052', and the lowest (54.1%) for 'ICPL 87049', when dehulled in the TADD (Singh et al. 1992b). Similar variations in *dhal* yield of these genotypes were observed, when dehulled by using the barley pearler (Table 5). A statistical comparison between dehulling methods indicated that the standard error (SE) and coefficient of variation (CV) of the procedures were the highest for stone *chakki* and the lowest for TADD. Not only did the stone *chakki* produce the highest percentage of brokens as dehulling losses (Table 6), it also led to highly variable and erroneous results on the *dhal* yield. Further, *dhal* yield obtained by a stone *chakki* was neither correlated with TADD nor with the barley pearler (Singh et al. 1992b). But, there were significant and highly positive correlations between TADD and barley pearler for *dhal* yield and broken fractions. These results indicate that, depending on the availability, either of these two methods could be used to evaluate the dehulling quality of pulses. Saxena et al (1993) reported that a metal *chakki* (similar to stone *chakki*) may be suitable for small scale processing of pigeonpea in Sri Lanka.

Dehulling losses

The primary objective of dehulling is to remove the seed coat from the cotyledons, but noticeable amounts of cotyledons and germs are removed during the operation (Aykroyd and Doughty 1964; Siegel and Fawcett 1976). As a result, considerable quantitative and qualitative losses occur during dehulling of pulses. The dehulling losses would primarily depend on the dehulling methods and seed characteristics of pulses (Matanhelia 1994). The dehulling losses in terms of brokens were the highest (24.6%) in the stone *chakki* and this might have been due to the attrition action of the stones employed for dehulling in this method (Singh et al. 1992b). In commercial *dhal* mills, *dhal* yields only approach 70%, which are much lower than the theoretical *dhal* yields (Natarajan and Shankar 1980). Parpia (1973) reported that the average *dhal* yield from household and traditional commercial dehulling methods varied from 68 to 75%, which was 10 to 17% less than the theoretical average value of 85%. Table 6 summarizes the survey data on dehulling losses in terms of powder, broken and husk fractions in case of *dhal* yield of chickpea and pigeonpea obtained by large and small scale dehulling methods. This study reports that *dhal* yields are higher in chickpea than in pigeonpea. Further, *dhal* yield in pigeonpea varies between 50% and 80% with a mean of 61% in small scale and between 60 and 85% with a mean of 70.6% in large scale processing. Similar figures were

TABLE 7. EFFECT OF DEHULLING ON THE CHEMICAL CONSTITUENTS OF *DHAL* AND POWDER FRACTIONS OF CHICKPEA (CV. 'ANNIGERI') AND PIGEONPEA (CV. 'C11')

Dehulling time, min	*Dhal*			Powder		
	Protein, %	Calcium, g.100 g^{-1} sample	Iron, %	Protein, %	Calcium, g.100 g^{-1} sample	Iron, %
0	18.6[a]	43.0	5.7	-	-	-
	21.4[b]	64.9	5.7			
2	18.0	39.5	5.0	23.6	85.0	12.0
	20.8	51.7	4.1	31.2	167.8	17.3
4	17.5	38.0	4.8	21.8	65.5	10.5
	19.6	45.7	3.6	27.1	94.1	9.2
8	17.5	36.5	4.3	19.8	45.0	8.5
	19.6	45.7	3.6	27.1	94.1	9.2
12	16.4	35.0	3.8	18.9	45.0	7.0
	20.3	51.1	4.0	29.7	118.8	11.9
SEM	± 0.18	± 1.80	± 0.40	± 0.21	± 2.90	± 0.30
	± 0.17	± 2.83	± 0.19	± 0.15	± 2.00	± 1.63

[a] Chickpea, [b] Pigeonpea. All units are averages of two replicates, and expressed on a moisture-free basis. Source : Singh et al (1989, 1992a)

noticed for chickpea (Table 6). This indicates that dehulling losses are significant, and vary with the scale of operation and the pulse crop. The highest *dhal* yield was reported to be obtained from a modern *dhal* mill, where material is heated in the hot air before dehulling (Kurien 1981). High *dhal* yield in small scale processing of pigeonpea was also obtained by stone *chakki*, when material was heated in an open-pan before dehulling (Singh and Jambunathan 1981). Losses in terms of brokens, and powder fractions are higher, when a village *chakki* is used, i.e., in small scale processing. *Dhal* yields obtained by household dehulling practice are noticeably lower than those obtained by the large scale dehulling from commercial *dhal* mills (Table 6). When four methods of dehulling were compared, the yields were the highest in dehulling by the tangential abrasive dehulling device (Singh et al. 1992b). Significant differences were observed in dehulling characteristics of cowpea, pigeonpea, and *mung* bean (Ehiwe and Reichert 1987). This study further reported that dehulling quality was generally poor, because of low yield and long dehulling time in *mung* bean.

