Towards redesigning indigenous mung bean foods

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This research was conducted under the auspices of the Graduate School VLAG (Advanced studies in Food Technology, Agrobiotechnology, Nutrition and Health Sciences).

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Thesis
submitted in fulfillment of the requirements for the degree of doctor
at Wageningen University
by the authority of the Rector Magnificus
Prof. Dr. M.J. Kropff,
in the presence of the
Thesis committee appointed by the Academic Board
to be defended in public
on Monday 29 April 2013
at 11 a.m. in the Aula.

Pradeep Kumar Dahiya

Towards redesigning indigenous mung bean foods

PhD Thesis, Wageningen University (Wageningen) The Netherlands (2013)
With references, with summaries in English, Dutch and Hindi

ISBN 978-94-6173-511-9

Abstract

Redesigning traditional foods requires consideration of the various factors affecting the nutrient intake from such foods. Amongst these factors are adequate consumption, proper nutrient bioavailability and consumer satisfaction. These factors are related to traditional food quality at various levels of the food network. The physical, food processing, nutritional and anti-nutritional properties of the mung bean were reviewed. Three major factors that affect the nutritional value of grains were identified, viz. genetic makeup, agronomical practices, and agro-ecological conditions. Consumer choices for mung bean products were analyzed with respect to perception, preferences and the resulting dietary practices, to determine their impact on their nutritional potential. Food choices were influenced more by social-economic restrictions than by consumer perception and preferences. Therefore, increasing the frequency of consumption of nutrient-rich products and use of mineral enhancing accompanying foods is recommended for better nutrition. The nutritional characteristics of newly bred and established mung bean varieties in the research community were analyzed. Results showed that varieties contained 18 - 23 g protein, 4.0 - 5.6 g crude fibre and 2.5 - 4.1 g ash per 100 g dry sample. Iron, zinc, calcium, sodium and potassium ranged from 3.4 - 4.6, 1.2 - 2.3, 79 - 115, 8.1 - 13.5 and 362 - 415 mg/100 g dry weight, respectively. Phytic acid and polyphenols averaged 769 and 325 mg/100 g dry weight, respectively. Varieties differed significantly in terms of nutrient and anti-nutrient contents. Newly bred varieties were not found to be significantly more nutritive than established ones and thus breeders are recommended to focus on a combination of crop yield, nutritional value and consumer preference traits. Nutritional characteristics of the indigenous foods made with mung bean were also analyzed. Average *in vitro* iron, zinc and calcium accessibility of the mung bean products were 1.6, 0.9 and 41.8 mg/100 g dry weight, respectively. Phytic acid and polyphenols averaged 210 and 180 mg/100 g dry weight, respectively, and were negatively correlated with *in vitro* mineral accessibility. *Dhals* were found to be nutritionally rich in terms of mineral accessibility. Critical evaluation of all the possible factors affecting nutritional potential suggests that *dhals* can be used as the vehicle for increasing the mineral uptake in the malnourished population through mung bean. However, identified technological options are required to be considered while redesigning traditional mung bean products.

Contents

Chapter 1

Introduction and thesis outline

1. Food security vis-a-vis food sovereignty

Food security means economic and physical access to adequate, safe and nourishing food that fulfills the dietary needs of individual persons. It is prerequisite for a suitable solution to global food problems like malnutrition, famine and starvation. Food security comprises the measures of resilience to disturbance to critical food supply due to various risk factors including droughts, economic instability and wars. It is based on “green revolution”- and agro-industrial models for agricultural development. However, these models are not universally applicable as they do not include region specific requirements (Patel, 2006). Food security highlights access to adequate nutrition for all through improved production and distribution of a few specific food crops. Therefore it serves to promote unidirectional corporate food regime leading to withdrawal of small-scale farmers, entrepreneurs and processors from the diversified traditional food systems. Thus, a flexible development model is required that can provide region-specific and sustainable solutions to bridge this gap.

Food sovereignty is a promising concept for agricultural development aimed at such a prerequisite. Food sovereignty can be described as the right of people to choose their own way of producing, processing and consuming foods that suit their local circumstances. One of the most accepted definitions of food sovereignty is as follows:

“Food sovereignty is the right of peoples to define their own food and agriculture; to protect and regulate domestic agricultural production and trade in order to achieve sustainable development objectives; to determine the extent to which they want to be self-reliant; to restrict the dumping of products in their markets; and to provide local fisheries- based communities the priority in managing the use of and the rights to aquatic resources. Food sovereignty does not negate trade, but rather it promotes the formulation of trade policies and practices that serve the rights of peoples to food and to safe, healthy and ecologically sustainable production.” (www.viacampesina.org)

Food sovereignty is an appropriate way to ensure people’s right to adequate food (Haugen, 2009). It guarantees improvement of the income of poor populations through agricultural productivity, improving nutrition through dietary diversity, improving food security, improvement of the ecological environment through enhanced biodiversity and increased use of indigenous food crops (Figure 1). These objectives are achieved by emphasizing principles like food for the people, empowering food providers, localizing food networks, development of locally controlled food systems, building understanding and techniques for local people and working with nature. These issues were previously ignored by development policies for empowering local farmers, peasants and small-scale entrepreneurs (Naranjo, 2012).

Realizing or sustaining food sovereignty of a region seems precarious in the modern world. Progressive mechanization and globalization of food production makes local food systems vulnerable, leading to adverse effects at individual, social, economic and ecological levels. Reversing this negative trend by parallel development of self-reliant localized food systems along with the existing globalized food systems necessitates a balanced approach.

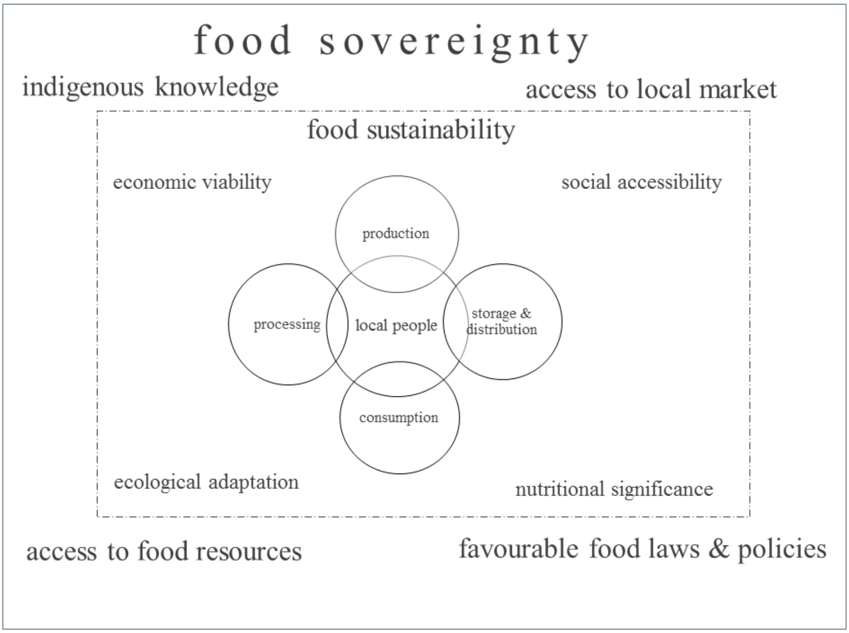

Figure 1. The concept of food sovereignty in relation to different realms

Food sovereignty as a multidimensional concept depends on different aspects of food such as its ecological suitability, economic viability, social acceptance, nutritional significance and political support. In order to achieve food sovereignty in a region, it is required to address each of these interrelated dimensions. However, this cannot be achieved in a single-action approach but requires a multi-disciplinary methodology.

The nutritional significance of food is an important dimension, which acts at the individual level. It includes the way how a food impacts an individual biologically. The main purpose of food is to ingest nutrients for health and well-being. To date, malnutrition problems persist around the globe, and this is a major health concern with adverse consequences for the development of resource poor populations. High rates of malnutrition persist today in spite of scientific development and research to decrease such suffering (Pathak and Singh, 2011). Nutrient malnutrition can be distinguished into macro-nutrient and micro-nutrient type of malnutrition. Iron deficiency, the world's most widespread nutritional disorder (Beard and Stoltzfus, 2001), affects billions of people, mostly women and children. This deficiency frequently affects rural populations that derive most of their income from traditional farming at the root level of the food chain. Micronutrient malnutrition adversely affects labour productivity, results in dropout rates of school attainment in children and leads to increased mortality and morbidity rates, thereby increasing overall health care costs (Underwood, 2000). This leads to considerable human and economic losses.

2. TELFUN –an interdisciplinary scientific approach to study food sovereignty issues

An interdisciplinary project called TELFUN (Tailoring Food Sciences to Endogenous Patterns of Local Food Supply for Future Nutrition) was formulated to study the concept of food sovereignty from different perspectives. The present thesis is part of this bigger framework, which is based on the philosophy of 'science in society' (Kleinman, 2005). The TELFUN project addresses the need of food sovereignty in developing countries and is based on the problem statement that the global food network is not appropriate for many regions (i.e. local) specific problems. Many local food networks exist and can be distinguished at multiple levels, interlinked and integrated with each other. These food networks are not competitive with the global corporate food network and are threatened to slowly disappear. Therefore the working hypothesis of the TELFUN project was formulated as:

"*Strengthening and extending multi-local food networks through appropriate technological and scientific practices is a suitable strategy for re-establishing food sovereignty and providing local populations with healthy and nutritional food products*"

To study this hypothesis, four key disciplines were identified, namely plant breeding, food technology, human nutrition and social sciences. Furthermore, three regions in the world were selected that differ in their social and technological settings, namely India (Haryana state), West Africa and the South American Andes region. Each region has its own production, processing and consumption patterns, which determined the choice for a particular indigenous crop for each region, namely mung bean, cowpea and lupine for India, West Africa and the Andean region, respectively. The choice of the particular crop for the respective regions was based on the relevance of the crop for the local food network. Each legume has its evolutionary center of origin in the respectively selected regions, which was also considered during selection to ensure ecological adaptability. Each researcher studied various aspects of the selected legume in the context of food sovereignty from his own discipline. The present thesis addresses the technology aspects of the case of mung bean in India.

3. The research area

Haryana, one of the states situated in northern India, which harbours a high level of local biodiversity, was selected as the locale for the research described in this thesis. In this state, Hisar district was selected. It is the third largest district in the state with third largest rural population. It has a high number of people involved in mung bean networks as farmers, household processors and consumers. Illiteracy is high, making this region prone to malnutrition. In terms of nutrient malnutrition, 42 % of children under 3 years were clinically underweight (too thin for their age) in 2005–06 compared with 34 % in 1998–99 in the state of Haryana (Chatterjee, 2007). During the same period, the number of children younger than 3 years who were too thin for their height, rose from 5 % to 16 %. Iron deficiency anaemia is also one of the major constraints of this state.

Agriculture occupies a prominent position in the state's economy, with a wide diversity of crops grown here. Amongst them are legumes, cash crops and feed crops. The food consumption patterns of the local population include diverse foods based on cereals, milk, fruits, vegetables and legumes (Manu and Khetarpaul, 2006). Food legumes have traditionally provided nutritionally balanced food to the northern Indians. Legumes are protein sources, particularly important for the vegetarian local population. Among the legumes, mung bean (*Vigna radiata (L.) R. Wilczek*) is one of the most important in the traditional diet. It is culturally accepted and ecologically suitable in northern India. The crop reportedly originates in the tropical regions of India (Harvey, 2006). Hisar district has the highest area under mung bean production in Haryana state. Mung bean, besides being micronutrient-rich, is able to fix nitrogen from the air through symbiotic association with *Rhizobium* bacteria. It constitutes an important supplement to the predominantly cereal-based diet of Asians, it is fairly easy to cultivate and acceptable to local tastes.

4. Mung bean: a promising vehicle for alleviating malnutrition

Green gram or mung bean (*Vigna radiata L. Wilczek*) is one of the most important food legumes grown and consumed in India. Mung bean is a protein-rich staple food. Amarteifio et al. (1998) reported 26.3 % crude protein, 59.8 % carbohydrate, 4.3 % crude fiber, 4.3 % ash and 6.8 mg /100 g of iron in mung beans. Depending on the variety, its protein content ranges from 15 % to 33 %, this is almost three times that of cereals (Dahiya et al., 2013). Mung bean protein is easily digestible, but lacks the essential sulfur-containing amino acids, methionine and cysteine, thereby limiting its protein quality. Nevertheless, the amount of methionine and cysteine in mung bean is still higher than in any other food legume. The biological value improves greatly when wheat or rice is combined with mung bean because of the complementary relationship of the essential amino acids. Mung bean *khichadi*, *i.e.* rice with mung bean *dhal*, and mung bean *dhal* with *chapatti* (Indian flat bread) are a few examples of Indian dishes with this kind of combination of a cereal and a pulse. Mung bean is particularly rich in leucine, phenylalanine, lysine, valine and isoleucine. The cystine and tryptophan contents of mung beans are 0.88 and 1.13 g /16 g nitrogen, respectively (Kochhar and Hira, 1997).

A B

Figure 2. Mung bean plant (A) and whole grains (B)

Mung bean is a rich source of phosphorus and vitamin A, and mung bean sprouts are rich in vitamin C. However, there are also many anti-nutritional factors, like phytic acid, polyphenols and trypsin inhibitors, present in mung bean. These are known to reduce the availability and digestibility of nutrients. Siddhuraju et al. (2002) reported 1.20 % of phytic acid, 0.45 % of total phenolic compounds and 1.5 % of saponins in mung bean. Mung beans also contain flatulence- causing coumpounds like raffinose, dietary fibers, and indigestible starch. Flatulence due to mung bean consumption is the result of the action of intestinal flora on these poorly digestible compounds. Although the compositional data of raw grains are not identical to the nutritional value of mung bean as consumed, they indicate the nutritional potential of the grain. Therefore, it is important to study the nutritional characteristics of the mung bean products as consumed.

Mung beans have to be cooked to render them digestible. Its grains can be used in food preparation as whole, split and dehulled split grains (Figure 2 and 3). The major domestic methods for processing mung beans are open cooking, pressure cooking, roasting, soaking, drying, boiling, sprouting, fermenting and frying (Figure 4). Different domestic methods are employed for specific types of mung bean food. Physical and functional properties of the mung bean varieties govern the behaviour of the mung bean grain or flour during the processing and thus determine the overall quality of the final product. Processing time is also directly associated with varietal differences.

A B

Figure 3. Split (A) and dehulled mung bean *dhal* (B)

Three types of mung bean (*i.e.* whole, split and dehulled split) can be processed to prepare main dishes, which are often eaten with chapatti. These products are called mung bean dhals. *Dhals* are also consumed with boiled or pressure cooked rice. Mung bean *khichadi*, a product prepared with rice and mung bean (whole or dehulled split mung beans) is recommended by doctors for ill and aged persons as it is easily digestible and considered to be a complete diet. Among the sweet products we encounter mung bean *halwa*, *laddu* and *burfi* (Figure 5). People take these products as dessert in their diets but poor people cannot afford these products as the sweet mung bean foods are relatively expensive. They take these products seasonally during festivals. Mung bean snacks are also very popular among the rural and urban population of India. There are various types of snacks like *pakore*, *namkeen*, *bhalle* and *papad* (Figure 5). *Pakore* is a fried snack, which is taken with various types of sauces during tea time. *Namkeen* can be either salty or spicy, and they are also taken with beverages. *Bhalle* are fried products consumed with curd, chopped onions and spices. Mung bean *papad*, roasted sheets of spiced mung bean dough, are consumed as such as an crispy snack. Mung bean *wadi* is a fermented product prepared by drying fermented spiced or simple mung bean paste. *Wadi* is consumed after cooking with chopped potatoes or other vegetables in the curries, which then are consumed with *chapattis*, *pranthas* (shallow fried *chapattis*) and rice.

Soaking | Roasting

Deep frying | Stir frying

Sun drying | Natural fermenting

Figure 4. Domestic methods of mung bean processing

Papad

Bhalle

Split dhal

Wadi

Halwa

Whole laddu

Figure 5. Indigenous mung bean food products

5. Food network approach for redesigning mung bean products

In the present thesis, factors affecting nutritional intake from mung bean foods and their acceptance by consumers were studied. These factors are located at various levels in the mung bean food network (production, processing and consumption) in terms of scientific and social parameters (Figure 6). The most important issues at the production level that have a direct impact on the mineral nutrition, are the nutrient content and the presence of anti-nutritional factors in established and improved mung bean varieties.

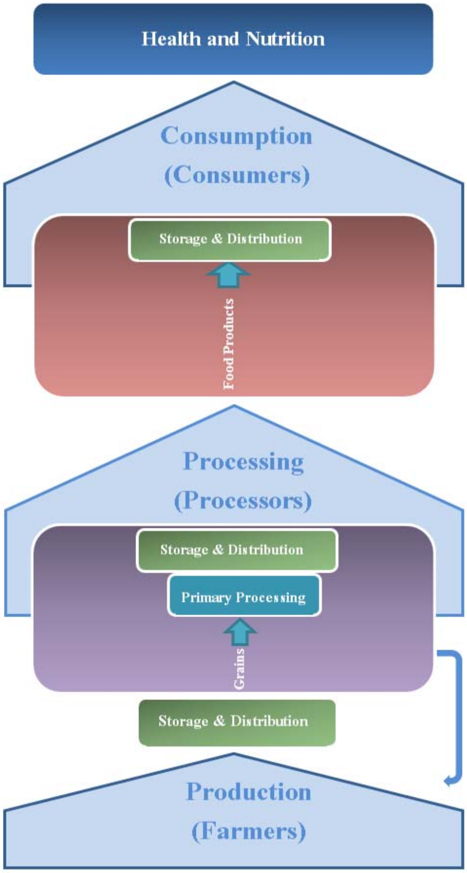

Figure 6. Mung bean food network

The physical and food processing properties are the quality parameters that govern the potential of a variety to be processed into a mung bean product that is appreciated by consumers. However, in the end the knowledge of the processors and their perception of the quality of the various varieties is decisive as to the products that become available to consumers. An important factor at the processing level is how processors apply their knowledge when they actually prepare mung bean foods as this will also affect the nutritional composition of the products (Cilla et al., 2011). This is reflected in the processing practices (Kumari et al., 2004). Different processing methods and different processing parameters like temperature, vessels used, duration, also impact the final nutritional properties of the product.

However, consumers' perception of product quality is also an important issue that affects the overall consumer choice. At consumption level, consumers preferences and dietary practices (Sparke and Menrad, 2011) affect the selection of products for consumption (Siró et al., 2008). These selections ultimately affect the nutritional status of an individual. Thus, the present research focused on these issues and therefore the research objectives were formulated to address them and to conceptualize their impact on achieving food sovereignty.

6. Hypothesis and research objectives

The TELFUN project aimed to identify different varieties of mung bean with desirable agronomic, food processing, nutritional traits and then to promote their production, processing and utilization through traditional technologies. Improving mung bean production and consumption is one of the most direct, low-cost ways for poor communities to improve their nutritional status, particularly in India where mung bean is frequently produced, processed and utilized. The hypothesis of the present project is that mung bean foods could be optimised for their nutritional value, and could constitute a suitable vehicle for the enrichment of the diet with micronutrients that are deficient in the majority of the Indian population. So far the best technologies to that effect have not been established and technological possibilities have not been tested for consumer acceptance of the resulting foods. Thus this project was designed to achieve the following research objectives:

1. To review the technological and nutritional potential of mung bean,
2. To determine the nutritional value of mung bean varieties,
3. To determine the nutritional value of indigenous mung bean foods,
4. To determine consumer choices and underlying factors, and
5. To identify technological options to redesign traditional mung bean products.

7. Outline of the thesis

The present chapter provides general information about the mung bean, describes the relevance of the PhD research, its research questions, objectives and the thesis outlines. In **chapter 2,** technological and nutritional properties of the mung bean are critically reviewed and discussed. Studies that need to be done based on the critical analysis are outlined. In **chapter 3,** consumer choices and consumption patterns of the mung bean products are investigated and linked to protein, iron and zinc uptake. Based on the first three aspects, it was found that further research was needed on nutritional properties of the established and advanced mung bean varieties. Consequently, **chapter 4** describes the physical and food processing properties of the mung bean varieties. **Chapter 5** investigates the nutritional characteristics of different indigenous mung bean food products. Finally, in **chapter 6**, a general discussion is given on the obtained results and a view on the degree to which the objectives have been achieved. Moreover, recommendations for further research are given.

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Dahiya, P. K., Linnemann, A. R., Nout, M. J. R., van Boekel, M. A. J. S., Khetarpaul, N., and Grewal, R. B. (2013). Mung bean: technological and nutritional potential *Critical Reviews in Food Science and Nutrition (Accepted)*.

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Chapter 2

Mung bean: technological and nutritional potential

This chapter has been accepted for publication as:

Dahiya, P. K., Linnemann, A. R., Nout, M. J. R., van Boekel, M. A. J. S., Khetarpaul, N., and Grewal, R. B. (2013). Mung bean: technological and nutritional potential *Critical Reviews in Food Science and Nutrition*.

Abstract

Mung bean (*Vigna radiata* (L.) R. Wilczek) has been intensively researched; scattered data are available on various properties. Data on physical, chemical, food processing and nutritional properties were collected for whole mung bean grains and reviewed to assess the crop's potential as food and to set research priorities. Results show that mung bean is a rich source of protein (14.6 to 33.0 g/100 g) and iron (5.9 - 7.6 mg/100 g). Grain colour is correlated with compounds like polyphenols and carotenoids, while grain hardness is associated with fibre content. Physical properties like grain dimensions, sphericity, porosity, bulk and true density are related to moisture content. Anti-nutrients are phytic acid, tannins, haemagglutinins and polyphenols. Reported nutrient contents vary greatly, the causes of which are not well understood. Grain size and colour have been associated with different regions and were used by plant breeders for selection purposes. Analytical methods require more accuracy and precision to distinguish biological variation from analytical variation. Research on nutrient digestibility, food processing properties and bioavailability is needed. Furthermore, the effects of storage and processing on nutrients and food processing properties are required to enable optimisation of processing steps, for better mung bean food quality and process efficiency.