Effect of dehulling on nutrient losses

Proper dehulling of pulses for human nutrition essentially relates to efficient separation of the seed coat from the cotyledons (Aykroyd and Doughty 1964). Most common methods of dehulling of legumes remove the germ along with the husk and thereby incur losses of vitamins and proteins, the important dietary constituents (Aykroyd and Doughty 1964). As shown in Table 7, there was a decrease in protein, calcium and iron contents of *dhal* of chickpea and pigeonpea with an increase in dehulling time (Singh et al. 1989, 1992a). This indicated that outer portions of cotyledons were richer sources of protein, calcium and iron. When the outer layers of the cotyledons of pigeonpea are scarified, there is a 12% yield loss known as the powder fraction (Singh et al. 1989), which is a rich source of protein, calcium and iron (Singh et al. 1989). This loss is assumed to be an equivalent of traditional dehulling in terms of quantitative losses of powder fraction. Considerable amounts of calcium (about 20%) and iron (about 30%) were removed by scarification in dehulling of pigeonpea (Singh et al. 1989). A similar observation was noticed in chickpea, where considerable amounts of calcium, iron and zinc were removed by dehulling for 4 min (Singh et al. 1992a). This study further reported that dehulling of chickpea may not affect the protein quality in terms of amino acids. The outer layers of pigeonpea cotyledons are rich sources of proteins (Reddy et al. 1979). These layers are removed during dehulling, resulting in considerable protein losses. Singh et al (1989) reported that calcium and iron were concentrated in the outer layers of cotyledons and would be lost during dehulling. Protein, calcium, and iron are important nutrients, which are deficient particularly in the diets of, infants, pre-school children and pregnant and lactating women of low income group. Losses of protein, calcium and iron in such processing practices of pulses will lead to further deficiencies among these vulnerable groups.

Effect of dehulling on cooking time of *dhals* of pulses

The cooking time of *dhals* of pulses is influenced by dehulling method (Singh 1987). This review has reported that there may not be a direct effect of the dehulling machines on the cooking time. It is not the mechanical action of the roller machines or disc shellers that influence the cooking time, but the pre-treatments given to pigeonpea seeds before dehulling that considerably influence the cooking time (ICRISAT 1981). Soaking the seeds in water and subsequent sun- or oven-drying increases the cooking time in grain legumes (Paredes-Lopez et al. 1991). As reported in Table 8, soaking and oven-drying (65°C overnight) of pigeonpea seeds before dehulling considerably increased the cooking time, as compared to the control i.e., untreated seed used for dehulling. Further, it was observed that while soaking the whole seed in water increased the cooking time of *dhal*, soaking in 1% solution of sodium carbonate decreased it considerably. This study was conducted by dehulling the pre-treated seeds in the tangential abrasive dehulling device (ICRISAT 1981). According to this study, not only differences in cooking time of *dhal* due to genotypes and pre-treatments were significant, interactions between genotypes and pre-treatments on cooking time were also significant. This implies that genotypes will also play an important role in influencing the cooking time due to pre-treatments. Eventhough it is very difficult, such studies on the effect of pre-treatments should be conducted on *dhal* prepared by the commercial *dhal* mills.

Varietal differences in dehulling quality

As shown in Table 8, a large variability existed in dehulling quality of *mung* bean, cowpea, chickpea, and pigeonpea cultivars, as determined by the

TABLE 8. THE COOKING TIME (Min) OF PIGEONPEA *DHAL* OBTAINED BY VARIOUS PRE-TREATMENTS BEFORE DEHULLING

Cultivar	None	Pre-treatment procedures[a] Oil (1% w/w)	Water (1%w/v)[b]	NaCl (1% w/v)[b]	Na_2Co_3 (1% w/v)[b]
'BDN-1'	20	20	26	20	16
'C 11'	16	20	24	20	16
'No 148'	16	16	20	14	12
'LRG-30'	16	18	22	18	14
'LRG-36'	14	18	24	14	12
SEM ±	1.0	0.8	0.9	1.0	0.7

[a] After pre-treatments, samples were dried at 65°C overnight before dehulling in tangential abrasive dehulling device (TADD). [b]Stored for 6 h.

tangential abrasive dehulling device (Ehiwe and Reichert 1987; Singh et al. 1992b). Pigeonpea varieties exhibited less variations in dehulling characteristics than cowpea varieties (Ehiwe and Reichert 1987). The *dhal* yield (47.8-90.2%) and dehulling time of cowpea genotypes varied widely, suggesting that it may be desirable to monitor these characteristics in a cowpea breeding programme. The dehulling quality of the *mung* bean cultivars was generally poor, because of low yields and long dehulling time (Ehiwe and Reichert 1987). These workers suggested that resistance to seed splitting during dehulling and a loosely bound state of seed coat to the cotyledons were the major seed factors responsible for good dehulling quality of these legumes. Variations in the degree of dehusking obtained with different pigeonpea varieties are possibly the result of varying extents of loosening of husk from the cotyledons after pre-milling treatments (Ramakrishnaiah and Kurien 1983). These workers reported that degree of dehusking of pigeonpea varieties ranged between 67.1% and 100.0%. Different varieties of pigeonpea displayed varying dehulling characteristics, independent of their size and husk contents, but were greatly influenced by other varietal characteristics, like quantity of germs and moisture level of grain (Ramakrishnaiah and Kurien 1983). In a recent study, *dhal* yield of pigeonpea genotypes ranging from 54.1% to 80.0% was reported (Singh et al. 1992b). This study also reported that some newly developed varieties of pigeonpea showed very good dehulling quality. Kurien and Parpia (1968) reported that smaller seeded varieties of pigeonpea grown in North India produced lower *dhal* yield, because the seed coats were firmly attached to the cotyledons. Parpia (1973) reported that *dhal* yields of white pigeonpeas were considerably higher than those of the red pigeonpeas. However, a recent study indicated no correlation between *dhal* yield and seed colour of pigeonpea varieties, thereby suggesting that the seed colour may not influence the dehulling quality of pigeonpea (Singh et al. 1992b).

TABLE 9. VARIABILITY IN *DHAL* YIELD OF DIFFERENT PULSES[a]

	Number of genotypes	*Dhal* yield Range	Mean
Cowpea	11	47.8 -90.2	76.0
Chickpea[b], *desi*	58	71.1 -87.3	79.5
Chickpea[b], *kabuli*	12	89.6 -93.8	91.4
Pigeonpea	23	79.0 -83.8	81.8
	10[c]	54.1 -80.0	71.3
Mung bean	24	58.2 -73.8	65.2

[a]All *dhal* yield values were obtained by using the tangential abrasive dehulling device (TADD). [a] Source : Ehiwe and Reichert (1987). [b] Source : Singh 1993 (unpublished). [c] Source : Singh et al (1992b).

Dhal yield of *desi* varieties of chickpea ranges between 71.1% and 87.3% and of *kabuli* varieties between 89.6 and 93.8% (Table 9). *Dhal* yield of *kabuli* varieties are generally higher than those of the *desi* varieties, because of their lower seed coat content. From the results of the above mentioned studies (Table 9), it is apparent that large variability exists in dehulling quality of different varieties of grain legumes. However, such a variability has not been used in the breeding programme to develop high *dhal* yielding varieties. It is also apparent that dehulling quality of pigeonpea has been the subject of several studies in the past. More efforts are needed to study this aspect in other pulse crops.

Future research needs

The greatest potential for providing high protein pulse food products to a large number of vegetarian population living in developing countries is by means of improving production and processing of these crops. There are possibly two approaches to improve the processing and consequently, the *dhal* yield in pulses : 1) development of suitable method and machinery for dehulling and 2) identification and development of suitable varieties of pulses with high dehusking efficiency. Over 90% of the pulses produced in the country are dehulled by the traditional methods. So far, the dehulling technology developed by the research organizations have not become popular with the users, primarily for economic reasons. Now, it is highly desirable that research and development activities must be geared towards developing efficient and economical methods for dehulling. Since ages, stone *chakki* has been used for dehulling. It is high time to replace it by a suitable dehulling unit that could be conveniently adopted by the households in villages. Suitable mini *dhal* mills should be developed so that these could be used by the cooperatives and other organizations engaged in similar activities. For this purpose, attrition type (disc sheller) or abrasion type (roller machine) should be thoroughly compared and investigated for their efficiency for dehulling different pulse crops.

The genotypic differences exist in the dehulling quality of pulses, and these have to be exploited by the plant breeders. Efforts are needed to investigate the physical and chemical nature of seed coat of different pulses in the light of differences in their dehulling characteristics, and to develop improved varieties. Also, it is desirable to develop varieties with uniform and round seed shape to increase *dhal* yield. The identification and development of varieties with improved dehulling characteristics must receive increasing attention in the future.

Improved crop value will ultimately depend on the commodity characteristics assessed by processors and consumers. Pre-treatments of dehulling should be refined and further developed as suitable processing package not only to improve the *dhal* yield, but also improve its acceptance and nutritive value. To reduce nutrient losses, efforts should be made to develop suitable methods to separate husk from the cotyledons, and to avoid the splitting step to save the germ portion, which is a rich source of vitamins.

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Received 23 July 1994; revised 2 January 1995; accepted 4 January 1995