Keywords: Nutrients, anti-nutrients, minerals, fatty acids, amino acids, physical properties.

1. Introduction

Mung bean or green gram (*Vigna radiata* (L.) R. Wilczek) has been cultivated in India since pre-historic times and is believed to be a native crop of India (1926). It is cultivated throughout Southern and Eastern Asia, Central Africa, some parts of China, South & North America and Australia, particularly for its protein-rich grains. Mung bean is a warm seasonal annual legume, grown mostly as a rotational crop with cereals like wheat and rice. Mung bean plants are erect with branches carrying pods in clusters near the top of the plant. Pods contain 8 - 15 seed grains. The grains are green or brown coloured and globose in shape with a flat hilum. The crop's main advantages are that, as a legume, it does not require fertilization for nitrogen (Murakami et al., 1991), and that it has a short growth cycle (75 - 90 days), requires little water and fits easily into crop rotations with cereals. It grows well under most adverse arid and semi-arid conditions.

Mung bean is considered a good source of protein (Engel, 1978). Its different food products such as dhals (*i.e.* thick stews from dehulled and split grains), sweets, snacks and savoury foods have evolved and became popular in the Indian subcontinent (Adsule et al., 1986; Singh et al., 1988), whereas products like cake, sprouts, noodles and soups evolved in oriental countries like China (Cheng et al., 1988; Singh and Singh, 1992), the Philippines (Rosario, 1991) as well as in Iran (Amirshahi, 1978) and Thailand (Prabhavat, 1990).

Biochemical analyses in previously published studies reveal that mung bean and its processed products are rich in nutrients. Chemistry and technology of mung bean have been reviewed previously by Adsule et al. (1986), who provided substantial information on the nutritional aspects, but only gave limited information on processing of mung bean. Some publications also reviewed mung bean food products (Adsule et al., 1986; Prabhavat, 1990; Rosario, 1991; Singh and Singh, 1992). However, these reviews are dated and do not deal in detail with the physical and food processing properties of mung bean grains, or other new developments in mung bean chemistry. Knowledge about the effects of food processing and physical characteristics is essential to enable standardization and quality assurance of foods prepared by different processing methods. The present review investigates the physical, chemical, food processing and nutritional properties of raw mung bean grain based on literature data and critically evaluates the similarities and divergences of the values in relation to the research methods used. Although the chemistry of raw grains does not represent the nutrient content of mung bean as consumed, the data establish the potential of stored nutritional composition of the grain. For each component, the reported values are, as much as possible, converted into the same unit, and their average, minimum and maximum values are calculated and reported in tables. Finally, further research needs are identified for strengthening the knowledge base of this important food grain.

For the purpose of this review, we searched all scientific publication sources relating to chemistry, processing and consumption of mung bean. We focussed, however, on the more recent literature data. We included 4 data sources from the period 1926 – 1960, 1 source from the seventies, 23 sources from the eighties, 36 from the nineties, 29 from the period 1991 – 2000, whereas the period 2001 till present yielded 50 relevant publications.

2. Physical and engineering properties

Knowledge of physical and engineering properties is essential for designing equipment for processing, transportation, sorting, separation and storage. Physical properties of mung bean grains and their relation with its chemical composition, particularly with moisture content, have been studied (Mangaraj et al., 2005; Nimkar and Chattopadhyay, 2001; Unal et al., 2008; Yildiz, 2005). The relevant physical properties of mung bean grains include shape, size, mass, volume, bulk density, true density, porosity, static friction against different surfaces, rupture strength, angle of repose and terminal velocity (Table 1). Volume, density and porosity are among the parameters that determine the suitability of mung bean grains for processing technologies and affect grain resistance towards air flow in transport and separation unit operations (Unal et al., 2008). Rupture strength of the grains determines the milling behaviour and cookability of the grains, as grains with low rupture strength will be easy to handle in flour making and soften easily during cooking. Dimensions of mung bean grains are important for the quality of its derived products, such as texture in the case of sprouts and consistency in the case of dhals. Consumer's appreciation for sprouts may vary with bean varieties of different sizes.

2.1 Dimensions and shape of the grain

Physical dimensions of the grain, *i.e.* length (L), width (B) and thickness (T), are relevant in grading, sorting, sieving and other post-harvest operations. Grain size plays an important role in selection and distribution of mung bean varieties around the globe, as consumers selected varieties with specific sizes along with other agronomic characteristics (Mangaraj et al., 2005; Tomooka et al., 1991). This has led to three mung bean areas on the basis of seed size, namely the Indian subcontinent with small-seeded mung bean, south-east Asia with large-sized mung bean and east Asia with medium-sized mung been grains (Tomooka et al., 1991). The reported length, width and thickness of the mung bean are given in Table 1. Dimensions of the mung bean grain were measured by analogue or digital Vernier calliper (Nimkar and Chattopadhyay, 2001), whereas Yildiz (2005) used a micrometer. Measurements were done at different moisture contents, ranging from 6.7 to 33.4 % dw (dry weight). From these results all authors (Nimkar and Chattopadhyay, 2001; Unal et al., 2008; Yildiz, 2005) concluded that length, width and thickness are a function of moisture content of the grains and that dimensions increase at higher moisture contents with a high correlation coefficient (R^2 = 0.998). The reported geometric mean diameter (D) was calculated by the equation $D = (LxBxT)^{1/3}$. The variation in the dimension may be due to the use of different varieties and can be influenced by sample quality, particularly moisture content. However, use of an analogue Vernier calliper or micrometer as tools of analysis seems to have no effect on the calculated values. Length / width ratio of the mung bean ranged from 1.0 to 1.5, which was used as an indicator of the shape of mung bean (Tomooka, 1991). Grain size is also reported to be correlated with protein content as discussed later in this article.

Sphericity of the grain is the geometric tolerance of the grain that indicates how much it deviates from a perfectly round sphere. Sphericity (φ) was calculated by the equation $\varphi = D/L$, where D is the geometric mean diameter and L is the length of the grain. Its value is the ratio and thus dimensionless. Higher values of sphericity indicate that the shape of the grain is closer to a sphere. This parameter is important in the movement of the grains during milling, sorting and dehulling processes and for determination of terminal velocity, the drag coefficient and the Reynolds number. The sphericity of the mung bean grain decreases non-linearly with an increase in the moisture content from 6.7 to 18.6 % (R^2 = 0.892) (Unal et al., 2008) and is comparable to that of cowpea (Yalcın, 2007), millet (Baryeh, 2002) and pea (Yalcın et al., 2007) with values ranging from 0.78 - 0.80, 0.79 - 0.80 and 0.84 - 0.85, respectively.

2.2 Grain colour and appearance

The colour of the mung bean grain is a quality indicator, as consumers select grains of a specific colour and reject others. Mung bean grains generally appear green but other colours have also been reported (Paroda and Thomas, 1988). The colour of the grain is due to the colour of the testa. The cotyledons are generally pale yellow. Colours of mung bean grains may range from dark green, light yellow, light green, deep green, shining green, dull green, golden yellow to mottled yellow (Katiyar et al., 2007; Yousif et al., 2003). Mung bean grains have been divided into five groups on the basis of grain colour, *i.e.* green with glossy seed, dull green, yellow with glossiness and dull lustre, black with glossy lustre and brown with dull seed lustre by Tomooka et al. (1991), who identified a geographic gradient for mung bean varieties based on grain colour. Most of the shiny green mung bean varieties (49 %) are from the Philippines, Vietnam, Thailand, India, Pakistan and Afghanistan, whereas dull green varieties are mainly from Korea, China, Taiwan, Turkey and Indonesia. Yellow coloured varieties are from Korea, Taiwan, the Philippines, Indonesia, Thailand and India but account for only 4 % of the studied varieties, whereas brown varieties are mainly from Iran, Iraq, Pakistan and the Afghan region (Tomooka et al., 1991). The variation in grain colour may be due to differences in genetic make-up (Akhtar et al., 1988; Bhadra et al., 1991; Chen and Liu, 2001; Katiyar et al., 2007; Pandey et al., 1989; Yousif et al., 2003) and storage conditions (Yousif et al., 2003). Colour of the grains is an important property for varietal identification and acts as a marker for breeding experiments (Chhabra et al., 1990). Dark coloured mung bean grains have been reported to contain higher polyphenol levels (Muhammed et al., 2010; Salunkhe et al., 1982), probably due to higher concentrations in the grain testa (Barroga et al., 1985). Yellow mung bean varieties contained higher quantities of seed coat polyphenols than green varieties, which indicate effective removal of polyphenols in yellow varieties by the dehulling process. Difference in colour in mung bean varieties is also due to different carotenoid contents as discussed later in the article. The colour of the grain imparts colour to certain food products prepared by use of whole mung beans, thus it seems that mung bean varieties that impart odd colours to a product will not be acceptable. Authors reported mung bean colours based on subjective observations; to our knowledge, no author reported the colour of mung bean based on instrumental studies.

2.3 Grain hardness

Hardness is the ability of the grain to resist penetration, breakage and scratching. Sood et al. (1982) reported grain hardness of nine mung bean varieties to range from 1.9 - 3.8 kg/seed with an average of 3.0 kg/seed, measured using a unspecified hardness tester. Grain hardness has been reported to correlate with grain weight (Humphry et al., 2005) and colour of the grains. Felicito and Evelyn Mae (1990) reported that high lignin and silica contents in combination with a compact solid structure can be the reason for the hardness of the seed coat in hard mung bean grains, as well as for their impermeability to water. Mendoza et al. (1988) reported that hardness of mung bean occurs in fresh grains mostly during the dry season and that yellow varieties are more likely to develop hardness. Felicito and Evelyn Mae (1990) reported that hydroxyprolines and pectins are not involved in the hard seed coat phenomenon of mung bean as they did not find hydroxyprolines in the amino acid profile of mung bean and the pectin content of normal and hard grains showed no significant difference. The authors also reported that the thickness of the seed coat of hard seeds was twice that of normal seeds, which may be due to the reported 9 to 25 % higher fibre content. Various authors (Molina et al., 1974; Werker et al., 1979) have correlated hardness of grains with high concentrations of pectin substances. To our knowledge, no study has been conducted on the effect of storage, maturity and moisture content on the hardness of mung bean grains. Similarly, no comparative study has been done on the grain hardness of the normal, as well as hard-to-cook mung bean grains, which would be important for optimization of the processing conditions.

Table 1 Physical and engineering properties of mung bean

Physical and engineering properties	Average*	Minimum	Maximum	References
Length (mm)	4.9	4.2	6.2	(Mangaraj et al., 2005; Nimkar and Chattopadhyay, 2001; Unal et al., 2008; Yildiz, 2005)
Width (mm)	3.7	3.2	4.5	(Mangaraj et al., 2005; Nimkar and Chattopadhyay, 2001; Unal et al., 2008; Yildiz, 2005)
Thickness (mm)	3.6	3.1	4.2	(Mangaraj et al., 2005; Nimkar and Chattopadhyay, 2001; Unal et al., 2008; Yildiz, 2005)
Geometric mean diameter (mm)	4.3	3.7	4.9	(Mangaraj et al., 2005; Unal et al., 2008; Yildiz, 2005)
Sphericity	0.82	0.75	0.90	(Mangaraj et al., 2005; Unal et al., 2008; Yildiz, 2005)
Volume (mm^3)	33.2	30.4	35.0	(Unal et al., 2008; Yildiz, 2005)
Thousand seed weight (g)	35.6	7.3	60.1	(Mangaraj et al., 2005; Nimkar and Chattopadhyay, 2001; Unal et al., 2008; Yildiz, 2005)
Bulk density ($kg.m^3$)	756.81	679.1	821.3	(Nimkar and Chattopadhyay, 2001; Unal et al., 2008; Yildiz, 2005)
True density ($kg.m^3$)	1335.4	1230.0	1456.7	(Nimkar and Chattopadhyay, 2001; Unal et al., 2008)
Porosity (%)	40.8	30.4	47.1	(Nimkar and Chattopadhyay, 2001; Unal et al., 2008; Yildiz, 2005)
Terminal velocity ($m.s^{-1}$)	7.5	4.9	12.1	(Nimkar and Chattopadhyay, 2001; Unal et al., 2008; Yildiz, 2005)
Angle of repose (degree)	27.6	25.9	29.4	(Nimkar and Chattopadhyay, 2001; Unal et al., 2008)
Projected area (mm^2)	18.4	17.5	19.3	(Unal et al., 2008)

* Mean value of all collected data.

2.4 Volume of the grain

Grain volume is a parameter that helps to calculate different other parameters that are important for handling processes. Yildiz (2005) reported a volume of 30 and 35 mm^3 for mung bean grains at moisture contents of 6.7 and 18.6 %, respectively. The variation in the volume of the mung bean grain is due to its moisture content, which depends on the maturity level of the grain at the time of harvest and post-harvest drying.

2.5 Grain weight

Grain weight is important for different handling processes. It varies within and between grains of different varieties in relation to growing conditions and maturity at harvest as this influences the moisture content. After harvesting its value may change depending on the storage conditions. Mung bean has relatively small grains in comparison to other commonly used pulses (Nimkar and Chattopadhyay, 2001). The reported thousand seed weights (Table 1) were estimated with moisture contents ranging from 8.4 to 33.4 % dw by weighing 100 randomly selected grains from the bulk and then calculating the 1000 grain weight. Tomooka (1991) observed a geographic gradient for the distribution of mung bean varieties on the basis of seed weight, as he did for seed colour. He noted that small-seeded varieties with a low seed weight were found predominantly in the Indian subcontinent and West Asia, whereas seeds with higher weights were found mainly in south-east Asian countries.

2.6 Bulk density of the grain

Mangaraj et al. (2005) and Unal et al. (2008) determined bulk density (ρ_b) with the help of a 1000 ml measuring cylinder, whereas Yildiz (2005) and Nimkar and Chattopadhyay (2001) used a hectolitre tester. Grain samples were poured in the measuring cylinder and weighed. Bulk density is expressed as the ratio of mass of the sample and its volume (Mangaraj et al., 2005; Nimkar and Chattopadhyay, 2001). The values of bulk density were reported to have a negative linear relationship with the moisture content (MC) of the grain. Unal et al. (2008) reported that the bulk density of the grain bears the following relationship with moisture content with a coefficient of determination of $R^2 = 0.99$:

$$\rho_b = 867.3 - 6.2\ MC$$

According to Nimkar and Chattopadhyay (2001) this relationship is:

$$\rho_b = 843.3 - 4.2\ MC$$

Unal et al. (2008) reported that the bulk density of mung bean at a moisture content of 14.7 % dw is larger than that of most pulses, for example gram and soya bean grain, due to the larger size of these grains as compared to mung bean. To our knowledge bulk density of whole mung bean flour has not been determined.

2.7 Grain (true) density

Grain density is the ratio of mass of the grain to its volume. It is different from the bulk density in the fact that true density is the density of a single grain, whereas bulk density is the density of certain amount of grains in a given vessel or container, which also includes the void spaces between the grains. It can be measured either by air or by liquid displacement methods. Water and toluene are the liquids used in the liquid displacement method. Unal et al. (2008) reported that true density shows a positive linear relation with moisture content, whereas Nimkar and Chattopadhyay (2001) found the opposite. These authors reported altogether different correlations, although both used the same toluene displacement method for the determination of true density by calculating the ratio of sample mass to the true volume of particles.

2.8 Porosity of the grain

Porosity of the bulk of grain is a measure of the void spaces in a material, and is a fraction of the volume of voids over the total volume. Its value depends on the values of true and bulk density. It is important as it influences milling properties, drying rate, breakage susceptibility and grain hardness. The bulk porosity (ε) of the mung bean grain was calculated by using mean values of the bulk density and true density in the flowing equation:

$$\varepsilon = 100\ [1 - (\rho_b / \rho_t)]$$

Where: ρ_b and ρ_t are bulk density and true density, respectively. Unal et al. (2008) reported that bulk porosity of mung bean at a moisture content of 12.6 % dw, (38.7 %) is smaller than for chick pea (43.6 %) and pigeon pea (41.7 %). This may be due to the larger sizes of chickpea and pigeon pea grains.

2.9 Terminal velocity of the grain

Terminal velocity is an important parameter in aerodynamic and hydrodynamic behaviour, and depends on acceleration of gravity and fluid flow. It is important, for instance, when separating chaff and grain. Terminal velocity has a positive linear relationship with moisture content of the grain. Nimkar and Chattopadhyay (2001) reported that an increase in terminal velocity with an increase in moisture content is due to the increase in mass of individual grains per unit frontal area facing the air stream during suspension. Moreover, an increase in moisture content also increases the size of the grain, which also affects terminal velocity. Most authors used air column and temperature-type anemometers to determine the terminal velocity. In this method, grains are positioned on a platform confronting a controlled airflow. By increasing the airflow gradually, the grains start to float to a certain height. The air velocity at this height is measured as terminal velocity.

2.10 Coefficient of static friction of the grain

The coefficient of friction is the degree of interaction between two surfaces. It has a dimensionless value from 0 to 1, the latter indicating a greater resistance. The coefficient of friction plays its role in transport, storage and packaging of mung bean grains (Unal et al., 2008), for example, in the construction of silo walls and selection of materials for post-harvest cleaning and grading equipment and packaging material. The reported values were assessed at moisture levels of grains ranging from 8.4 - 33 % dw. The coefficient of static friction of mung bean showed a positive linear relationship with moisture content. According to Nimkar and Chattopadhyay (2001), this increase is due to increased adhesion between the grains and the material surface at higher moisture contents. The coefficient of static friction of mung bean is reported to be highest against rubber (from 0.40 to 0.63) and least for glass (from 0.32 to 0.35). Nimkar and Chattopadhyay (2001) reported that rubber as a surface for sliding offered maximum friction followed by galvanized iron, fibre board, stainless steel, aluminium and glass. To determine the coefficient of static friction, the authors placed a plastic cylinder of 100 mm diameter and 50 mm height filled with sample on an adjustable tilting plate. The cylinder was raised slightly so as not to touch the surface. Next, the surface with the cylinder resting on it was inclined gradually using a screw device, until the box just started to slide down. The angle of tilt was read.

2.11 Angle of repose of grain

Angle of repose is the angle made by the inclined plane with the horizontal surface such that the body lying on the inclined plane is just at the verge of sliding down along the inclined plane. It is the measure of the maximum slope at which grains are stable. It is an important bulk property of the mung bean as it is required for the storage of the grains in piles and to design processing equipment and hoppers or silos to store. It can also be used to size a conveyor belt for transporting the grains from one part of a processing plant to another. It is measured by allowing bulk of grain to slide down from one side of the topless, bottomless box to make a heap at a certain angle. The angle made is measured as angle of repose. The reported values vary from 26 to 31° with an average of 28° (Nimkar and Chattopadhyay, 2001; Unal et al., 2008) at moisture contents ranging from 7.3 to 33.4 % dw. The angle of repose was found to increase with an increase in the moisture content of the grain. Nimkar and Chattopadhyay (2001) reported that the angles of repose of mung bean are lower than those of pumpkin seeds and higher than those of chickpea.

2.12 Rupture strength of grain

Rupture strength is the minimum force applied to axial dimensions (length, width and thickness) of the grain to deform it. Unal et al. (2008) reported that rupture strength is highly dependent on the moisture content and they indicated that greater forces were necessary to rupture seeds with lower moisture contents. The small rupturing force at higher moisture content is attributed to the fact that grain becomes more sensitive to cracking at high moisture content. Rupture strength of the grain has its importance during the development of mechanization of production processes for the preparation of e.g. porridge, semolina and split legume. The rupture strength of the mung bean was determined with a penetrometer at moisture contents ranging from 7.3 to 17.8 %.

2.13 Projected area of grain

The projected area of grain reflects its fluidization characteristics for which its front two-dimensional area is measured. It is important for the design and development of conveyers for transporting grains and agricultural machines. Unal et al. (2008) reported values for the projected area of 17.0 and 19.2 mm^2 with an average of 18.4 mm^2 in mung bean grains at moisture contents of 7.3 to 17.8 % dw. The projected shape is globose, and reported to increase with an increase in moisture content. The projected area of the mung bean was determined by using a digital camera.

3. Chemical composition

The mung bean grain has three main parts, viz. testa, embryo and cotyledons, which respectively constitute 12.2 -23.5, 2.3 and 76.5 - 87.2 % dw of the whole grain

(Muhammed et al., 2010; Singh et al., 1968). The chemical constituents are unevenly distributed in the different parts of the grain. The major chemical components of mung bean dry matter are carbohydrates, proteins, fat, fibre, ash, fatty acids and amino acids, while micronutrients include minerals and vitamins. The minimum and maximum reported values along with calculated average value of each chemical constituent are given for each parameter in the respective tables.

3.1 Proximate analysis

The reported values for macronutrients are presented in Table 2. The crude protein content of mung bean shows large variations, which may be due to differences between varieties (Thakare et al., 1988; Yohe and Poehlman, 1972), different methods of analysis and growth conditions, as discussed later. Most authors used the microKjeldahl method for analysis with a conversion factor of 6.25 to determine the protein content, whereas Cai et al. (2002) used the combustion method to extract nitrogen from their sample to nitrogen oxide, reducing it to nitrogen, which then is detected by a thermoconductivity detector. Most of the protein in mung bean is present in the cotyledons, with the majority of protein as salt-soluble storage globulins. Mung bean contains both storage proteins found in legume grains, viz. legumin and vicilin. Vicilin protein is glycosylated contrary to legumin globulin. Vicilin is more abundant in mung bean than legumin (Sathe, 1996). Vicilin is rich in acidic amino acids. Bhadra et al. (1991) reported a negative correlation between protein content and grain size; varieties with small-sized grains and a low yield were found to have a high protein content. However, Trung and Yoshipa (1983) reported a positive correlation between seed size and protein content (r = 0.555). Research at the Asian Vegetable Research Development Centre (AVRDC) is based on crosses between large-seeded Philippine and small-seeded Indian cultivars (Poehlman, 1991). Tomooka et al. (1992) distinguished eight protein types of mung bean varieties distributed over different geographical areas and, based on this, the authors suggested the origin of mung bean to be west Asia instead of India. Four proteins, named Vig r2 (52 kDa), Vig r3 (50 kDa), Vig r4 (30 kDa) and Vig r5 (18 kDa), in mung bean grains were reported to be potentially allergenic in nature as they induced strong IgE-mediated reactions (Misra et al., 2011). This is the only study on the potential allergic nature of proteins in mung bean and therefore further studies are required.

There is a wide variation in the reported lipid content that may be due to the genetic variation and/or different analytical methods. Most authors used soxhlet equipment and some Soxtec, which reduces the extraction time to 2 - 3 hours as compared to more than 6 hours for soxhlet equipment.

The average crude fibre content is 4.6 g/100 g dw. Fibre content of mung bean is correlated with seed hardness due to the fact that hard seeds have a thick seed coat (Felicito and Evelyn Mae, 1990). The seed coat contains 12 % more fibre than the cotyledons (Felicito and Evelyn Mae, 1990). Singh et. al. (1968) reported that 80 - 93 % of the crude fibre in mung bean is present in the seed coat, whereas the embryo contains only 2 - 3 % crude fibre. Apart from the reported maximum and minimum values, there is no wide variation in fibre content of mung bean. Most authors used the AOAC method to determine crude fibre, whereas El-Adawy et al. (2003), who reported the highest value of 6.2 g/100 g dw, did not mention the method used.

Khattak et al. (2007b) reported the ash content of thirteen varieties with an average value of 0.18 g/100 g dw. This value is much lower than the average of the values from all other authors. The reason for this deviation is not known. In general there is wide variation in the reported ash content, which may be partly genetic (Grewal and Jood, 2009). All authors used the AOAC method to determine the ash content.

The energy content of mung bean grains averages 344 kcal/100g dw. As the major energy components of mung bean are present in the cotyledons, removal of the seed coat and embryo during dehulling does no significantly reduce its energy value (Singh et al., 1968).

The variation in the reported values of the macronutrients is very large. This may be attributed to differences in detection methods and/or mung bean varieties. Most authors determined carbohydrates by difference. The number of authors who determined macronutrients in mung bean is large compared to those who measured other parameters like nutrient digestibility and bioavailability.

3.2 Carbohydrates

Carbohydrates in mung bean (Table 3) have been analysed by many authors; starch has been studied by most. Starch is used in noodle-making in oriental countries (Cheng et al., 1988; Singh and Singh, 1992), except South Asian countries like India and Pakistan. Other carbohydrates in mung bean, including monosaccharides -maltose, glucose, xylose-, oligosaccharides -raffinose, stachyose, verbascose- starch components -available and resistant starch- and fibres -lignin, cellulose-, have been studied less frequently. There is wide variation in the carbohydrate fractions in mung bean, the reasons of which could be genetic makeup, or grain maturity. The amounts of maltose, xylose, arabinose and inositol in mung bean were reported as 0.12, 0.36, 0.07 and 0.04 % of soluble sugars, respectively (Bravo et al., 1999). Oligosaccharides, such as raffinose, stachyose and verbascose, are associated with intestinal gas (flatus) production after consumption of beans (Adsule et al., 1986; Anisha and Prema, 2008; Devadas et al., 1977

Table 2 Macronutrient composition of mung bean

Macronutrient	Average*	Minimum	Maximum	References
Moisture (g/100 g)	9.80	4.10	15.20	(Kadwe et al., 1974; Khatoon and Prakash, 2004; Khattak et al., 2007a; Mubarak, 2005; Sampath et al., 2008; Tsou and Hsu, 1978; Watson, 1977)
Crude protein (g/100 g) dm	23.8	14.6	32.6	(Barakoti and Bains, 2007; Bravo et al., 1999; El-Adawy et al., 2003; Fatima and Kapoor, 2006; Ignacimuthu and Babu, 1987; Jood et al., 1998; Kadwe et al., 1974; Khader and Rao, 1986; Khatoon and Prakash, 2004; Khattak et al., 2007a; Khattak et al., 2007b; Mallillin et al., 2008; Mubarak, 2005; Poehlman, 1991; Prabhavat, 1990; Rao and Deosthale, 1983; Rao and Belavady, 1979; Sathe, 1996; Shehata and Thannoun, 1980; Singh and Singh, 1992; Tsou and Hsu, 1978; Watson, 1977)
Crude lipid (g/100 g) dm	1.22	0.71	1.85	(Barakoti and Bains, 2007; Bravo et al., 1999; El-Adawy et al., 2003; Fatima and Kapoor, 2006; Jood et al., 1998; Khatoon and Prakash, 2004; Mubarak, 2005; Poehlman, 1991; Prabhavat, 1990; Sathe, 1996; Shehata and Thannoun, 1980; Singh and Singh, 1992; Tsou and Hsu, 1978; Watson, 1977)
Crude fiber (g/100 g) dm	4.57	3.8	6.15	(Barakoti and Bains, 2007; El-Adawy et al., 2003; Mubarak, 2005; Poehlman, 1991; Prabhavat, 1990; Sathe, 1996; Shehata and Thannoun, 1980; Singh and Singh, 1992; Tsou and Hsu, 1978; Watson, 1977)
Ash (g/100 g) dm	3.51	0.17	5.87	(Barakoti and Bains, 2007; Bravo et al., 1999; El-Adawy et al., 2003; Fatima and Kapoor, 2006; Khatoon and Prakash, 2004; Khattak et al., 2007a; Mubarak, 2005; Poehlman, 1991; Prabhavat, 1990; Rao and Deosthale, 1981; Rao and Deosthale, 1983; Sathe, 1996; Shehata and Thannoun, 1980; Tsou and Hsu, 1978; Watson, 1977)
Carbohydrate (g/100 g) dm	61.0	53.3	67.1	(El-Adawy et al., 2003; Mubarak, 2005; Poehlman, 1991; Prabhavat, 1990; Sathe, 1996; Shehata and Thannoun, 1980; Singh and Singh, 1992; Watson, 1977)
Energy (kcal/100 g) dm	344	338	347	(Poehlman, 1991)

* Mean value of all collected data.

Table 3 Carbohydrate profile of mung bean

Carbohydrates (%)	Average*	Minimum	Maximum	References
Monosaccharides				
Glucose	0.3	0.2	0.4	(Udayasekhara Rao and Bhavani, 1978)
Total soluble sugars	5.6	3.9	8.5	(Adsule et al., 1986; Goel and Verma, 1981; Kataria et al., 1988; Singh et al., 1989)
Reducing sugars	1.8	0.39	4.7	(El-Adawy et al., 2003; Kataria et al., 1988; Urooj and Puttaraj, 1994)
Non reducing sugars	6.3	4.9	8.1	(Anisha and Prema, 2008; Kataria et al., 1988; Kuo et al., 1988)
Oligosaccharides				
Sucrose	1.3	0.3	2.1	(Adsule et al., 1986; Anisha and Prema, 2008; Devadas et al., 1977; Goel and Verma, 1981; Poehlman, 1991; Udayasekhara Rao and Bhavani, 1978)
Raffinose	1.1	0.3	2.6	(Bravo et al., 1999; Devadas et al., 1977; Goel and Verma, 1981; Philip and Prema, 1998; Poehlman, 1991; Udayasekhara Rao and Bhavani, 1978)
Stachyose	1.6	1.0	2.8	(Adsule et al., 1986; Anisha and Prema, 2008; Devadas et al., 1977; Goel and Verma, 1981; Kuo et al., 1988; Philip and Prema, 1998)
Verbascose	2.7	0.9	3.8	(Adsule et al., 1986; Devadas et al., 1977; Philip and Prema, 1998; Poehlman, 1991)
Fibers				
Total dietary fiber	18.8	14.5	24.5	(Khatoon and Prakash, 2006; Lin and Lai, 2006; Veena et al., 1995)
Insoluble dietary fiber	15.3	13.1	19.0	(Khatoon and Prakash, 2006; Lin and Lai, 2006; Rao, 2003; Veena et al., 1995)
Soluble dietary fiber	2.3	0.7	5.6	(Khatoon and Prakash, 2006; Lin and Lai, 2006; Rao, 2003; Veena et al., 1995)
Lignin	3.9	2.2	7.2	(Adsule et al., 1986; Rao, 2003)
Cellulose	3.9	2.5	4.6	(Adsule et al., 1986; Rao, 2003)
Hemi cellulose	4.7	0.3	9.1	(Adsule et al., 1986)
Starch				
Amylose	24	14	35	(Adsule et al., 1986)
Starch	47	37	58	(Adsule et al., 1986; Aman, 1979; Bravo et al., 1999; El-Adawy et al., 2003; Fatima and Kapoor, 2006; Kataria et al., 1988; Khatoon and Prakash, 2006; Kuo et al., 1988; Prabhavat, 1990; Sathe, 1996; Urooj and Puttaraj, 1994; Veena et al., 1995)
Available starch	37	37	37	(Veena et al., 1995)
Resistant starch	8.9	8.9	8.9	(Veena et al., 1995)

* Mean value of all collected data.

Goel and Verma 1981; Kuo et al., 1988; Philip and Prema, 1998). Flatulence is caused by such oligosaccharides that escape digestion and are fermented by the intestinal microflora. Mung beans contain less stachyose than red gram, lentils and bengal gram. Fermentation was reported to reduce the flatulence factors in mung bean (Goel and Verma, 1981).

3.3 Amino acid composition

The highest values of amino acids in mung bean are reported for glutamic acid (18.3 g/16 g of N) and aspartic acid (12.9 g/16 g N) (Table 4). Sekhon et al. (1980) reported a negative correlation of protein in mung bean with lysine and threonine, whereas a positive correlation of these amino acids with methionine has been found, suggesting that an increase in the methionine content in mung bean is always accompanied by a decrease of the total protein content in mung bean. Isoleucine, leucine, phenylalanine, tyrosine and valine were found to be higher in the globulin fraction of the protein, whereas lysine, methionine, threonine and tryptophan were higher in the albumin fraction (Bhatty, 1982).

Mubarak (2005) reported a chemical score of 76 % for mung bean amino acids, which was calculated using the FAO/WHO (1973) reference pattern, whereas Tsou et al. (1979) reported that the chemical score of mung bean proteins is about 32 % of egg protein (FAO, 1970) or 40 % of the FAO provisional pattern. Mung bean grains are adequate in most essential amino acids with the exception of the sulphur-containing amino acids methionine and cystine, which can be compensated by consuming mung bean in combination with cereals. Cereals are rich in sulphur-containing amino acids and the deficiency of lysine in cereals gets compensated by its presence in mung bean. A 7:3 ration of rice protein to mung bean protein was suggested as good for consumption (Florentino, 1974). Geervani and Theophilus (1980) reported the availability of lysine, methionine and cystine in mung bean grain to be 78, 83 and 94 %, respectively. Khan et al. (1979) reported a significant correlation (r = 0.97) between the biological value and the total amount of sulphur-containing amino acids in mung bean. This also indicates that from a nutritional point of view it is advisable to consume mung bean in combination with foods high in sulphur-containing amino acids.

In general, wide variations exist in the reported values of the amino acid contents, which may be due to differences in the mung bean varieties used by the different authors, as different accessions of mung bean were reported to contain different amounts of the same amino acid, like lysine and methionine (Yohe and Poehlman, 1972). Another possible reason can be the analytical methods used by different authors. Cai et al. (2002) determined the cysteine and cystine contents of mung bean protein by analyzing the cysteic acid produced by oxidation of the cysteine and cystine. A microbiological assay was used by Vijayabaghavan and Srinivasan (1953) for most of the amino acids, but methionine was determined colorimetrically.

3.4 Lipid fraction

Most lipid research on leguminous crops was on soya bean. Few investigations have dealt with the lipid fraction in mung bean (Table 5) and thus the information on the fatty acid composition of the mung bean is scanty. Lipids are components measured after saponification as compared to crude lipid, which is measured by a solvent extraction method like in, e.g., soxhlet. Adsule et al. (1986) reviewed the fatty acid composition of mung bean. The different fatty acids present in mung bean are palmitic, stearic, oleic, linoleic, linolenic, arachidic, behenic, capric, lauric and myristic acid. Abdel-Rahman et al. (2007) reported 33.1 % of total fat to be linoleic acid, which was higher than recorded by Adsule et al. (1986). Both authors reported that linoleic acid is the fatty acid that is present in the highest amount and that the quantity of lauric acid is the lowest in mung bean. The total amount of essential fatty acids in mung bean is reported to be 50.1 % of total fat. Gopala Krishna et al. (1997) reported 35.6 % saturated fatty acids, 5.4 % monounsaturated fatty acids, 37.1 % diunsaturated fatty acids and 21.8 % triunsaturated fatty acids in the oil extracted from the mung bean grain. Oil content of the mung bean is reported to vary from 2.1 to 2.7 % (Zia-Ul-Haq et al., 2008). Reflective index, relative density, saponification value, iodine value andunsaponifiable matter of the oil is found to be 1.5, 1.0 g/cm^3, 173 to 181 mg KOH/g, 114 to 117 and 13.8 to 15.0 % w/w, respectively (Zia-Ul-Haq et al., 2008).

Gopala Krishna et al. (1997) investigated the tocopherol and tocotrienol content of mung bean. The reported values for α, β, and γ tocopherol are 10.9, 0.9 and 1458 mg/100g fat, respectively, while the values for α, β, and γ tocotrienol are 2.7, 0.9 and 1.9 mg/100g fat, respectively. The total tocopherol content of mung bean (12.5 mg/100 g) is reported to be higher than in black gram (6.7 mg/100 g), bengal gram (11.4 mg/100 g) and horse gram (7.4 mg/100 g). The authors used a HPLC method to determine tocopherol isomers. There is no study for tocopherols and tocotrienol in mung beans.

Table 4 Amino acid composition of mung bean

Amino acid (g/16 g of Nitrogen)	Average*	Minimum	Maximum	References
Alanine	4.1	3.6	4.5	(Abd El-Moniem, 1999; Dzudie and Hardy, 1996; Mubarak, 2005)
Arginine	5.8	4.5	6.7	(Abd El-Moniem, 1999; Dzudie and Hardy, 1996; Mubarak, 2005)
Aspartic acid	13.0	12.0	15.1	(Abd El-Moniem, 1999; Dzudie and Hardy, 1996)
Cysteic acid	13.5	13.5	13.5	(Mubarak, 2005)
Glutamic acid	18.3	13.6	21.7	(Abd El-Moniem, 1999; Dzudie and Hardy, 1996; Mubarak, 2005)
Glycine	3.6	3.2	4.3	(Abd El-Moniem, 1999; Dzudie and Hardy, 1996; Mubarak, 2005)
Histidine	3.2	2.4	5.6	(Abd El-Moniem, 1999; Dzudie and Hardy, 1996; Mubarak, 2005)
Isoleucine	4.3	3.6	5.4	(Abd El-Moniem, 1999; Dzudie and Hardy, 1996; Mubarak, 2005)
Leucine	7.6	6.9	8.7	(Abd El-Moniem, 1999; Dzudie and Hardy, 1996; Mubarak, 2005)
Lysine	6.5	4.1	8.1	(Abd El-Moniem, 1999; Dzudie and Hardy, 1996; Geervani and Theophilus, 1980; Khader and Rao, 1996; Khader and Rao, 1986; Mubarak, 2005; Rao and Belavady, 1979)
Methionine	1.2	0.5	1.9	(Dzudie and Hardy, 1996; Geervani and Theophilus, 1980; Khader and Rao, 1996; Khader and Rao, 1986; Kochhar and Hira, 1997; Mubarak, 2005; Rao and Belavady, 1979)
Phenylalanine	5.4	4.6	6.2	(Abd El-Moniem, 1999; Dzudie and Hardy, 1996; Mubarak, 2005)
Proline	4.5	3.7	5.6	(Dzudie and Hardy, 1996; Mubarak, 2005)
Serine	4.9	4.0	5.8	(Abd El-Moniem, 1999; Dzudie and Hardy, 1996; Mubarak, 2005)
Threonine	3.2	2.7	4.0	(Abd El-Moniem, 1999; Dzudie and Hardy, 1996; Geervani and Theophilus, 1980; Khader and Rao, 1996; Khader and Rao, 1986; Mubarak, 2005)
Tryptophan	1.2	0.5	3.4	(Abd El-Moniem, 1999; Dzudie and Hardy, 1996; Geervani and Theophilus, 1980; Khader and Rao, 1996; Khader and Rao, 1986; Kochhar and Hira, 1997; Mubarak, 2005; Rao and Belavady, 1979)
Tyrosine	2.7	2.2	3.3	(Abd El-Moniem, 1999; Mubarak, 2005)
Valine	5.1	4.1	6.4	(Abd El-Moniem, 1999; Dzudie and Hardy, 1996; Mubarak, 2005)

* Mean value of all collected data.

Abdel-Rahman et al. (2007) reported the values of 32.3, 7.6, 6.6, 5.7 and 2.8 % of lipid fraction for phospholipids, monoglycerides, 1, 2 and 2,3 diglycerides, sterols and 1,3 diglycerides in mung bean, respectively. They also reported that the free fatty acid, hydrocarbons, sterols and tri-glyceride fractions constitute 8.4, 6.7, 5.6 and 30.1 % of the lipid fraction in mung bean, respectively.

Table 5 Lipid fraction of mung bean

Lipid Fraction	% of Total fat content	References
Total saturated fatty acids	27.7	(Sathe, 1996)
Total unsaturated fatty acid	72.8	(Sathe, 1996)
C16:0 (Palmitic)	14.1	(Sathe, 1996)
C18:0 (Stearic)	4.3	(Sathe, 1996)
C18:1 (Oleic)	20.8	(Sathe, 1996)
C18:2 (Linoleic)	16.3	(Sathe, 1996)
C18:3 (Linolenic)	35.7	(Sathe, 1996)
C21 (Behenic acid)	9.3	(Sathe, 1996)

3.5 Vitamins

Vitamins reported in mung bean are thiamine, riboflavin, niacin, pantothenic acid and nicotinic acid (Table 6). Vitamin C was reported to range from 0 to 10 mg/100 g dw (Prabhavat, 1990) with an average of 3.1 mg/100 g dw. This variation could be due to experimental variation or genetic differences; the author does not provide an explanation. Barakoti et al. (2007) reported 0.62 g/100 g (fresh weight) ascorbic acid using the AOVC method (1996), whereas Kylen and McCready (1975) reported no ascorbic acid using the method involving extraction by 5 % metaphosphoric acid in the bromine-oxidized filtrate by the 2,4 dinitrophenylhydrazine procedure. Apart from these three studies, all other reported values do not mention any underlying experimental research, thus more research needs to be done to assess the precise amount of ascorbic acid in raw mung bean. The number of authors who investigated the vitamin content is lower than the number of authors who determined macronutrients. Harina and Ramirez (1978) studied the carotenoid content of twenty mung bean varieties of different colour and sizes and found that green coloured mung bean grains contained higher amounts of carotenoids (0.9 mg/100 g) than yellow varieties (0.7 mg/100 g), which is attributed to higher amounts of carotenoids in the seed coat of green coloured varieties (41.5 %) than in that of yellow varieties (16.2 %) (Harina and Ramirez, 1978). These authors also found that the carotenoid content in cotyledons of mung bean (0.5 - 0.8 mg /100 mg), differs slightly between green and yellow varieties, whereas it varies significantly in seed coats (0.07 - 0.44 mg /100 mg) of green and yellow mung bean varieties. Carotenoids in mung bean are present in the form of β-carotene and xanthophylls (Harina and Ramirez, 1978). These authors also found that grain size has no correlation with the carotenoid content in mung bean. The riboflavin content of mung bean is found to be 0.29 mg/100 g (Nisha et al., 2005), which they assumed to be stable due to the protective effect of some unknown phytochemicals present. These authors also suggested further research on these phytochemicals and their protective effect on the riboflavin in mung bean. Degradation of riboflavin in mung bean during processing follows a first order reaction at temperatures ranging from 50 - 120 ºC (Nisha et al., 2005). To our knowledge, there is no study on folic acid in mung bean.

Table 6 Vitamin composition of mung bean

Vitamin (mg/100 g) dw	Average*	Minimum	Maximum	References
Thiamine	0.5	0.12	0.7	(Abdullah and Baldwin, 1984; Ghavidel and Prakash, 2006; Kylen and McCready, 1975; Prabhavat, 1990; Sathe, 1996)
Riboflavin	0.3	0.23	0.47	(Abdullah and Baldwin, 1984; Kylen and McCready, 1975; Prabhavat, 1990; Sathe, 1996)
Niacin	2.2	1.1	3.1	(Abdullah and Baldwin, 1984; Kylen and McCready, 1975; Prabhavat, 1990; Sathe, 1996)
Vitamin C	3.1	0	10	(Barakoti and Bains, 2007; Prabhavat, 1990)
Pantothenic acid	1.9	1.9	1.9	(Poehlman, 1991)
Nicotinic acid	1.6	1.6	1.6	(Rao and Belavady, 1979)

* Mean value of all collected data.

3.6 Minerals

Minerals and trace elements are important for human health as they, for instance, play a significant role in the metabolism by acting as co-factor of enzymes. Mung bean contains a relatively high amount of minerals according to the literature reviewed (Table 7). The minerals in mung bean grains are calcium, copper, iron, potassium, magnesium, manganese, sodium, zinc and other elements of nutritional importance like phosphorus, which is comparable to other pulses. Of these, iron, zinc and calcium are the most important due to their physiological functions in the human body. Insufficient iron uptake is one of the most important factors for anaemia throughout the world (Wang et al., 2008).

The total mineral content in mung bean grain is reported to be 3.5 g/100 g dw (Adsule et al., 1986). The cumulative mineral contents represent less than the total ash content; this is due to the fact that the minerals are determined as elements and the ash contains their salts. Ash may also contain salts of which the elements were not determined. Literature shows that mung bean contains considerable amounts of iron, calcium and potassium. The amount of calcium in mung bean is four times higher than in cereals but the amounts of calcium, iron, zinc, and phosphorus are lower than in soya bean. Singh et al. (1968) reported the distribution of different minerals in the anatomical parts of mung bean. They reported that calcium is primarily present in the seed coat (30 to 50 %, i.e. (812 mg/100 g dw), iron in the embryo (23 mg/100 g dw) and seed coat (17 mg/100 g dw) and phosphorus in the embryo (756 mg/100 g dw) and cotyledons (341 mg/100 g dw). Removal of the embryo and seed coat during dehulling and milling will not affect the nutritive value of mung bean grain much (except for crude fibre and calcium), as these only account for a small proportion of whole mung bean grain (Singh et al., 1968).

Researchers used different methods to determine minerals, which might have contributed to the wide variation in the reported data. Rao and Deosthale (1981) used the AOAC (1960) method for calcium, phosphorous and iron whereas magnesium, zinc, manganese, copper and chromium were analysed using atomic absorption spectrometry. Barakoti and Bains (2007) also used atomic absorption spectrometry. Fatima and Rashmi (2006) used AOAC (1995) methods, whereas Kadwe et al. (1974) used the EDTA titration method for calcium and magnesium. Khatoon and Prakash (2004) used the method of Ranganna (1986). Moreover, the variation in the mineral contents can also be due to genetic differences, which, among others, control the mechanism by which roots absorb minerals from the soil, and the translocation and physiological role of minerals in the plant as suggested by Frossard et al. (2000). This author also mentioned that mineral uptake mechanisms depend on root mycorrhiza and architecture, which may vary from variety to variety causing variation in mineral contents.

Iron content has been studied the most in mung bean as compared to other minerals, probably due to its high significance for human health. After iron, calcium is the most studied mineral, followed by phosphorus.

Few authors have determined mineral bioavailability in mung bean. However, this is significant from a nutritional point of view. Reported values for the iron bioavailability in mung bean show wide variation, which may be due to different genetic factors (Chitra and Rao, 1997). Presence of minerals as such is of relative importance, as their actual absorption in the human body is affected by many factors that may be related to human physiology and/or the characteristics of the food itself. Among the food-related factors, presence of anti-nutritional components is most important. Literature shows that mineral bioavailability is affected by the presence of anti-nutritional factors like phytic acid, polyphenols as well as fibre (Canniatti Brazaca and Da Silva, 2003).

Mung bean varieties with high amounts of anti-nutritional factors cause a lower bioavailability of minerals (Grewal and Jood, 2006). The presence of relatively high amounts of phytic acid in mung bean is not only indicative of a low mineral bioavailability of divalent minerals like iron, zinc and calcium but also of a low bioavailability of phosphorus, which was reported to be unavailable in young chickens (Common, 1939) as phosphorus in mung bean grain is mainly present in phytic acid. The wide variation in the reported mineral bioavailability may partly be due to the genetic basis (Jood et al., 1998). Minerals present in large amounts, like calcium, can also affect the iron and zinc bioavailability negatively. Variation in the amount of anti-nutrients (Jood et al., 1998; Kataria et al., 1989) and presence of endogenous phytase can also affect mineral bioavailability.

Increasing the mineral bioavailability in mung bean is possible by plant breeding, agricultural practices and food processing techniques. Varieties can be developed with better abilities to acquire nutrients from the soil, and agronomic practices like fertilisation influence the mineral content of the harvested seeds. Furthermore, it is possible to use breeding techniques to increase the concentration of nutrient-uptake enhancers, like ascorbic acid, and to decrease the concentration of nutrient-uptake inhibitors like phytic acid, polyphenols, etc. (Frossard et al., 2000). Food processing techniques like fermentation and germination help in dephytinisation (Barakoti and Bains, 2007; Hemalatha et al., 2007a). Processes like dehulling and cooking can reduce the amount of polyphenols, thereby increasing the nutritional value of the grain (Madhuri et al., 1996). Thus, increasing the iron content in mung bean will not be effective if anti-nutrients affecting its bioavailability are present in large quantities.

Table 7 Mineral composition of mung bean

Mineral (mg/100 g dw)	Average*	Minimum	Maximum	References
Calcium	113.4	55	200	(Fatima and Rashmi, 2006; Grewal and Jood, 2006; Hemalatha et al., 2007b; Kadwe et al., 1974; Khatoon and Prakash, 2004; Poehlman, 1991; Prabhavat, 1990; Rao and Deosthale, 1981; Sathe, 1996; Singh et al., 1988; Tsou and Hsu, 1978; Watson, 1977)
Copper	1.0	0.9	1.5	(Poehlman, 1991; Sathe, 1996)
Iron	5.9	4	7.6	(Barakoti and Bains, 2007; Chitra and Rao, 1997; Fatima and Kapoor, 2006; Fatima and Rashmi, 2006; Grewal and Jood, 2006; Hemalatha et al., 2007b; Hira et al., 1988; Kadwe et al., 1974; Khatoon and Prakash, 2004; Lestienne et al., 2005b; Narasinga Rao and Tatineni, 1982; Poehlman, 1991; Rao and Deosthale, 1981; Rao and Deosthale, 1983; Sathe, 1996)
Potassium	956.6	326	1246	(Poehlman, 1991; Prabhavat, 1990; Sathe, 1996; Watson, 1977)
Magnesium	162.4	50	320	(Kadwe et al., 1974; Poehlman, 1991; Prabhavat, 1990; Rao and Deosthale, 1981; Rao and Deosthale, 1983; Sathe, 1996; Tsou and Hsu, 1978)
Manganese	1.05	1.0	1.1	(Poehlman, 1991)
Sodium	16.7	6	30	(Prabhavat, 1990; Sathe, 1996)
Phosphorous	384.4	271	590	(Fatima and Rashmi, 2006; Kadwe et al., 1974; Khatoon and Prakash, 2004; Prabhavat, 1990; Rao and Deosthale, 1981; Rao and Deosthale, 1983; Sathe, 1996; Watson, 1977)
Phytin phosphorous	171.3	140	206	(Annapurani and Murthy, 1985; Barakoti and Bains, 2007)
Zinc	2.7	2.4	3	(Hemalatha et al., 2007b; Lestienne et al., 2005b; Rao and Deosthale, 1983)

* Mean value of all collected data.

The term mineral bioavailability as used in the literature usually does not represent actual bioavailability in the human body, but signifies the *in vitro* mineral solubility assessed after treatment with digestive enzymes. To our knowledge, no study investigated the bioavailability of minerals from mung bean through the use of radioactive markers in humans. Molar ratios of phytic acid with minerals have been used as an indicator of their bioavailability (Adeyeye et al., 2000). In the case of mung bean, there is no literature available reporting these ratios.

3.7 Anti-nutritional compounds

Anti-nutritional factors (Table 8) are chemical compounds that negatively affect digestion, bioavailability and bioconversion, and restrict the realization of the full nutritional potential of the food. Anti-nutritional components reported in mung bean are tannins, phytic acid, haemagglutinins, polyphenols, trypsin inhibitor and proteinase inhibitor. Phytic acid is the myo-inositol 1, 2, 3, 4, 5, 6, hexakis-dihydrogen phosphate present in the crystalline form inside protein bodies in the cotyledons. It is negatively charged at physiological pH, having a high affinity for positively charged divalent mineral ions making them unavailable for absorption. Phytic acid is the main seed storage molecule for phosphorus and is essential for seed development and germination. Phytates are compounds formed by the interaction of phytic acid with minerals. In legumes, phytates are present in the protein bodies of the endosperm. Wide variation exists in the reported values of phytic acid in mung bean, which may be due to genetic differences as there are reports suggesting a genetic basis of inheritance of phytate content in mung bean (Sompong et al., 2009). However, the variation could also be due to the method of analysis. Lestienne et al. (2005a) determined phytate in mung bean by estimation of the myo-inositol hexaphosphate content obtained by anion exchange HPLC separation, whereas Grewal and Jood (2006) extracted phytic acid using 0.5 M HNO_3 and determined it colorimetrically. The reported value in mung bean is high enough to bind a significant amount of minerals, thus reducing their bioavailability. Based on the mean values presented in tables 7 and 8 for iron and phytic acid, molar ratios of phytate/iron and phytate/zinc amount to 6.3 and 16.3, respectively, in raw mungbean. These values greatly exceed the cut-off values, viz. <0.4 and <5 resp., regarded for adequate bioavailability (Nout, 2009). However, phytic acid can be reduced during cultivation and by food processing, which may improve this situation. However, the reduction of phytic acid during cultivation is not possible after a certain minimum limit as a further reduction hampers the physiological growth of the seedling (Bohn et al., 2008). Nutritionally, phytic acid can be considered an anti-nutritional compound but it provides resistance to the grain against the bruchid beetle *Callosobruchus maculatus* during storage (Srinivasan et al., 2007). Therefore, adequate food processing is important to degrade phytic acid (Coelho et al., 2002). Fermentation, germination and dehulling are the food processing operations reported to effectively reduce the phytic acid content in mung bean (Barakoti and Bains, 2007; Hemalatha et al., 2007a).

Haemagglutinins are the sugar binding proteins that bind with red blood cells and agglutinate them. They bind with specific receptors at epithelial cells of the intestine, causing lesions and improper microvillus development leading to abnormal absorption of nutrients. Only two authors (El-Adawy et al., 2003; Mubarak, 2005) investigated haemagglutinin activity in mung bean and they did not show much variation. The amount of haemagglutinin can be reduced by germination (El-Adawy et al., 2003). A high temperature treatment during processing is reported to reduce haemagglutinins in red kidney beans (Thompson et al., 1983). The lectin content in mung bean is lower than in pea but higher than in lentils (El-Adawy et al., 2003).

Tannins are polyphenols that affect protein digestibility by making strong bonds with them, thus rendering them unavailable for absorption. The wide variation in the polyphenol content in mung bean could be due to genetic makeup (Dicko et al., 2002), type and amount of fertilization and the production site (Hamouz et al., 2006). Mung bean contains a considerable amount of polyphenols that affects the nutrient digestibility and bioavailability adversely. Therefore, efforts should be made to reduce the amount in mung bean grains. The possibilities for breeding seem promising in this respect, as polyphenols are reported to be present in higher amounts in coloured and darker legume varieties than in pale varieties (Salunkhe et al., 1982). Thus, colour of the mung bean can be used as a marker for the selection of varieties with lower amounts of polyphenols. Thus, products made of yellow or light coloured mung bean varieties might have higher protein digestibility and mineral bioavailability, as polyphenols has been reported to reduce the protein digestibility and mineral bioavailability. Muhammed et al. (2010) suggested that, being bioactive molecules, the seed coat polyphenols can help the seed against pathogens and improve seed viability. Therefore, the yellow mung beans varieties may be cultivated for better yields. At food processing level, polyphenols can be reduced subsequently by using various processing methods. Polyphenols in mung bean have been reported to have a low protein precipitating capacity and relatively high flavanol contents (Barroga et al., 1985). These authors also reported that 81 - 85 % of the polyphenols are present in the seed coat, which is 3 to 4 times more than in the cotyledon. Mung bean varieties contain 68 - 83 g/ 100g in the seed coat as compared to 17 - 32 g/100g in the cotyledon (Muhammed et al., 2010). The reduction in the polyphenol content due to dehulling ranged between 14 % and 52 % (Muhammed et al., 2010). Nevertheless, even when 52% of polyphenols would be removed, the remaining concentrations (cf. Table 8) would still have a strong inhibitory effect on e.g. iron bioavailability (Hurrell et al., 1999).This indicates that dehulling during dhal making is effective in reducing the polyphenol content of the food. Polyphenols are also reduced by roasting and leaching during soaking (Barroga et al., 1985).

Trypsin inhibitors inhibit proteolytic enzymes thereby affecting protein digestion adversely. Trypsin inhibitor in mung bean does not inhibit chymotrypsin as well as vicilin peptidohydrolase (Chrispeels and Baumgartner, 1978). Trypsin inhibitor activity of mung bean is much lower than that of soya bean, kidney bean and chickpea (Guillamón et al., 2008). Germination and soaking reportedly lower the trypsin inhibitor activity. Trypsin inhibitors are low molecular weight proteins and thus likely to leach during soaking. Trypsin inhibitor activity is also reduced by heat treatments (Chandrashekar et al., 1989).

The presence of other anti-nutrients like proteinase inhibitors and sulphydryl proteinase inhibitors in mung bean has not been reported. However, Marickar and Pattabiraman (1988) found a chymotrypsin inhibition of 427 µg/g in mung bean, indicating the presence of chymotrypsin inhibitors. To our knowledge, there is no published report on the presence of phytosterols, goitrogens and toxicants such as phenolic glycosides, quinones, chromones, phynyl propanoids, anthrones, etc. in mung bean.

The presence of anti-nutritional factors in mung bean indicates that it is necessary to process the grain before consumption. The anti-nutritional factors can be partially removed or degraded by processing methods like fermentation, germination and soaking, whereas a positive impact of mineral enhancers to increase mineral bioavailability has also been reported (Canniatti Brazaca and Da Silva, 2003). This can be one of the reasons why mung bean is consumed in the form of various food products, viz. snacks, sweets and savoury products.

Table 8 Anti-nutritional factors in mung bean

Anti-Nutritional Properties	Average*	Minimum	Maximum	References
Tannins (mg/100g)	366.6	100.4	575	(Das et al., 2005; El-Adawy et al., 2003; Hemalatha et al., 2007a; Hemalatha et al., 2007b; Mubarak, 2005; Narasinga Rao and Prabhavathi, 1982; Noor et al., 1980; Sathe, 1996)
Phytic acid (mg/100g)	441.5	230.2	808.3	(El-Adawy et al., 2003; Grewal and Jood, 2006; Hemalatha et al., 2007b; Kataria et al., 1989a; Mubarak, 2005; Philip and Prema, 1998)(Das et al., 2006; Fatima and Kapoor, 2006; Lestienne et al., 2005c)
Haemagglutinin activity (HU/g)	2615	2560	2670	(El-Adawy et al., 2003; Mubarak, 2005)
Polyphenols (mg/100g)	462.5	285	808	(Barakoti and Bains, 2007; Fatima and Kapoor, 2006; Grewal and Jood, 2006; Hemalatha et al., 2007b; Kataria et al., 1989a)
Trypsin inhibitor activity (TIU/mg of protein)	17.3	12.6	24.1	(El-Adawy et al., 2003; Mubarak, 2005; Noor et al., 1980)

* Mean value of all collected data.

4. Nutritional properties

In vitro digestibility and bioavailability of nutrients are important properties, as they indicate the amount of the nutrient that is potentially absorbed by the human body. Digestibility and bioavailability are affected by other chemical components in the grain such as bioavailability enhancers like vitamin C in the case of iron, but also by inhibitors of digestibility or bioavailability, such as phytic acid and polyphenols in the case of divalent minerals. Reports on *in vitro* protein digestibility show wide variation for mung bean (Table 9). *In vitro* protein digestibility is usually determined by measuring the change in the pH of the sample solution after incubation at 37 ºC with a trypsin - pancreatin enzyme mixture (Mertz et al., 1983). The wide variation in the protein digestibility can be due to variation in the actual protein content as well as the presence of trypsin inhibitor, which has been reported to reduce the digestibility of protein. The protein digestibility of mung bean can be increased by thermal processing methods, which help in unfolding the protein structure and degrading anti-nutritional factors.

True digestibility of mung bean was reported to be 73 % (Mubarak, 2005; Tsou and Hsu, 1978). Protein efficiency ratio of mung bean is 4.29, which is quite high, whereas the essential amino acid index is 67.8. Rat feeding experiments show that a combination of 75 % protein from rice and 25 % protein from mung bean gives a protein efficiency ratio equivalent to 75 % of casein protein (Tsou and Hsu, 1978).

Net protein utilization of the food is the ratio of amino acid converted to proteins to the ratio of amino acids supplied. Its value ranges from 1 to 0, with 1 meaning 100 % utilization of nitrogen present as protein, whereas 0 indicates no utilization. Tsou et al. (1979) reported that the biological value of mung bean could be improved by incorporating the high methionine character of black gram in mung bean through breeding as this character is not associated with a lower digestibility of proteins in black gram, and thus the desirable character of a high digestibility of mung bean will not be affected. The author also suggested that the amount of dipeptides present in mung bean also affects the biological value of its proteins. The dipeptides present in mung bean are γ -glutamyl-S-methylcystine and γ-glutamyl-S-methylcystine sulfoxide. The amount of the latter is smaller than that of the former compound (Otoul et al., 1975). This author also concluded that grains of mung bean were characterized by the presence of γ-glutamyl-S-methylcysteine and its sulphoxide, which makes it different from grains of urd bean (*Vigna mungo*), as the latter does not contain these compounds but is particularly rich in γ -glutamylmethionine and its sulphoxide.

Table 9 Nutritional properties of mung bean

Nutritional properties	Average*	Minimum	Maximum	References
In vitro protein digestibility (%)	70.2	52	83.9	(Khatoon and Prakash, 2006; Mubarak, 2005)(Hira et al., 1988; Singh and Padmakar, 1991)
In vitro starch digestibility (mg/100 mg Maltose released)	10.3	10.3	10.3	(Khatoon and Prakash, 2004)
Apparent digestibility	65.4	65.4	65.4	(Tsou and Hsu, 1978)
True digestibility (%)	49.2	25	73.3	(Tsou and Hsu, 1978)
Net protein utilisation (NPU)	56.3	53	59.7	(Tsou and Hsu, 1978)
Biological value (%)	64.0	39	80.7	(Geervani and Theophilus, 1980; Poehlman, 1991; Rosaiah et al., 1993; Sathe, 1996; Tsou and Hsu, 1978; Vijayabaghavan and Srinivasan, 1953)
Digestibility coefficient	75.5	62	82	(Geervani and Theophilus, 1980; Poehlman, 1991; Sathe, 1996)
Chemical score (%)	76.2	76.2	76.2	(Mubarak, 2005)
Essential amino acid index (%)	67.8	67.8	67.8	(Mubarak, 2005)

* Mean value of all collected data.

5. Food processing properties

The food processing properties of a raw food material determine its behaviour during processing and thus affect the quality of the end product. The main food processing properties of significance for whole mung bean flour and grains are wettability, water and oil absorption capacity, gelation and emulsifying capacity, hydration capacity, hydration index, swelling capacity, swelling index, cooking time and leached out solids (Table 10). Water absorption capacity of mung bean flour is important since many products are prepared from flour dough and thus the quality of the final products is related to the water absorption capacity. The considerable variation in the data may be due to differences in chemical composition of the grains of different varieties. Most of the authors used centrifuge techniques for the determination of water absorption capacity. Its value has been reported to increase by germination and to decrease by dehulling (Ghavidel and Prakash, 2006). Hydration capacity is the increase in weight of grains after absorption of water. Hydration capacity and hydration index are essential in producing sprouts, and thus high quality sprouts are those possessing a high hydration capacity. Swelling capacity is the increase in the volume of the seed after absorption of water. Hydration and swelling capacity are the indicators of the potential of a grain to absorb water thereby gaining weight and volume. These parameters depend on the size of grains; Indian mung bean varieties with a small grain size will have lower hydration and swelling capacities than the large-sized varieties of south-east Asian countries. This may the reason for the production of large amounts of sprouts in Europe and in oriental countries, but not in India.

Table 10 Food processing properties of mung bean

Food processing properties	Average*	Minimum	Maximum	References
Water absorption capacity (%)	131	79	187	(El-Adawy et al., 2003; Ghavidel and Prakash, 2006; Hira et al., 1988; Kochhar and Hira, 1997; Nagmani et al., 1997; Rosario and Flores, 1981)
Hydration capacity (g per seed)	0.034	0.033	0.034	(Aggarwal et al., 2004; Khattak et al., 2007)
Hydration index	0.015	0.01	0.02	(Aggarwal et al., 2004; Khattak et al., 2007)
Swelling capacity (ml/seed)	0.041	0.006	0.076	(Aggarwal et al., 2004; Khattak et al., 2007)
Swelling index (ml/seed)	0.07	0.03	0.13	(Aggarwal et al., 2004; Khattak et al., 2007)
Cooking time (minutes)	37	14	60	(Aggarwal et al., 2004; Hira et al., 1988; Khattak et al., 2007; Kochhar and Hira, 1997; Rosaiah et al., 1993)
Leached out solid (%)	3.7	2.9	4.5	(Rosaiah et al., 1993)
Oil absorption capacity (g of oil/g of flour)	0.8	0.8	1.9	(Ghavidel and Prakash, 2006; Mesallam and Hamza, 1987)
Emulsification capacity (ml of oil/g of flour)	33.9	19.8	48.0	(Ghavidel and Prakash, 2006; Mesallam and Hamza, 1987)

* Mean value of all collected data.

The gelation capacity of mung bean flour is important in products which utilise oil for processing. The reported value of the gelation capacity of mung bean is contributed to the presence of protein (particularly the globulin fraction) and starch (Rosario and Flores, 1981). The authors used the least concentration end-point method for determination of gelation capacity in mung bean. In this method samples of different concentrations were stirred and adjusted to pH 7.0 with 0.5 M NaOH. Then 10 ml aliquots were heated for 10 min in an 80 °C water bath and cooled to 0 °C in an ice-bath. The strength of the coagulum was evaluated by inverting the tube. The lowest concentration of protein which formed a stable gel or which remained inverted in the tube was termed the gelation end-point.

Cooking time for mung bean grains varies from 14 (Khattak et al., 2007b) to 60 minutes (Aggarwal et al., 2004). The average cooking time is 37 minutes. The wide variation in the reported values is attributed to the fact that cooking time depends on the variety and the “hard-to-cook” phenomenon, which is related to storage conditions and duration of storage (Rodriguez and Mendoza, 1990). The influence of varietal differences on the amount of hard-to-cook seeds has been reported by Felicito and Evelyn Mae (1990). Cooking time might also depend on the chemical composition of the grain and seed coat. Thus, different varieties of mung bean with varying amounts of chemical constituents will have different cooking times. However, till now no study has confirmed this correlation and thus it is necessary to determine the possible factors affecting the cooking time of mung bean grains.

Leached out solids during the cooking of grains determine the consistency and overall sensory acceptability of the products, particularly in soups and dhals. The average of reported values for the amount of leached out solids is 2.9 % for different varieties (Rosaiah et al., 1993). The authors do not discuss the reported values but it seems likely that the amount of leached out solids is correlated with the rupture strength of the grains, as mung bean varieties with lower rupture strength tend to have lower amounts of leached out solids. Until now no study has been conducted to confirm this supposition. Cooking time and temperature also influence the leached out solids and thus need to be studied.

Oil absorption capacity is relevant for mung bean as different products, particularly sweets and snacks, are prepared with mung bean flour as raw material and frying as processing method. Thus, it is important to use mung bean flour with a low oil absorption capacity to limit the fat content of the final product, which determines sensory characteristics as well as the shelf life. Oil absorption of whole mung bean flour has been studied, but oil absorption capacity of whole mung bean grain and dehulled mung bean grain is also important as these are used in making snacks. Therefore oil absorption capacity of the mung bean grains and the effect of grain moisture and oil temperature on it, should also be studied to optimize the frying of the mung bean grain to make snacks, like *namkeen*. Similarly, oil absorption of dehulled mung bean grain flour needs to be studied as mung bean *laddo*, an Indian sweet, is prepared from it with fat.

Emulsification capacity of whole mung bean flour is important for products that involve dough and batter making as important unit operations. Dzudie and Hardy (1996) reported the emulsification capacity of dehulled mung bean to be 21.7 ml of oil/g of flour, which is higher than for dehulled red common bean (19.8 ml of oil/g of flour), black common bean (14.5 ml of oil/g of flour) and white common bean (15.5 ml of oil/g of flour). These authors suggested its appropriateness as an ingredient for meat analogs. Ghavidel and Prakash (2006) correlated emulsification capacity with the quality and quantity of soluble protein in mung bean and showed that during dehulling as soluble protein increases emulsification capacity also increases. Emulsification capacity of dehulled mung bean flour was found to be 73 ml of oil/g of flour. Emulsification activity of whole mung bean flour is found to be 54 % while its emulsification stability is 51.8 % (Ghavidel and Prakash, 2006). Germination is reported to increase the emulsification activity in mung bean by 3 % and emulsification stability by 5 % (Ghavidel and Prakash, 2006). These authors suggested that partial denaturation, increased hydrophobicity -to a certain extent- and increased protein solubility during germination might be the possible factors resulting in increased emulsification activity and stability in germinated mung bean four as compared to non-germinated mung bean flour. Similarly dehulling also increased emulsification activity and stability in mung bean, which is also suggested to be due to an increase in total and soluble protein content (Ghavidel and Prakash, 2006). High emulsification activity and stability of whole, dehulled and germinated mung bean flours make them useful in food systems requiring stabilized colloidal emulsions (Ghavidel and Prakash, 2006). Emulsification capacity, activity and stability should be determined for mung bean grains of different varieties so as to know their possible correlation with genetic makeup. Moreover, it will also help the characterisation of mung bean varieties for their usefulness as meat analogs and in stabilized colloidal emulsions as proposed by several authors.

Information on food processing properties of mung bean flours is scarce. Certain food processing properties, like the pH of whole mung bean flour, have not been studied. It is important to know the pH of grain flour in a water suspension, since some food processing properties, such as solubility and emulsion properties, are highly affected by pH (McWatters and Cherry, 1977). Knowledge of food processing properties can help in new product development and mechanisation of old traditional processes for the preparation of mung bean foods.

6. Conclusion and recommendations

The nutritional value of mung bean cannot be precisely evaluated from the data presented in literature to date. There are variations in the reported data which might be due to a number of factors, but these factors have not been studied. Area of origin is one of the main factors contributing to the variation in values of different properties. Trung and Yoshida (1983) studied mung bean varieties from the Philippines and India and found that Philippine varieties are higher in protein content (23.4 %) and 1,000 seed weight (59.1g) than Indian varieties with an average 19.8 % protein and a 1,000 grain weight of 27.3g. The genetic makeup of the grain is one of the reasons for the variation in mung bean properties. Colour of the grains is a function of genetic makeup of the variety and thus varies among varieties (Paroda and Thomas, 1988). Variations in properties were also noticed between wild and cultivated varieties. Cultivated mung bean varieties were found to posses higher amounts of certain amino acids like lysine, valine, isoleucine, leucine, phenylalanine and tyrosine than wild varieties (*Vigna radiata* var. *sublobata*) in central India (Babu et al., 1988). The wide variation in the nutritional value also seems to be controlled by agronomical practices and location-to-location variations, which are insufficiently quantified. For example, phosphorus in the form of fertilizers is added for the proper growth of plants, but it has been reported that its use increases the phytate content of grains (Coelho et al., 2002).

Similarly, food processing properties need to be researched more and the effects of factors like temperature, pH, and particle size on the variation in the reported data for different food processing properties. This variability in the reported values for different properties of mung bean may be due to raw material used for experimentation like quality of the sample, age of the sample, pre-treatment given to the sample etc. Physical and engineering properties of the grain are strongly affected by moisture content, which may vary in relation to the duration of storage after harvesting (Unal et al., 2008; Yildiz, 2005).

Storage conditions are reported to influence the food processing properties of the grain too. For example, cooking time increases with an increase in the storage period (Vimala and Pushpamma, 1985). The level of insect infestation during the storage of grains has also been reported to influence the chemical composition of the mung bean grains (Modgil and Mehta, 1994). Apart from the variability in the material, the analytical methods (sampling plans, sampling methods, analytical methods and analytical quality control) can be another reason for the variability in reported values.

Our review shows that limited work has been carried out on the physical properties of mung bean and their relationship with moisture content. Nutritionally, mung bean seems to have a good potential with a higher protein content than chick pea, lower fat content than soya bean and a considerable amount of iron. The grain quality depends mainly on genetic factors, of which the expression is modified by agronomical practises. From the literature review on mung bean and its properties, it can be concluded that the reported information shows variations, although many investigations have been published about the nutritional properties of mung bean. There are gaps in the information on the different properties of the mung bean, which need to be filled as these play an important role in the nutritional potential of the grain and its processing behaviour. The lack of information about some of the components, like vitamins and fatty acids, also persists. During future investigation of mung bean properties, care should be taken to control the experimental setup and limit the variability in sampling and analytical techniques. Data related to quality control during the various steps of analysis should be described in detail. Information on the type of sample used for analysis, like whole grain, dehulled or dehusked grain, should be clearly described; some authors, like (Elkowicz and Sosulski, 1982) failed to do this.

With respect to further research, we make the following recommendations:

1. Most mung bean breeding research has focused on yield, early maturation with uniform maturity and stable yield, resistance to pests, pathogens and drought (Singh and Ahlawat, 2005). This needs to be expanded with nutritional and food processing properties.
2. More attention should be given to the appropriateness of analytical methods to be able to separate biological variation from analytical variation. Use of specific methods with good detection limits is advocated.
3. Research on digestibility and bioavailability of nutrients in mung bean is needed as the factors that affect them are many and their behaviour is not well understood.
4. Food processing properties need to be determined in greater detail, as literature on these parameters is limited.
5. Various properties of the dehusked mung bean dhal and dehulled mung bean dhal need to be determined as many products are made from them instead of whole mung bean grain, particularly in India.
6. The protein quality of mung bean needs to be improved by use of biotechnological and plant breeding techniques.

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Chapter 3

Consumption habits and innovation potential of mung bean foods

Abstract

Consumption habits for mung bean foods were assessed by the free word association method and interview techniques. Four groups of closely related products and perceived quality were revealed. The largest group comprised sweets and snacks, which were associated with unhealthiness, expensiveness and sensory liking. Another group consisted of split *dhals* associated with convenience and healthiness. It appeared that under different circumstances food choices vary and are influenced more by socio-economic restrictions then by consumer perception and preferences. Scenario analysis based on consumer perception, preferences, practices and nutritional value of products revealed *dhals* as the most promising food for innovation.

Key words: Indian traditional food products, consumer knowledge, quality perception, consumer preferences, dietary practices, halwa, *dhals*, nutrition, food innovation and convenience.

1. Introduction

Malnutrition is a major concern in India; the number of malnourished children, for instance, is amongst the highest in the world (Pathak and Singh, 2011). Combating malnutrition through upgrading indigenous foods and dietary diversification is a promising approach (Ruel and Levin, 2002). Indigenous foods are culturally accepted, ecologically adapted and easily accessible. However, for technological improvements to take full advantage of their nutritional potential, product development should be consumer oriented to ensure acceptance (Linnemann et al., 2006).

Consumer choices for food are influenced by the perception of food quality, food preferences, food awareness, accessibility and affordability (Siró et al., 2008). Therefore, it is important to know these factors that influence consumer's choice and their relation with the nutritional potential of a food product. This study aims to identify these factors in three different aspects of food consumption, namely perception, preferences and consumption practices, and their interrelation with each other, as well as with the nutritional potential of food products.

Perception is understood as a psychological phenomenon by virtue of which an individual understands sensory information (Giampieri-Deutsch, 2012), whereas preferences are consumer's choices in the absence of socio-economic constraints. Different aspects of food choices and consumption need different approaches for data collection. This study was formulated using both quantitative and qualitative approaches through the combination of structured interviewing, participant-observation, focus group discussions and the free word association methodology. Focus group discussions and participant observation yield the diversity of food consumption patterns. The free word association methodology is one of the commonly used qualitative techniques for assessing one's beliefs and attitudes (Guerrero et al., 2010; van Kleef et al., 2005). This method will reveal the conscious factors governing consumer choices in terms of perception, whereas interview techniques will help in understanding the unconscious concepts and associations with foods.

In the present study, mung bean (*Vigna radiata* (L.) R. Wilczek) foods in northern India were used as they are an important component in the diet, rich in minerals and proteins (Dahiya et al., 2013) and culturally accepted. Mung bean is known in many forms in terms of varieties and products with diverse consumption and processing patterns. Nutritionally it is recognized as one of the potential legumes for the South Asian population (Yang and Tsou, 1998). Diversity in mung bean products gives consumers an assortment from which they can select their preferred food consciously and unconsciously in different situations and according to sensory liking, accessibility, affordability and ease of processing.

This study aimed to understand different aspects of mung bean consumption to conceptualise its food consumption pattern with its associated influencing factors, to enable a critical evaluation of the innovation potential for improvement in terms of nutritional contribution to malnourished people.

2. Methods

2.1 Research area

The research was conducted in the Hisar district of Haryana state in northern India. Haryana is an agricultural state and one of the largest mung bean producers in India. Hisar was selected as the research area as this district has the highest production of mung bean in Haryana state. A multi-stage sampling procedure was used for the selection of blocks in districts, villages and respondents. Hisar city was selected to include urban consumers of mung bean. For rural consumers two blocks, namely Hisar-1 and Barwala, were selected. From each block one village was selected, Dhiktana village from Barwala block and Mangali village from Hisar-1 block.

2.2 Demographic details of the respondents

The 152 respondents in our study were from Hisar city (50 %) and both villages (50 %), included 50 % males and 50 % females of different ages and economic background. Amongst the respondents 19.1, 25.0, 38.8 and 17.1 % were aged from 8-19, 20-35, 36-50 and above 50 years, respectively. Out of these 71.1 % were married. In terms of education status 30.9 % were uneducated, 13.2 % had a primary level school education, 20.4 % had a secondary level school education and 13.8 % had a high level school education, whereas 16.4 % were graduates and 5.3 % were post graduates. The occupations included farmers (15.2 %), house wives (30.3 %), civil servants (20.3 %), businessmen (10.5 %) and school students (23.7 %). The annual income of the respondents (in Indian rupees (1 US $ = 54.5 Indian rupees)) ranged from 0 - 2000 (5.3 %), 2001-5000 (18.4 %), 5001-10000 (38.2 %), 10001-15000 (25.0 %) and above 15001 (13.1 %).

2.3 Focus group discussions

To take stock of the different mung bean varieties produced and processed and the mung bean based foods consumed by the population, focus group discussions with 10-12 participants were conducted in each rural and urban area. Focus groups consisted of at least one commercial and one household processor of mung bean, along with female, male, children and elderly people as consumers of mung bean. Group participants were informed about the purpose of the focus group discussion. Participants were asked to freely interact with each other on the given topic. Theme for the focus group discussions was the number and type of mung bean products commonly processed and consumed. Participants were asked to sort products into groups and to identify the main characteristics of each group formed. The probes used for the discussion were household/commercial products and *dhals*, sweets and snacks. Key points commented about the mung bean products were recorded. During the discussions 14 mung bean products were identified, which were used later in the free word association test. The outcome was also used to validate and develop the interview questionnaire.

2.4 Interviews with structured questionnaire

A cross sectional survey of consumers was conducted using a structured questionnaire. The questionnaire was framed into four sections to collect data about consumer knowledge of mung bean products, preferences, quality perception and consumption practices, respectively. Questions were designed to gather both qualitative data through multiple choice questions and quantitative data through open questions. Pre-testing and finalizing of the questionnaire was done on the basis 5 test interviews and suitable changes were made. The questionnaire was in English, and was translated in the local language (Hindi) or dialect (*Haryanvi*) when needed during data collection. The objective of this part of the study was explained to each respondent before the interview. Data was taken personally by administering the interview schedule to the respondents.

2.5 Free word association tests

All respondents participated individually in this test. The objective of this test was not disclosed at the start of the test to minimize bias. The test started with a short discussion about the respondent's food consumption pattern to get the interviewee focused on the topic. Next, the procedure of a free word association test was explained using examples of food products other than mung bean products. The respondents were asked for their opinion of all the 14 mung bean products one by one. The test involved confronting the respondent with the product (the stimulus) and then waiting for the first few verbal responses that came to his/her mind. Each respondent was asked to elicit any number of different words in his own regional language. A maximum of 30 seconds was allowed for responding. The total duration of the test, including discussion and explanation, ranged from 15 to 20 minutes. All the words were recorded.

All elicited words associated with mung bean and its derived products were translated into English. For each product, words with similar meanings were grouped into several categories. This categorization was done manually considering word synonymy. The frequencies in each category were determined by counting the number of respondents who associated those words with mung bean and its derived products. Associated words for different products were compared and merged into ten response categories considering their similar meaning and these were labeled. The response categories included (1) sensory liking or disliking, (2) having a positive or negative health impact, (3) affordability or expensiveness, (4) easy or difficult to get, and (5) easy or difficult to process. Easy to get and easy processing was represented by 'convenience' and difficult to get and difficult processing by 'inconvenience'. Frequency of words used for each response category was calculated for each product.

2.6 Statistical analysis

Data were analyzed using descriptive statistics (mean, frequencies and percentages). Chi-square was calculated to analyze differences in the consumer perception of quality of mung bean and its derived products. Correspondence analysis was applied to investigate the relationship between mung bean products and response categories (Sourial et al., 2010). All statistical analyses were performed with PASW Statistics (Version 18.0.2) IBM Co. USA.

3. Results

3.1 Mung bean varieties and derived food products

Hybrid as well as local, traditional mung bean varieties are produced, processed and consumed in the research area. Hybrid mung bean varieties are *asha*, *muskan* and *satya*. There is no particular name for the local, traditional varieties; people use the word *desi* (meaning “local”) to designate them. These varieties have small-sized and bright green coloured grains. Consumers are not aware about the varieties used for mung bean products; generally they select a variety with small, round, bright green coloured grains, without damaged grains, clean and reasonably priced. However, commercial processors select mung bean varieties according to the product they want to prepare.

With respect to mung bean foods, 14 mung bean products were identified and classified into four groups. The first group consisted of the *dhals* (i.e. *whole dhal*, *split dhal*, *dehulled split dhal*). *Dhals* are spiced curries of whole or split legumes, with thick soup-like consistency commonly consumed with cereal products like rice and *chapattis* (Indian flat bread).

The second group comprised the sweets, which included three products, namely *laddu, burfi* and *halwa,* prepared with dehulled split mung bean by shallow frying the mung bean flour or paste and addition of *ghee* (clarified butter oil) and sugar. It also included *whole laddu*, which are round balls of crushed whole grains prepared by shallow frying with *ghee*.

The third group, the snacks, included *namkeen, papad, bhalle* and *pakore*. *Namkeen* are deep fried, spiced or salted, dehulled split mung bean grains. *Papad* is a spiced flat roasted product of dehulled split mung bean. *Bhalle* are round balls of deep fried, dehulled, fermented mung bean paste, whereas *pakore* are round or irregular shaped balls of deep fried fresh paste of dehulled or split mung bean with some spices and vegetables.

Wadi, *ankurit dhal* and *khichadi* each have distinctive characteristics and were grouped as the fourth category of mung bean products. *Wadi* are irregular shaped, sun dried dumplings of fermented, dehulled mung bean paste, which are cooked as curry with spices and other vegetables. *Ankurit dhal* are germinated mung bean grains eaten as such or in salads after shallow frying. *Khichadi* is a thick porridge like product prepared by cooking split or dehulled grains with white rice.

3.2 Consumer awareness and preferences

The data depicting consumer awareness and preferences for mung bean and its derived products is given in Table 1. The majority of consumers were familiar with all mung bean products except for one product called *whole laddu*. It is processed mostly by rural families. The majority of consumers did not know the processing of mung bean products, except for *dhals*, *khichadi* and *ankurit dhal*. Similarly, consumers had limited knowledge of storage methods for most of the mung bean sweets and snacks. Use of refrigeration as storage method was quite common in case of foods with high moisture content such as *dhals*, *khichadi* and sprouts. Low moisture foods like *dehulled laddu*, *namkeen*, *papad* were kept at room temperature.

Household utensils were the most used storage medium for mung bean products, except for sweets and snacks, which were stored in plastic bags. Mung bean grains were mainly kept in gunny bags at farmers' and wholesale merchants' level, while plastic packaging was common at retail level. Urban household consumers used metal utensils to store the grains. Rural household consumers also used mud-baked and clay-paper mash based utensils for mung bean grain storage. Most of the products were reported to be available in urban as well as rural areas except for *whole laddu*, which is typically a rural, home-made product. Only old rural ladies know how to prepare it. *Dhals* like *whole dhal* and *split dhal*, sweets like *burfi, halwa* and *laddu* and snacks like *namkeen*, *papad*, *pakore* and *bhalle* were the most liked products, whereas *dehulled dhal* and *khichadi* were not liked by consumers.

Consumers wanted *halwa* and snack likes *namkeen*, *pakore*, *bhalle* to be present in ready-to-eat or cook form. Sweets like *dehulled laddu*, *burfi*, *halwa* and snacks like *namkeen* and *papad* were purchased from retails shops. *Dhals*, *khichadi* and *ankurit dhal* were said to be household products, whereas snacks like *pakore* and *bhalle* were purchased from street vendors. Whole mung bean grains were usually purchased from whole sale or retail shops. In general, *dhals* were reported to be household products and sweets commercial products. Snacks were considered to be both commercial and household products.

Table 1. Consumer awareness and preferences for mung bean and its derived food products

Products	Main processing step						Storage method				Storage/ packaging medium				Place of availability				Preferences for consumption			Would a ready to eat form be desirable?		Place of purchase			
	Fermentation	Roasting	Germination	Cooking	Frying	Don'' know	Refrigeration	Room temperature	Don't store	Don't know	Utensil	Plastic bag	Gunny bag	Don't know	Rural	Urban	Both	Don't know	Like very much	Moderately liked	Not like	Yes	No	Retail shop	Home made	Street vendor	Don't know
Whole grains [1]	0 [2]	0	0	0	0	0	0	152	0	0	44	4	92	12	0	0	152	0	0	0	0	0	0	0	0	0	0
Whole dhal	0	0	0	134	0	18	134	0	0	18	134	0	0	18	0	0	152	0	151	0	1	50	102	0	152	0	0
Split dhal	0	0	0	134	0	18	134	0	0	18	134	0	0	18	0	0	152	0	135	0	17	40	112	0	152	0	0
Dehulled dhal	0	0	0	134	0	18	134	0	0	18	134	0	0	18	0	0	152	0	76	37	39	35	117	0	152	0	0
Whole laddu	0	0	0	15	6	131	43	0	0	109	43	0	0	109	40	14	0	98	36	15	101	2	150	0	54	0	98
Dehulled laddu	0	0	0	9	20	123	23	62	0	67	46	39	0	67	10	9	133	0	93	27	32	29	123	152	0	0	0
Burfi	0	0	0	2	13	137	49	25	0	78	60	22	0	70	0	7	145	0	121	24	7	24	128	152	0	0	0
Halwa	0	0	0	3	29	120	54	13	13	72	54	26	0	72	0	28	124	0	113	39	0	75	77	152	0	0	0
Namkeen	0	0	0	0	19	133	0	74	27	51	0	101	0	51	0	2	150	0	141	4	7	152	0	140	12	0	0
Papad	0	143	0	0	0	9	0	99	14	39	0	113	0	39	0	0	136	16	141	11	0	152	0	138	0	0	14
Pakore	0	0	0	0	118	34	10	40	1	101	50	0	0	102	0	0	100	52	130	17	5	82	70	0	0	100	51
Bhalle	20	0	0	0	102	30	10	33	0	109	43	0	0	109	0	0	152	0	121	16	15	93	59	0	31	121	0
Wadi	22	0	0	0	0	130	46	0	0	106	46	0	0	106	0	0	130	22	98	41	13	90	62	116	14	0	22
Kichadi	0	0	0	84	0	68	97	0	0	55	97	0	0	55	0	0	152	0	35	72	45	38	114	0	152	0	0
Ankurit dhal	0	0	91	0	0	61	67	0	0	85	67	0	0	85	0	0	152	0	77	65	10	94	58	0	144	8	0

[1] Whole grains were purchased at wholesale shop, retail shop and directly from farmers by 74, 34 & 44 consumers, respectively
[2] Figures in the table are the number of respondents out of 152 total respondents

3.3 Consumer perception of quality

The interview data depicting consumer perception of mung bean and its derived products are given in Table 2. The interviews demonstrated that consumers are aware of the safety of most of the products and that they considered *dhals*, sweets, snacks, *wadi*, *khichadi* and *ankurit dhal* to be safe for consumption. *Pakore* and *bhalle* were considered as moderately safe or unsafe. Consumers considered *dhals*, *wadi*, *halwa, khichadi* and *ankurit dhal* to be healthy. *Dehulled dhal*, *khichadi* and *ankurit dhal* are easily digested foods according to the respondents. *Halwa* and *whole laddu* were said to be consumed to increase body weight. They are considered good for growing children to gain strength. Most of the consumers judged the quality of the products on the basis of sensory characteristics, whereas for snacks the location of processing was also considered. Sensory quality was the key reason for the consumption of most of the products, but *dehulled dhal, whole laddu*, *dehulled laddu, halwa*, *wadi*, *khichadi*, and *ankurit dhal* were also consumed because of perceived health promoting properties. The most important sensory parameters for the various products as perceived by consumers were consistency (*mung bean dhals*), colour, texture and taste (*halwa*), taste and texture (*laddu*, *papad* and *namkeen*), texture (*bhalle & wadi*), consistency (*khichadi*) and appearance and texture (*ankurit dhal*).

The results of the free word association test showed similar perceptions among the mung bean consumers as the interviews. From the free word association tests, ten response categories were identified for the mung bean and different derived products (Table 3). These categories were found to significantly determine the consumer perception of quality of mung bean products. Consumers responded more to three types of *dhals, halwa, burfi, khichadi* and *bhalle* compared to other products. In terms of the response categories, which were the focus of the research, the majority of the consumers associated mung bean and its derived products with sensory liking, which accounted for 32 % of all the associated words. After sensory liking, 'positive health effects' was the next most important response category indicating consumers perception towards mung bean products. Overall, sensory disliking, positive health effects, negative health effects, affordability, expensiveness, easy to get, difficult to get, easy processing and difficult processing accounted for 12, 17, 11, 8, 9, 2, 2, 4 and 4 % of the total responses, respectively.

Correspondence analysis between mung bean products and response categories showed that certain response categories were more strongly associated with specific products (χ^2 = 1537.5, P < 0.0005). Four clear, closely related clusters were identified (Figure 1). Cluster one shows the association of *dehulled dhal* with positive health effects and convenience (easy processing). The second cluster indicates sensory disliking and affordability as the response categories, which are closely associated with *wadi* and *khichadi*. *Khichadi* and *wadi* are strongly associated with sensory disliking but moderately with affordability. The third cluster contains *whole laddu* and difficult to get, but the association between them is weak. This cluster is weakly associated with the other three clusters. In the fourth cluster, which is also the largest, there are many products and response characteristics. The majority of the products in this cluster are sweets and snacks. This cluster includes sensory liking, negative health effects and expensive as the response characteristics and *pakore*, *bhalle*, *namkeen*, *burfi*, *halwa*, *ankurit dhal*, *dehulled laddu*, *whole dhal* as products and raw mung bean. *Bhalle* and *burfi* are more strongly associated with negative health effects, whereas *pakore*, *namkeen*, *papad*, *burfi*, *halwa* and *dehusked laddu* were strongly associated with sensory liking.

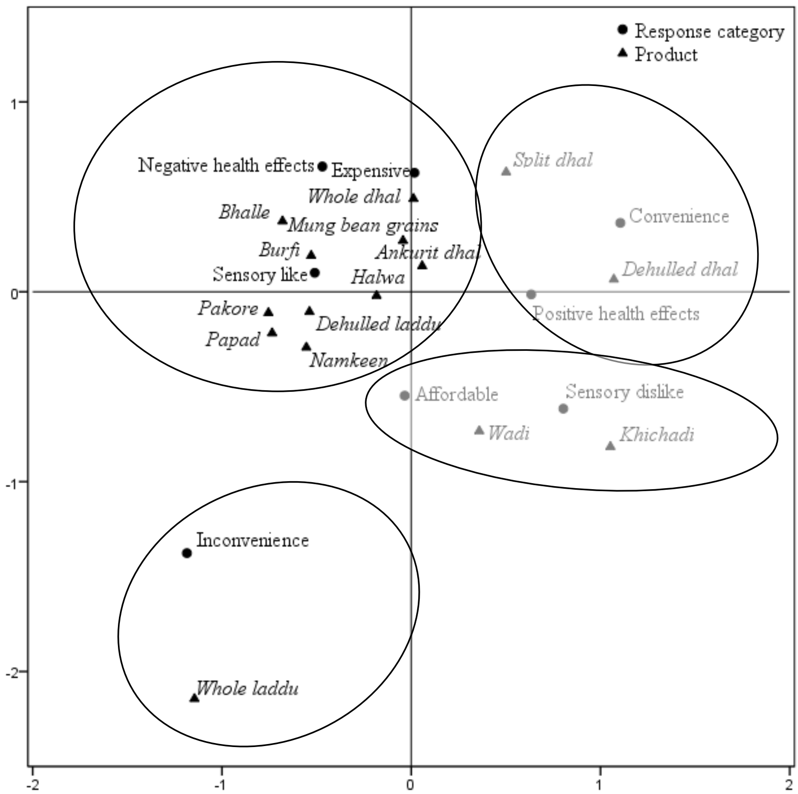

Figure 1. Correspondence analysis of response categories associated with mung bean and its derived products

Table 2. Consumer perception of mung bean and its derived food products

Products	Safety			Healthiness			Criteria to judge Quality[1]		Reason for consumption		
	Safe	Moderately safe	Unsafe	Healthy	Moderately healthy	Unhealthy	Sensory quality	Location of processing	Sensory liking	Health promoting	Affordability
Whole grain	133 [2]	19	0	133	19	0	152	0	97	1	54
Whole dhal	127	25	0	127	25	0	152	0	151	0	1
Split dhal	132	20	0	132	20	0	152	0	135	0	17
Dehulled dhal	150	2	0	152	0	0	152	0	76	33	43
Whole laddu [1]	44	108	0	44	108	0	58	0	14	40	0
Dehulled laddu	94	52	6	94	52	6	152	0	140	12	0
Burfi	97	48	7	84	61	7	110	42	147	5	0
Halwa	117	25	10	98	41	13	106	46	114	38	0
Namkeen	137	15	0	136	16	0	129	23	152	0	0
Papad	143	9	0	143	9	0	123	29	152	0	0
Pakore	78	32	42	78	32	42	76	76	152	0	0
Bhalle	77	36	39	66	65	21	85	67	152	0	0
Wadi	133	19	0	133	19	0	152	0	95	41	16
Khichadi	144	8	0	144	8	0	152	0	27	91	34
Ankurit dhal	127	18	7	127	18	7	152	0	77	65	10

[1] 98 consumers did not respond to criteria to judge quality of product and reason for consumption
[2] Figures in the table are the number of respondents out of 152 total respondents

Table 3. Frequencies of word associations for different response categories associated with mung bean products

Food Products		Response categories										Total (per Product)
		Sensory		Health effects		Cost		Accessibility		Processing		
Types	Name	Like	Dislike	Positive	Negative	Affordable	Expensive	Easy to get[2]	Difficult to get[3]	Easy[2]	Difficult[3]	
Raw grain	Whole grain	139[1]	33	65	41	41	47	5	4	15	1	391
Dhals	*Whole dhal*	121	30	78	58	23	52	3	6	20	1	392
	Split dhal	101	37	92	59	15	51	25	4	50	0	434
	Dehulled dhal	45	97	109	34	24	49	20	1	50	0	429
Sweets	*Whole laddu*	18	3	13	5	10	2	0	3	0	35	89
	Dehulled laddu	118	25	23	35	38	25	1	1	0	15	281
	Burfi	140	24	19	31	13	54	4	16	1	20	322
	Halwa	132	31	76	40	33	59	5	20	1	30	427
Snacks	*Namkeen*	75	16	4	8	19	13	5	6	0	4	150
	Papad	108	14	15	16	15	9	3	1	0	15	196
	Pakore	117	24	16	57	20	4	2	15	4	11	270
	Bhalle	101	16	29	89	27	16	2	4	1	15	300
Others	*Wadi*	72	59	34	2	23	10	3	1	2	4	210
	Khichadi	45	102	103	8	52	5	0	3	42	6	366
	Ankurit dhal	77	6	67	12	3	2	0	2	7	3	179
Total (per response category)		1409	517	743	495	356	398	78	87	193	160	

[1]Figures in table are number of responses
[2]Convenience (easy to get and easy processing)
[3]Inconvenience (difficult to get and difficult processing)

3.4 Consumer dietary practices

The interview data depicting consumer practices for consumption of mung bean and its derived products are given in Table 4. *Dhals*, *khichadi* and *wadi* were consumed by the respondents mainly at lunch and dinner, whereas *namkeen* and *pakore* were consumed mainly at tea time. *Dhals*, sweets, *khichadi*, *ankurit dhal* and *wadi* were consumed at home, whereas *bhalle* was reported to be a street food. On the contrary, there was no fixed place for the consumption of *namkeen*, *papad* and *pakore*. *Dhals, halwa, pakore* and *wadi* were said to be consumed warm, whereas *dehulled laddu*, *whole laddu, papad, namkeen, bhalle* and *ankurit dhal* were consumed cold.

Mung bean products were consumed in different seasons; sweets were only seasonally consumed, whereas *dhals* and *khichadi* were consumed weekly or monthly by most consumers. Low frequency of consumption of legume is in line with results previously published (Arlappa et al., 2010). Mung bean snacks were consumed at least once per month or seasonally. Sweets and snacks were consumed with hot drinks like tea and coffee. *Bhalle* and *khichadi* are the only two products that were consumed with cold food products like curd and *lassi* (buttermilk). *Dhals* and *wadi* were consumed with staple products like rice, *chapatti,* and *parantha* (shallow fried *chapatti).* There is no typical pre-consumption processing required except warming for *dhals*, *halwa*, *wadi* and *khichadi* and flame roasting for *papad*.

4. Discussion

4.1 Consumer awareness and preferences for mung bean and its derived products

The limited awareness of consumers about mung bean varieties used in the preparation of products shows its insignificance for product quality at household level. This implies that the household products can be prepared using any of the frequently used varieties without a significant change in product specific characteristics. On the contrary, the preference of processors for specific varieties indicates that the quality of commercial products is related to the type of mung bean variety used. To date, no research has been conducted that explains the varietal effect on the quality of mung bean products.

The restricted knowledge of consumers with respect to whole *laddu*, as compared to other products, indicates that this food is less important in the daily consumption pattern. Processing knowledge seems to have a significant role in consumer choice. Processing of sweets and snacks is difficult and lengthy and thus limits their processing knowledge to specialised processors. This may be the reason why these products are commercial products rather than being part of household dishes.

Preference for consumption of the various mung bean products differed from their consumption practices. Notably, the preference for *khichadi* was found to be lowest in sheer contrast to its consumption frequency, which was much higher than that of the most preferred products like *halwa* and *laddu.* There are socio-economic and psychological factors that could explain the lower preference for *khichadi* and *dehulled dhal* and the higher preference for *halwa* and *laddu. Khichadi* and *dehulled dhal* are considered as food for diseased people as they are recommended by doctors for their good digestibility. The costs of *laddu* and *halwa* are much higher than that of *khichadi* and *dhal*. Moreover, *halwa* and *laddu*, being seasonal and commercial products are not available throughout the year. Consumers are not able to purchase them often and thus consume *khichadi* and *dhal* frequently.

Table 4. Consumer practices for consumption of mung bean products

	Time of consumption			Location of consumption				Temperature during consumption		Frequency of consumption			Accompanying foods				Pre-consumption processing		
Products	Tea time	Lunch/ Dinner	Anytime	Home	Retail shop	Street	Any where	Warm	Cold	Weekly	Monthly	Seasonally	Hot drinks[2]	Cold foods[3]	Staple foods[4]	None	Warming	Roasting	Not required
Whole dhal	4[1]	67	81	152	0	0	0	152	0	91	61	0	0	0	152	0	152	0	0
Split dhal	2	62	88	152	0	0	0	152	0	98	54	0	0	0	152	0	152	0	0
Dehulled dhal	2	62	88	152	0	0	0	152	0	89	63	0	0	0	152	0	152	0	0
Whole laddu[5]	0	0	69	54	0	0	0	23	31	0	0	54	43	0	0	25	23	0	0
Dehulled laddu	0	0	152	134	18	0	0	9	143	0	0	120	26	0	0	126	9	0	143
Burfi	0	0	152	138	14	0	0	9	143	0	0	145	41	0	0	111	9	0	143
Halwa	0	0	152	107	45	0	0	133	19	0	0	152	19	0	0	133	133	0	19
Namkeen	31	0	121	0	0	0	152	0	152	21	31	100	128	0	0	24	0	0	152
Papad	21	0	131	0	0	0	152	18	134	12	22	92	18	0	0	134	0	152	0
Pakore	52	0	100	48	15	3	86	152	0	5	26	121	128	0	0	24	152	0	0
Bhalle	0	0	152	37	0	115	0	0	152	15	45	92	0	152	0	0	0	0	152
Wadi	2	73	77	152	0	0	0	152	0	13	98	41	0	0	152	0	152	0	0
Khichadi	0	69	83	152	0	0	0	92	60	45	49	58	76	43	0	33	117	0	35
Ankurit dhal[6]	0	0	134	152	0	0	0	33	119	10	33	109	0	0	0	152	0	0	152

[1] Figures in table are number of respondents out of 152 total respondents
[2] Hot drinks include tea and milk
[3] Cold foods include *Lassi* (buttermilk) and curd
[4] Rice, *Chapattis*, *Prantha* (shallow fried *chapattis*) and *Puri* (deep fried *chapattis)*
[5] 98 consumers did not responded to location of consumption & 129 also did not know about Pre-consumption processing of *Whole laddu*
[6] 18 consumers consume *Ankurit dhal* during breakfast

Convenience is another essential factor indicated by consumers, which therefore has an impact on the potential of a product to significantly contribute to the nutritional status of its consumers. In this respect, while keeping mid-day meal in mind it would seem that sweets and snacks are perfect as there is no fixed time for their consumption. However, sweets and snacks are prepared by difficult and lengthy processing, which affects the convenience of their use in a negative way. Technological improvements in these products to make them available in ready-to-eat form are a prerequisite to make them more widely available. Until then, their potential as a food to improve the nutritional status is restricted.

4.2 Consumer perception

Sensory attributes of the various mung bean products were found to play an important role in the consumer perception of product quality. Consumer perception of the safety of the mung bean products showed that household products are considered to be safer than commercially available products like sweets and snacks. *Dhals* are household products and therefore consumers are aware of the way of processing and thus trust them to be safe to eat. Sweets were considered to be moderately healthy due to their high fat content. *Pakore* and *bhalle* were considered as unhealthy due to their availability in the street, which is associated with low quality processing and unhygienic conditions. This is also evident from the fact that for snacks the location of processing is thought to be one of the criteria to judge the quality of product. However, most of the consumers judge the quality of the products on the basis of sensory characteristics, which shows this to be the main indicator of quality. As street foods are perceived to be rather unsafe and poor quality products, there is potential for technological developments to make these products available in ready-to-cook or ready-to-eat form as consumers shows a high preference for them.

4.3 Consumer dietary practices

Interactions between consumer knowledge, perception, preferences and socio-economic circumstances compels consumers to adopt certain dietary practices (Dewettinck et al., 2008; Sorensen et al., 2003). Moreover, dietary practices are one of the key factors deciding the nutritional status of an individual. For instance, vegetarian dietary practices have drawbacks associated with it in terms of mineral nutrition compared to non-vegetarian dietary practices. Similarly, mung bean dietary practices seem to have few drawbacks, and thus provide technological options for improvement. Mung bean consumer's preferences indicated that most of the consumption habits have been developed and evolved with social experiences but still some consumption related constraints exist, which were estimated to have major nutritional and health impact leading to public health problems like mineral deficiency.

Frequency of consumption is a decisive factor for the extent in which a food contributes towards nutrition. *Dhals*, *namkeen* and *khichadi* have the highest frequency of consumption. Such a low frequency of mung bean consumption in a vegetarian population, which depends on legumes for their protein source, is noticed. However, consumers have other legumes like chick pea, pigeon pea as an alternative for consumption (Manu and Khetarpaul, 2006). Thus, this possibility of preparing *dhals* with different legumes restricts daily mung bean *dhal* consumption. But, compared to mung bean sweets and snacks, the higher frequency of consumption of *dhals* and *khichadi* shows their potential to satisfy hunger and their larger contribution towards overall nutrition. Therefore, the consumption of *dhals* indicates their potential for being a vehicle to improve the nutrition status of the population.

Apart from the frequency of consumption and convenience, accompanying products also influence the potential of food products to contribute to the nutritional status of its users. Consumers eat *dhal* with many variations in its recipe. One of the important variations is spinach mung bean *dhal*. This product containing spinach might not be a good source of mineral nutrition as oxalates in spinach might hinder mineral absorption in the human intestine (Gupta et al., 2006). Similarly, results indicate that snacks are consumed with hot drinks like tea and coffee. This dietary habit shows ineffective use of total minerals present in snacks, as tea contains tannins that potentially bind with minerals, thereby reducing their bioavailability (Temme and Van Hoydonck, 2002). However, another mung bean dietary pattern in which consumers add lemon juice to dhals prior to consumption indicates a promising combination as ascorbic acid in lemon enhances iron absorption through solubilisation by reduction of ferric iron to ferrous iron (Fidler et al., 2003). The combination of these products is expected to improve nutrient bioavailability. From a nutritional point of view, combinations of foods high in sulphur-containing amino acids with mung bean are advisable, as it lacks methionine (Mendoza et al., 2001). Consumption of *dhals* with cereal products like Indian bread and rice indicate potential combination in terms of amino acid nutrition. This consumption pattern provides balanced amount of lysine, a limiting amino acid in cereals and methionine, limiting amino acid in legumes. Cereal based mung bean products like *khichadi* and *dhal parantha* (Indian bread prepared with cooked *dhal* and wheat flour) are considered good in terms of balanced amino acid intake.

Accompanying food seems to have significant impact on the overall nutritional potential of mung bean foods. Therefore research on the effects of mung bean product combinations on the overall nutritional profile of dishes is advocated.

4.4 Innovation potential

Single or few options in diet lead to malnutrition, but despite diverse mung bean food products to choose from, the adverse health implications persists (Pathak and Singh, 2011). Redesigning traditional foods for combating household nutritional insecurity requires careful selection of food products. Several mung bean products seem to offer potential as vehicles to alleviate malnutrition on the basis of nutritional composition (e.g. mineral contents and their bioavailability), consumer characteristics (i.e. knowledge, perception, preference and practices) and socio-economic circumstances. Factors like affordability, ease of processing, storage methods used, product procurement, time of consumption, temperature during consumption and pre-consumption requirement govern the accessibility aspect of the mung bean products. However, perceived sensory liking, positive health perception, nutrient content, food preference, frequency of consumption and accompanying food products determine the nutritional contribution of the products to the overall food intake. These factors interact with each other and lead to final food choice. In case of mung bean foods, the consumers prefer products with high sensory quality. Thus, they prefer to consume sweets like *halwa* and *laddu,* but perceive *khichadi* as healthy. However, consumers choose *dhals* for day to day consumption. This indicates that in certain circumstances food choice is influenced more by social-economic restrictions then by consumer perception and preferences (Hoefling and Strack, 2010).

In order to get a holistic view of these influences on food choice, the selected factors were ranked and used to outline different scenarios (Table 5). These scenarios provide insight in the options for using mung bean foods to alleviate malnutrition while staying as close as possible to local food uses and preferences. All products were ranked on the basis of data from tables 1-4 that present different aspects of mung bean consumption. Table 5 shows that *dhals* are the most promising products but also that different factors favour different products. Increasing the weight for certain factors might give different ranking results. This is relevant because certain factors can be adjusted by dedicated technological research, i.e. they can be improved to match consumer wants.

Table 5. Product ranking for factors affecting consumer choices influencing the overall nutritional contribution

	Factors affecting consumer choice	*Dhals*			Sweets				Snacks				Others		
		Whole dhal	*Split dhal*	*Dehulled dhal*	*Whole laddu*	*Dehulled laddu*	*Burfi*	*Halwa*	*Namkeen*	*Papad*	*Pakore*	*Bhalle*	*Wadi*	*Khichadi*	*Ankurit dhal*
Consumer perception	*Sensory liking*	5	4	2	11	8	10	6	7	13	9	12	3	1	14
	Positive health effects	7	8	11	10	5	4	9	3	6	1	2	14	13	12
Nutritional potential	*Protein contribution /portion* [A]	10.5	4	13	8	9	12	14	6	1	2	6	3	10.5	6
	Iron contribution/portion [A]	11.5	6	14	13	8.5	10	11.5	3	1	4	7	2	5	8.5
	Zinc contribution/portion [A]	8	4	13	11.5	11.5	10	14	5	1	3	7	2	9	6
Consumer preference	*Comparative food selection*	14	10	3	1	4	9	8	12	13	11	7	6	2	5
Consumption practices	*Frequency of consumption* [B]	13	14	12	2.5	2.5	2.5	2.5	8	6	5	9	10	11	7
	Accompanying products [C]	11.5	11.5	11.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	14	11.5	9	4.5
Overall ranking score		80.5	61.5	79.5	61.5	53	62	69.5	48.5	45.5	39.5	64	51.5	60.5	63
Nutritional Scenario (A X 2)		110.5	75.5	119.5	94	82	94	109	62.5	48.5	48.5	84	58.5	85	83.5
Consumption Scenario (B X 2)		93.5	75.5	91.5	64	55.5	64.5	72	56.5	51.5	44.5	73	61.5	71.5	70
Accompanying food Scenario (C X 2)		92	73	91	66	57.5	66.5	74	53	50	44	78	63	69.5	67.5

The possible flexible factors that determine the innovation potential are nutrient content (nutritional scenario-1), frequency of consumption (consumption scenario-2) and accompanying products (accompanying food scenario-3) as indicated in table 5. Nutritional scenario is calculated by giving extra weight to the intake of protein, iron and zinc per portion of the mung bean food (data not shown). Consumption scenario is calculated by giving extra weight to the frequency of consumption of each mung bean products. Similarly, accompanying food scenario is calculated by giving extra weight to accompanying foods with potential to improve nutritional quality of foods. Interestingly, all scenarios lead to the same conclusion, namely that *dhals* are the most promising product.

Dhals are valuable because they are highly nutritious and deliver sustenance while simultaneously being easy to digest and process. *Dhals* also contribute significantly in terms of protein, iron and zinc nutrition. Further improvements can be made by breeding for varieties that have better characteristics from a nutritional point of view (Dahiya *et al.* submitted). These products are also relatively cheap, easily available and have convenient processing. Moreover, reformulation of their recipes offer options for nutritional improvement by incorporating nutrient-rich locally available ingredients like vegetables fruits and spices (Shanmugasundaram, 2007). Few examples of this approach are provided by supplementing mung bean based dishes used in a school feeding program in India (Sathya et al., 2002; Vijayalakshmi et al., 2008). *Dhals* are not usually accompanied by any other foods while consuming, which might reduce their nutrient availability. Processing methods of *dhals* involve only cooking and soaking, thus providing potential for incorporating other nutrient enhancing processing methods like fermentation or germination to prepare these products with improved or minimal change in sensory parameters. Poor sensory attribute in *dehulled dhal* should be improved by enriching with local vegetables. Therefore, research in nutritional enhancement of *dhals* is required.

Apart from product development, redesigning traditional foods is also required at consumption level. As different accompanying foods might give different nutritional output, it is important to select accompanying foods with care. Therefore, social extension program like self-help groups can play their role in spreading the awareness of proper dietary habits for harnessing proper nutritional output of mung bean foods. Food-based dietary guidelines are required to be designed to ensure proper awareness through extension activities (Brown et al., 2011).

Thus, when deciding about the choice of any food product as a vehicle to alleviate malnutrition among relevant populations, we advocate not merely relying on sensory appreciated products but using an approach that takes account of other factors that govern food choice as well. Moreover, indigenous mung bean consumption possesses different technological and behavioral constraints for which multi-disciplinary research and development can be utilized for proper rectification or improvisation.

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Chapter 4

Nutrient composition of selected newly bred and established mung bean varieties

Abstract

Seven newly bred and three established varieties of mung bean were analysed for proximate composition, minerals, anti-nutrients and *in vitro* mineral accessibility. They contained 18 - 23 g protein, 4.0 - 5.6 g crude fibre and 2.5 - 4.1 g ash per 100 g dry sample. Iron, zinc, calcium, sodium and potassium ranged from 3.4 - 4.6, 1.2 - 2.3, 79 - 115, 8.1 - 13.5 and 362 - 415 mg/100g dry weight, respectively. Phytic acid and polyphenols averaged 769 and 325 mg/100g dry weight, respectively. Varieties differed significantly in terms of nutrient and anti-nutrient contents. Phytic acid and polyphenols were negatively correlated with *in vitro* mineral accessibility and nutrient digestibility. Protein and starch digestibility ranged from 53 - 67 g/100g dry weight and 20 - 29 mg maltose released/g dry weight, respectively. Average molar ratios of phytic acid to iron and zinc were 16.8 and 52.7, respectively. Differences in *in vitro* iron and zinc accessibility could not be explained by phytic acid to calcium nor magnesium molar ratios. However, the phytic acid amount in mung beans suffices to bind all minerals into indigestible complexes. The newly bred varieties have better agronomic yields but no better nutritional potential than the established varieties tested.

Key words: *Vigna radiata*, iron, zinc, calcium, *in vitro* digestibility, *in vitro* accessibility.

1. Introduction

Mung bean (*Vigna radiata* (L.) R. Wilczek) is an important legume in the diet of the majority of Indians, who consume it in different forms like dhals, sweets, snacks and savoury food products. Mung bean has protein content comparable to that of chick pea (*Cicer arietinum*) but contains less anti-nutritional (Chitra et al., 1995) and flatulence factors than soya bean (Abdullah et al., 1984). Mung bean is rich in micronutrients and can be used to deliver minerals to malnourished populations if processed well to retain them in the diet. Mung bean varieties are grown in wide agro-climatic zones and have diverse agronomical, processing and nutritional characteristics (Bisht et al., 2005; Makeen et al., 2007; Tomooka, 1991). The suitability of a particular variety for processing and consumption depends primarily on its quality characteristics, particularly physical properties and chemical composition.

The presence of anti-nutrients such as phytic acid (PA) and polyphenols was shown to reduce the digestibility (Binita and Khetarpaul, 1997) and bioavailability of nutrients present in mung bean (Dave et al., 2008; Mubarak, 2005). There are several approaches to increase nutrient bioavailability and digestibility at the primary production level. The first is by breeding varieties with better abilities to acquire nutrients from the soil, and the second is to optimize agronomic practices like fertilisation. Furthermore it is also possible to use breeding techniques for increasing the concentration of mineral enhancers like ascorbic acid and for decreasing the concentration of nutrient inhibitors like phytic acid, polyphenols, etc. (Frossard et al., 2000).

Most of the mung bean breeding research in India has focused on high and stable yield, early and uniform maturity, resistance to pests, pathogens and drought (Singh and Ahlawat, 2005). These selection criteria may have produced varieties with altered nutritional composition of the grains. Moreover, breeding for improved nutritional composition is limited by the fact that some plant components that are undesirable from nutritional point of view are physiologically important for the plant itself. For instance, phytic acid is required for seed germination, but it is detrimental to micronutrient uptake in humans (Coelho et al., 2002).

To date, little effort has been made to evaluate the nutrient composition of new varieties of mung bean, which were bred for their disease resistance and high yield, and established varieties with respect to their contribution to human nutrition. Therefore, in the present study, seven newly bred varieties and three established varieties of mung bean were investigated for nutritional quality.

2. Materials and methods

2.1 Sampling

The mung bean varieties used for the study (Table 1) were grown using identical agronomic practices (e.g. fertilizer, irrigation) by the Department of Plant Breeding, CCS Haryana Agricultural University, Hisar, India. Raw, fully mature, disease-free mung bean grains were cleaned of extraneous matter, broken grains and weed grains, dust and other foreign materials, mixed well and ground to fine powder in an electric grinder (Cyclotec M/s Tecator, Hoganas, Sweden) and passed through a 0.5 mm sieve. Powders were stored in sealed air-tight plastic containers in a refrigerator at 5 ºC until analysis.

Pepsin, pancreatin, pancreatic amylase and bile were obtained from Sigma-Aldrich Co. USA. All other reagents used for the analyses were of analytical grade and glassware was acid (1 g/100mL HCl) washed.

2.2 Selection and description of mung bean varieties

Ten mung bean varieties were selected, namely seven newly bred at CCS Haryana Agricultural University and three established in Haryana state in India.

2.3 Analytical methods

2.3.1 Proximate composition

The following AOAC methods (1990) were used to determine proximate composition: drying at 105 ºC for 24 h for moisture (AOAC 925.10), incineration at 550 ºC for ash (AOAC 923.03), defatting in Soxhlet apparatus using hexane for crude lipids (AOAC 920.39), digestion with NaOH and H_2SO_4 for crude fibre (AOAC 962.09) and microKjeldahl method for crude protein (AOAC 960.52). For conversion of Nitrogen to crude protein, a conversion factor of 6.25 was used. The carbohydrate content was estimated by difference of protein, fibre, ash, fat and 100. Energy was calculated using Atwater energy conversion factors of 4.0, 4.0 and 9.0 kJ/g, for protein, carbohydrate and fat, respectively. Proximate composition was determined using dried samples. Values are presented as g/100g on dry weight basis.

2.3.2 Mineral composition

Calcium, iron and zinc contents were determined by first digesting 1 g of sample using 25 ml diacid mixture ($HNO_3/HClO_4$: 5/1, v/v) after which the digested solution was filtered through Whatman no. 42 filter paper. Volume of the solution was made up to 50 ml and then the mineral content was determined by Atomic Absorption Spectrophotometer 2380, Perkin - Elmer (Waltham, USA) using the method of Lindsey & Norwell (1969).

2.3.3 *In vitro* protein and starch digestibility

In vitro protein digestibility was determined by the method of Mertz *et al.* (1983). The method involved treatment of 250 mg sample with 20 ml pepsin reagent (0.1 mol/L KH_2PO_4 (pH 2.0) containing 0.2 g/ 100mL pepsin) and then incubating at 37 ºC for 3 h with constant shaking. The digested protein was then separated by sedimenting residual protein with 5 ml of 50 g/ 100mL trichloroacetic acid and centrifugation at 16,770 xg for 10 min. The Nitrogen content of the supernatant containing digested protein was determined by the microKjeldahl method (AOAC, 1990).

In vitro starch digestibility was assessed by using pancreatic amylase. Twenty - five mg of the defatted sample was dispersed in 1 ml 0.2 M phosphate buffer (pH 6.9). Half a millilitre of pancreatic amylase was added and then the suspension was incubated at 37 ºC for 2 h. After incubation, 3 ml of 3, 5 - dinitrosalicyclic acid reagent was quickly added and then heated for 5 min in a boiling water bath. Next, the mixture was cooled and distilled water was added to get 25 ml. This solution was filtered and liberated maltose was measured colorimetrically at 550 nm. Maltose was used as standard and the values are expressed as mg of maltose liberated per gram of sample (Singh et al., 1982).

Table 1 Characteristics of the selected mung bean varieties

Mung bean varieties		Level of resistance to Mung bean Yellow Mosaic Virus	Growing season	Yield (kg/ hectare)	Crop duration (Days)
Established varieties	Asha	Tolerant	Autumn	1000	60
	Muskan	Resistant	Autumn	1000	80
	Satya	Resistant	Autumn	1300	66
Newly bred varieties	MH 124	Resistant	Autumn	1300	65
	MH 125*	Resistant	Autumn	1200	65
	MH 318	Resistant	Autumn/Summer	1500	58
	MH 421	Resistant	Autumn/Summer	1300	60
	MH 539	Resistant	Autumn/Summer	1400	60
	MH 560	Resistant	Autumn/Summer	1600	60
	MH 564	Resistant	Autumn/Summer	1500	60

Source: Kumar, pers. comm. (2010) Senior Scientist at CCS Haryana Agriculural University, Hisar (India)
*Notified for farmers' use in 2009

2.3.4 *In vitro* mineral accessibility

In vitro iron accessibility was determined by digesting the sample with a single enzyme method as described by Rao & Prabhavathi (1978). This method is convenient, requires a minimum of chemicals, and is well suited for comparative purposes. Obviously, it does not necessarily predict exactly what will happen in-vivo, but neither do the more sophisticated in-vitro approaches.

The method involved incubation of 2 g of powdered sample with 25 ml 0.5 g/ 100mL pepsin in 0.1 mol equi/L HCl solution in a water bath of 37 ºC for 90 min, after adjusting the pH to 1.3 using HCl. The mixture was then centrifuged at 1000 xg for 45 min and the supernatant was filtered through Whatman no. 44 filter paper. Iron in the filtrate was determined according to the AOAC (1995) method by treating with 1 ml hydroxylamine hydrochloride solution and 5 ml acetate buffer solution and then reacted with α, α′ dipyridyl to yield colour which was read at 510 nm.

In vitro zinc and calcium accessibility were assessed with the multiple enzyme method of Kim & Zemel (1986). The method involved hydration of 2 g sample with 3 ml distilled water. Hydrated samples were then treated with 20 ml pepsin solution (0.1 g / 100mL pepsin in 0.1 N HCl). Next the pH was adjusted to 1.5 followed by incubation at 37ºC for 1 h in a controlled temperature chamber cum shaker (BTI-100B, Biotechnologies Inc., New Delhi). After incubation the pH was raised to 6.8 with NaOH and 2.5 ml of a suspension containing 0.5 g/100mL pancreatin and 5 g/100mL bile was added and again incubated for 1 h at 37 ºC in the controlled temperature chamber cum shaker. Next, the volume was increased to 50 ml with distilled water and immediately centrifuged at 1000 xg for 45 min at 5ºC. Supernatants were removed and again centrifuged at 28,350 xg for 45 min at 5ºC. The supernatant was digested with diacid mixture ($HNO_3/HClO_4$: 5/1, v/v) and then soluble calcium and zinc were determined by an Atomic Absorption Spectrophotometer 2380, Perkin-Elmer (Waltham, USA) using the method of Lindsey & Norwell (1969). Lanthanum chloride was added during the determination according to Vaessen and Van de Kamp (1990).

2.3.5 Phytic acid and polyphenol content

Phytic acid (PA) was estimated colorimetrically by the method of Davies & Reid (1979), by incubating 500 mg of sample with 20 ml of 0.5 M HNO_3 for 3 h with continuous shaking. The suspension was then filtered through Whatman no. 1

filter paper. One ml of this suspension was made up to 1.4 ml using distilled water and then mixed with 1 ml ferric ammonium sulphate solution containing 50 μg of Fe. The test tube containing this suspension was placed in boiling water for 20 min. Next, the suspension was cooled to room temperature and 5 ml iso - amyl alcohol was added followed by 0.1 ml ammonium thiocyanate solution (100g/l). The content was mixed well, and centrifuged at 1000 xg for 10 min. Colour intensity in alcohol was read at 465 nm using a spectrophotometer (BTI-1100, Biotechnologies Inc., New Delhi, India). For phytic acid determinations, phytic acid sodium salt hydrate (Sigma, P0109) was used for calibration purposes.

Total polyphenols were extracted from 500 mg of defatted sample by refluxing with 50 ml methanol containing 1 g/100mL HCl for 4 h. The extract was concentrated by evaporating methanol on a boiling water bath and brought to 25 ml with methanol-HCl solution (Singh and Jambunathan, 1981). Half a millilitre of extract was made up to 8.5 ml with distilled water, mixed with 0.5 ml Folin Denis reagent and shaken. After 3 min, 1 ml of saturated sodium carbonate was added, followed by shaking. After an h, the absorbance was read at 725 nm. Calculations were done using absorbance and expressed as tannic acid equivalent (Swain and Hills, 1956). The PA : Zn, PA : Ca and PA : Fe molar ratios were calculated using the method of Wyatt & Triana-Tejas (1994).

2.4 Statistical analysis

Three samples of each mung bean variety were analysed. Mean ± standard deviation values were calculated. Comparison of means was performed by one way analysis of variance (ANOVA) followed by Tukey multiple comparison test. Significance was accepted at $P<0.05$ (Panse and Sukhatme, 1961). Pearson linear correlation coefficients were determined to relate the nutrient digestibility and accessibility with concentrations of anti-nutritional factors. All statistical analyses were performed with PASW Statistics (Version 18.0.2).

3. Results and discussion

3.1 Proximate composition

Crude protein contents were significantly different ($P<0.05$) among the mung bean varieties (Table 2). However, they all fall within the range of data published elsewhere for mung bean (Kochhar and Hira, 1997; Lotika and Bains, 2007). This implies that the newly bred varieties are not necessarily better suppliers of protein than the established varieties, which is supported by the fact that even higher protein contents, i.e. 26.9 g/100g (Grewal and Jood, 2009) and 27.7 g/100g (Ghavidel and Prakash, 2007) have been reported in mung bean. Moreover, crude protein may contain nutritionally less important non-protein nitrogen. Therefore, varieties with a higher content of crude protein may not necessarily have a better protein quality. The crude lipid contents did not differ significantly ($P<0.05$) among the varieties and were within normal ranges as published elsewhere, with the highest concentration (1.3 g/100g) found in MH 564. The ash contents of the mung bean varieties ranged from 3.1 to 4.1 g/100g dry weight which is also within the range of other published values (Lin and Lai, 2006). MH 560 had the highest ash content. In contrast, MH 125 had highest content of accessible minerals. This could be due to the presence of lower concentrations of anti-nutritional factors in the latter variety. Crude fibre contents in the mung bean varieties were not different from values reported elsewhere (Lotika and Bains, 2007). The tested varieties could be distinguished into groups of similar nutrient composition. MH 125 and MH 539 had the highest crude protein, whereas MH 124, MH 421 and MH 560 contained the least crude protein. Among newly bred varieties, crude fibre was highest in MH 125 with considerable amounts present in MH 124, MH 421 and MH 564. Among the established varieties, the highest crude fibre was found in Muskan (5.2 g/100g), which is comparable to that of newly bred variety MH 125 (5.4 g/100g).

3.2 Mineral content

The mineral concentrations are presented in Table 3. Although there are statistically significant differences between mineral levels among the varieties, their levels are within the expected range for mung bean (Jood et al., 1998). The significant difference in the mineral content of the varieties may have several reasons, but are most likely due to the ability of the root to absorb minerals from the soil, the physiological role of minerals in the plant and the translocation of minerals in the plant as suggested by Frossard et al. (2000). These authors also concluded that the mineral uptake mechanism varies among varieties, depending on root mycorrhiza and plant architecture. The cumulative mineral contents represent only about 30 % of

Table 2. Proximate composition of newly bred and established mung bean varieties

Mung bean varieties		Moisture	Crude protein	Crude fat	Crude fibre	Ash	Carbohydrate*	Energy**
Established varieties	Asha	9.2 ± 0.2^{de}	20.0 ± 0.50^{bc}	1.32 ± 0.09^{a}	4.2 ± 0.10^{ab}	3.21 ± 0.10^{abcd}	71.3 ± 0.5^{de}	1578 ± 4.0
	Muskan	9.7 ± 0.0^{cde}	22.1 ± 0.20^{def}	1.22 ± 0.1^{a}	5.2 ± 0.17^{d}	3.27 ± 0.23^{bcd}	68.2 ± 0.4^{abc}	1557 ± 3.2
	Satya	8.7 ± 0.2^{bc}	22.8 ± 0.10^{f}	1.31 ± 0.1^{a}	4.2 ± 0.09^{ab}	2.79 ± 0.26^{a}	68.9 ± 0.3^{abc}	1585 ± 3.0
Newly bred varieties	MH 124	8.7 ± 0.2^{bc}	19.1 ± 0.01^{ab}	1.24 ± 0.1^{a}	4.6 ± 0.29^{bc}	3.12 ± 0.11^{abc}	71.9 ± 0.3^{ef}	1571 ± 3.1
	MH 125	8.3 ± 0.2^{ab}	22.9 ± 0.95^{f}	1.23 ± 0.2^{a}	5.4 ± 0.19^{d}	3.08 ± 0.04^{abc}	67.4 ± 1.0^{a}	1557 ± 6.1
	MH 318	9.7 ± 0.2^{f}	20.8 ± 0.08^{bcd}	1.51 ± 0.11^{a}	4.1 ± 0.09^{a}	3.65 ± 0.09^{de}	69.9 ± 0.2^{cd}	1575 ± 2.7
	MH 421	8.8 ± 0.1^{cd}	17.9 ± 0.10^{a}	1.16 ± 0.1^{a}	4.4 ± 0.10^{abc}	3.37 ± 0.26^{cd}	73.3 ± 0.3^{f}	1510 ± 3.1
	MH 539	8.9 ± 0.1^{cd}	22.7 ± 1.05^{ef}	$1.36 + 0.19^{a}$	4.7 ± 0.10^{c}	3.35 ± 0.13^{bcd}	67.9 ± 1.1^{ab}	1568 ± 6.6
	MH 560	8.0 ± 0.1^{a}	19.6 ± 0.26^{abc}	1.48 ± 0.4^{a}	5.2 ± 0.10^{d}	4.08 ± 0.01^{e}	69.7 ± 0.5^{bcd}	1550 ± 5.0
	MH 564	9.5 ± 0.2^{ef}	21.1 ± 1.0^{cde}	1.64 ± 0.1^{a}	4.5 ± 0.09^{abc}	2.89 ± 0.10^{ab}	69.9 ± 1.0^{cd}	1585 ± 6.1

Values (g/100g) are expressed as Mean $\pm$ Standard Deviation (n=3) on dry matter basis (except for moisture)
Means in the same column with the different superscripts are significantly different at $P < 0.05$
*Calculated by difference from protein, fat, ash, fibre and dry matter
** Energy (kJ/100g) = (Fat (g) x 9.0+ Protein (g) x 4.0 +Carbohydrate (g) x 4.0) x 4.184

Table 3 Mineral composition of newly bred and established mung bean varieties

Mung bean varieties		Iron	Zinc	Calcium	Magnesium	Sodium	Potassium
Established varieties	Asha	3.9 ± 0.06^{c}	1.2 ± 0.03^{a}	103 ± 1.6^{d}	157 ± 2.4^{d}	9.4 ± 0.3^{ab}	363 ± 1.5^{a}
	Muskan	3.6 ± 0.15^{a}	1.7 ± 0.05^{cd}	98 ± 0.4^{c}	137 ± 3.0^{b}	10.6 ± 0.4^{cd}	403 ± 1.7^{e}
	Satya	3.9 ± 0.10^{c}	1.3 ± 0.05^{ab}	95 ± 1.5^{c}	129 ± 3.0^{a}	8.7 ± 0.4^{a}	389 ± 3.1^{c}
Newly bred varieties	MH 124	3.9 ± 0.03^{c}	1.4 ± 0.05^{ab}	97 ± 3.0^{c}	158 ± 1.1^{d}	8.5 ± 0.4^{a}	380 ± 1.3^{b}
	MH 125	4.6 ± 0.10^{d}	1.7 ± 0.14^{d}	114 ± 1.0^{e}	166 ± 1.6^{e}	13.2 ± 0.3^{f}	411 ± 1.2^{fg}
	MH 318	4.4 ± 0.14^{d}	1.5 ± 0.05^{abc}	90 ± 0.6^{b}	156 ± 1.6^{d}	10.4 ± 0.3^{bc}	407 ± 2.5^{eg}
	MH 421	4.4 ± 0.09^{d}	2.1 ± 0.14^{e}	104 ± 1.6^{d}	147 ± 1.4^{c}	10.0 ± 0.2^{bc}	398 ± 1.1^{d}
	MH 539	3.4 ± 0.01^{a}	1.3 ± 0.02^{a}	81 ± 1.2^{a}	159 ± 1.0^{d}	11.7 ± 0.4^{de}	382 ± 1.6^{b}
	MH 560	3.4 ± 0.15^{a}	1.4 ± 0.04^{ab}	105 ± 0.9^{d}	150 ± 1.4^{c}	11.8 ± 0.5^{e}	414 ± 1.1^{f}
	MH 564	3.8 ± 0.13^{bc}	1.5 ± 0.13^{cd}	94 ± 2.3^{c}	157 ± 2.3^{d}	8.8 ± 0.3^{a}	394 ± 1.6^{d}

Values (mg/100g dry matter) are expressed as Mean ± Standard Deviation (n=3);
Means in the same column with the different superscripts are significantly different at $P < 0.05$

the total ash content; this is due to the fact that the minerals are determined as elements and the ash contains their salts. Ash may also contain salts of which the elements were not determined.

MH 125 had the highest content of iron, calcium, magnesium and sodium and might thus be of nutritional interest. In addition, MH 421 had the highest zinc content and considerable amounts of iron, calcium and magnesium. The presence of large amounts of particular minerals can influence the absorption of others. Competition can take place, i.e. a higher amount of calcium and magnesium compared to iron and zinc may reduce their accessibility, but may also be favourable when such major minerals occupy binding sites on mineral chelating compounds such as phytic acid and polyphenols. All varieties contained considerable amounts of magnesium, and higher amounts of iron and zinc than found in wheat and rice (Srikumar, 1993). Therefore, mung bean may contribute to mineral intake when eaten with cereals, particularly products of refined cereal flour. However, the favourable mineral content of mung beans does not necessarily result in high dietary mineral intake. Optimum food processing methods are essential to avoid losses and enhance the accessibility of minerals for adequate intake.

3.3 Phytic acid and polyphenols

Phytic acid and polyphenol contents are presented in Table 4. Phosphorus in mung bean is mainly stored in the form of phytic acid. The phytic acid content of the tested varieties was within the range reported elsewhere (Jood et al., 1998; Kataria et al., 1989) . However, some authors reported considerably lower phytate contents, i.e. 236 mg/100g (Lestienne et al., 2005) and 201.3 mg/100g (Philip and Prema, 1998) . The differences from previous studies could be due to the method of analysis. Lestienne et al. (2005), for instance, determined phytate in mung bean by the estimation of the myo-inositol hexaphosphate content obtained by anion exchange HPLC separation, which is a more specific method for inositol-hexa-phosphate than the method used by us, which determines all inositol phosphates. However, much higher phytic acid contents (1020 - 1480 mg/100g) have also been reported in mung bean (Chitra et al., 1995). Phytic acid molecules are negatively charged at physiological pH and bind with divalent ions making them unavailable for absorption. Nutritionally there is no significant variation in the phytic acid as its amount is sufficient to bind the minerals to form indigestible complexes.

Among the selected mung bean varieties, polyphenol contents were highest in MH 318 and lowest in MH 125. The polyphenol concentrations in the tested varieties are within the normal range published elsewhere (Jood et al., 1998; Kataria et al., 1989). This range (270.5 - 353.0 mg/100g) is genetically determined (Dicko et al., 2002). Polyphenols are mainly present in the seed coat (Barroga et al., 1985); they are present in higher amounts in coloured or darker legume varieties (Salunkhe et al., 1982). The newly bred varieties tested still contain considerable polyphenol concentrations, and as such they do not represent an improvement compared to the established varieties. Polyphenols in mung bean are considered as anti-nutrient compounds with respect to mineral accessibility, but may also have positive health benefits (Randhir et al., 2004).

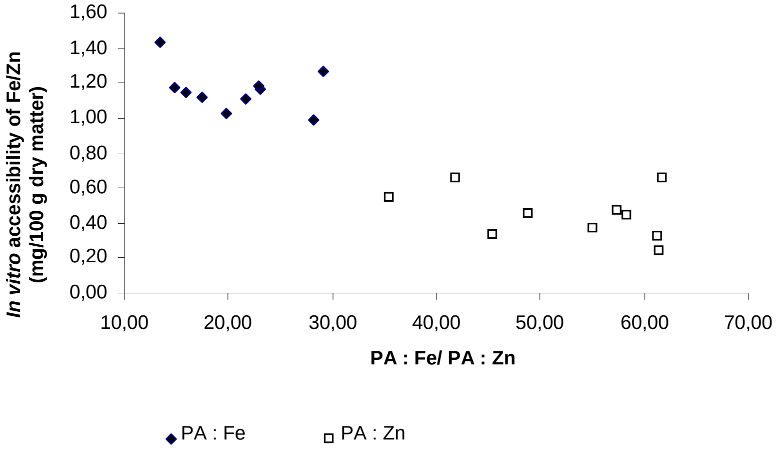
Phytic acid to mineral molar ratios (Table 4) is used as an indicator for the bioaccessibility of minerals. The average PA : Fe and PA : Zn of the varieties are 16.8 and 52.7 respectively. This is much higher than the values of 2.8 and 8.2 respectively, as reported by Lestienne et al. (2005). The PA : Fe molar ratio in mung bean is lower than in cereals like maize (34.4), sorghum (22.8) (Lestienne et al., 2005) and rice (49.5) (Liang et al., 2007), but higher than in soya bean (10.1) (Lestienne et al., 2005). The PA : Zn ratio in mung bean is lower than in sorghum (62.8) (Lestienne et al., 2005), but higher than in rice (42.0) (Liang et al., 2007) and maize (40.6) (Lestienne et al., 2005).

Table 4. Phytic acid (PA), polyphenols & molar ratios of phytic acid to minerals of newly bred and established mung bean varieties

Mung bean varieties		Phytic Acid (mg/100g)	Polyphenols (mg/100g)	PA : Fe Molar Ratio	PA : Zn Molar Ratio	PA : Ca Molar Ratio	PA : Mg Molar Ratio
Established varieties	Asha	$748 + 4.6^{abc}$	$353.0 + 3.5^{de}$	16 ± 0.3	62 ± 1.5	0.44 ± 0.01	0.17 ± 0.002
	Muskan	734 ± 11.0^{ab}	317.2 ± 4.2^{c}	17 ± 0.8	46 ± 1.6	0.46 ± 0.01	0.20 ± 0.005
	Satya	765 ± 7.5^{cd}	272.7 ± 3.5^{a}	17 ± 0.5	58 ± 2.1	0.49 ± 0.01	0.21 ± 0.005
Newly bred varieties	MH 124	789 ± 12.2^{de}	325.2 ± 3.2^{c}	17 ± 0.3	58 ± 2.1	0.50 ± 0.02	0.18 ± 0.003
	MH 125	726 ± 6.8^{a}	270.5 ± 5.0^{a}	14 ± 0.3	42 ± 3.4	0.39 ± 0.00	0.16 ± 0.002
	MH 318	807 ± 8.5^{e}	363.9 ± 5.4^{e}	16 ± 0.5	55 ± 2.0	0.55 ± 0.01	0.19 ± 0.003
	MH 421	765 ± 9.5^{cd}	293.4 ± 5.0^{b}	15 ± 0.4	35 ± 0.5	0.45 ± 0.01	0.19 ± 0.003
	MH 539	786 ± 11.5^{de}	352.7 ± 5.5^{ade}	20 ± 0.3	61 ± 1.3	0.60 ± 0.01	0.18 ± 0.003
	MH 560	806 ± 9.3^{e}	345.9 ± 2.1^{d}	20 ± 0.9	62 ± 2.0	0.47 ± 0.01	0.20 ± 0.003
	MH 564	760 ± 4.6^{bc}	347.2 ± 3.0^{d}	17 ± 0.6	49 ± 4.3	0.49 ± 0.01	0.18 ± 0.003

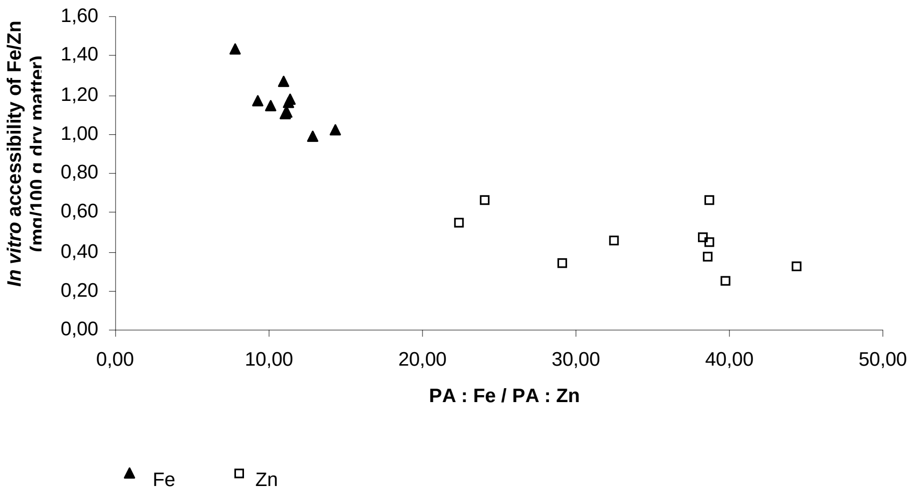
Values are expressed as Mean ± Standard Deviation (n=3) on dry matter basis
Means in the same column with the different superscripts are significantly different at $P < 0.05$

Critical values of molar ratios of phytic acid to a mineral for adequate mineral absorption have been reported as < 0.24 for phytate/calcium (Morris and Ellis, 1980), < 1 for phytate/iron (Hallberg et al., 1989), < 10 for phytate/zinc (Morris and Ellis, 1980) and < 3.5 for phytate x calcium/ zinc (Fordyce et al., 1987). High PA : Zn and PA : Fe ratios indicate poor iron and zinc accessibility. These ratios vary among mung bean varieties, showing that varieties with lower phytic acid to mineral ratios have comparatively higher mineral accessibility. The values of PA : Ca are much lower than PA : Fe and PA : Zn due to the presence of higher amounts of calcium in the mung bean varieties. In the selected varieties it seems that *in vitro* iron and zinc accessibility was not affected by PA : Fe and PA : Zn (Fig. 1) in the tested range. The divalent calcium cation, because of its higher concentration and stronger affinity for phytate, may exert a sparing action for iron and zinc by forming phytate - calcium complexes. However, when assuming that all calcium would be complexed with PA, there would still remain enough phytic acid to make insoluble complexes with iron and zinc. Figure 2 shows that *in vitro* iron and zinc accessibility did not improve as a function of PA : Fe (9.3 -12.9) and PA : Zn (22.7 - 39.8) ratios calculated with amounts of phytic acid left after binding with all calcium. This suggests that the molar ratios PA:Fe and PA:Zn were still too high to allow a better accessibility of Fe and Zn. Figure 3 shows that PA : Ca is one of the possible factors affecting the *in vitro* calcium accessibility. Calcium can also form calcium - zinc - phytate complexes, which have a lower solubility product than phytic acid - zinc or phytic acid - calcium complexes (Fordyce et al., 1987). The magnesium content in the varieties is even higher than of calcium, which indicates possibilities of formation of magnesium - phytate complexes and thus making phytate unavailable for iron and zinc. But, as indicated in Figure 4, it seems that the concentration of magnesium is not determining iron and zinc accessibility, which is also supported by the *in vivo* studies that suggested that the concentration of magnesium does not have a significant impact on zinc bioavailability as compared to the concentration of calcium (Forbes et al., 1984). None of the phytic acid to mineral ratios could explain the lower mineral accessibility and thus predict mineral bioavailability.



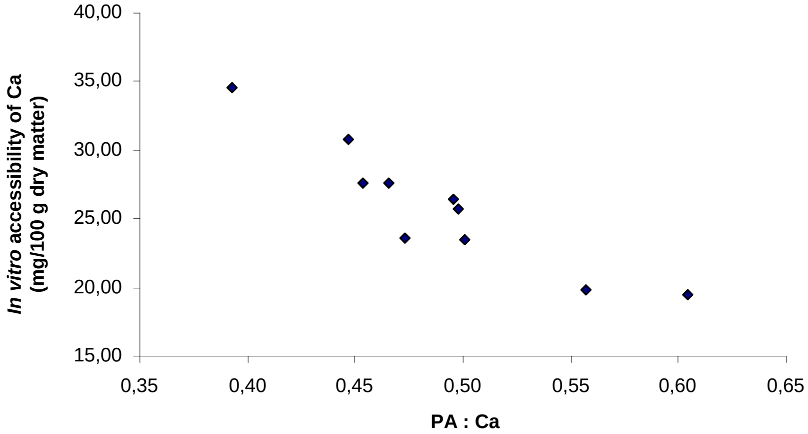
PA : phytic acid, Fe : iron, Zn : zinc

Figure 1. *In vitro* accessibility of Fe and Zn as affected by PA : Fe and PA : Zn molar ratios, respectively



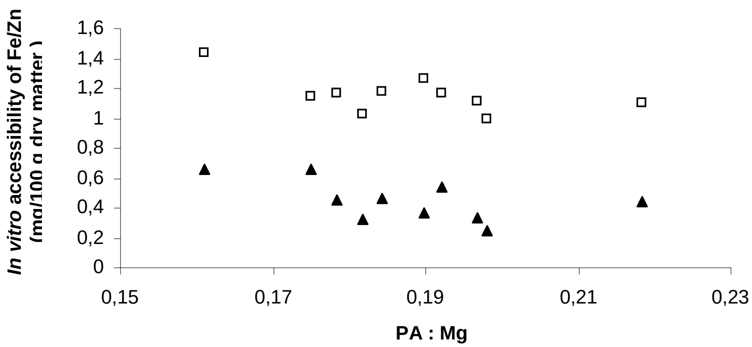
PA : phytic acid, Fe : iron, Zn : zinc

Figure 2. *In vitro* accessibility of Fe and Zn as affected by PA : Fe and PA: Zn molar ratios respectively (as calculated by phytic acid available after binding with all calcium present)



PA : phytic acid, Ca : calcium

Figure 3. *In vitro* calcium accessibility as affected by PA : Ca molar ratio



PA : phytic acid, Fe : iron, Zn : zinc, Mg : magnesium

▲ Zn □ Fe

Figure 4. *In vitro* accessibility of Fe and Zn as affected by PA : Mg molar ratio

This may be because the phytate concentrations were excessively high and also because mineral ratios depend on other factors like pH, temperature, ionic strength and presence of other mineral ions. In terms of improvement in varieties through breeding techniques, MH 125 seems to be improved nutritionally as it had the lowest phytate to mineral ratios, which indicate higher mineral bioavailability. However, agronomically there is no significant improvement due to its lower yield as compared to MH 560 and MH 564.

3.4 *In vitro* nutrient digestion and mineral accessibility

In vitro protein digestibility of varieties showed significant diversity ranging from 53.1 g/100g dry weight in MH 560 to 67.1 g/100g dry weight in MH 125 (Table 5). The remaining protein may be indigestible due to the presence of trypsin inhibitors and hemaglutinins in mung bean, which has been reported as the main reason for lower protein digestibility in legumes (Mubarak, 2005). Negative correlations between phytic acid and *in vitro* protein digestibility were found (R^2 = - 0.85) as shown in Figure 5. Thus, the presence of different amounts of phytic acid in these varieties might also have caused the variation in *in vitro* protein digestibility, as phytic acid - mineral complexes bind with peptides to form insoluble phytic acid - mineral - peptide complexes (Bhatia and Khetarpaul, 2009). Protein digestibility in mung bean has been reported to be lower than that of lentils (Singh and Jood, 2009).

In vitro starch digestibility was found to be lowest (19.6 mg maltose released/g) in MH 560 and highest (28.6 mg maltose released/g) in MH 125 (Table 5). The results of the present study are consistent with that of earlier studies (Grewal and Jood, 2009; Jood et al., 1998). Except for MH 125, all high yielding newly bred varieties showed considerably lower starch digestibility than the established varieties. There was a negative correlation of *in vitro* starch digestibility with phytic acid (R^2 = - 0.83) and polyphenols (R^2 = - 0.47) as shown in Figure 5. This difference in starch digestibility among varieties may be due to differences in amounts of anti-nutrient factors like phytic acid (Yoon et al., 1983) and polyphenols (Farias et al., 2007) due to their inhibition of amylase. The native starch is present in granules, which are only affected by hydrolytic enzymes if damaged; further processing such as heating may cause gelatinization, and this will increase susceptibility to enzymatic activity. Other food processing methods such as grinding, hydration

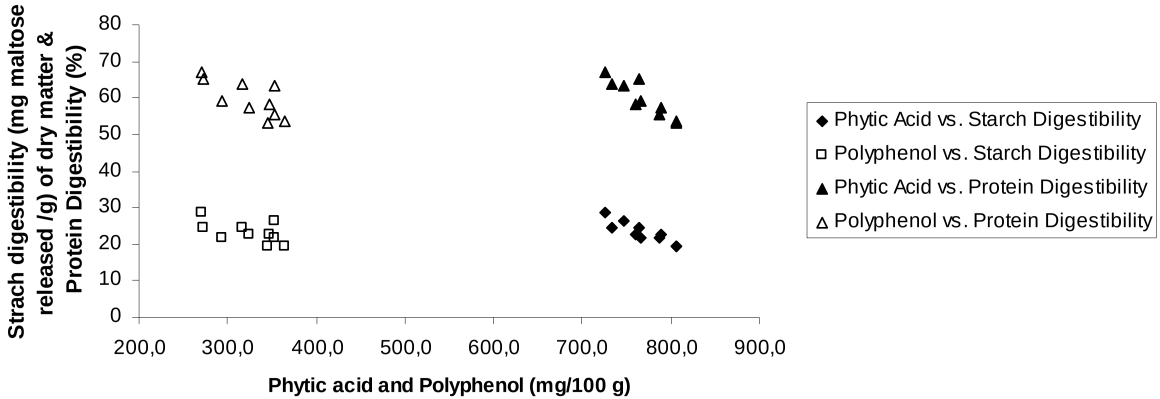


Figure 5. *In vitro* protein and starch digestibility as a function of phytic acid and polyphenol

Table 5. *In vitro* nutrient digestibility and mineral accessibility of newly bred and established mung bean varieties

Mung bean varieties		*In vitro* protein digestibility (g/100g dw)	*In vitro* starch digestibility (mg maltose released/ g)	*In vitro* iron accessibility		*In vitro* zinc accessibility		*In vitro* calcium accessibility	
				mg/100g food	g/100g iron	mg/100g food	g/100g zinc	mg/100g food	g/100g calcium
Established varieties	Asha	63 ± 0.3^{e}	26.5 ± 0.23^{d}	1.15 ± 0.03^{ab}	28.9	0.65 ± 0.02^{e}	29.1	30.8 ± 0.29^{e}	29.5
	Muskan	$63. \pm 0.7^{e}$	24.4 ± 0.39^{c}	1.12 ± 0.08^{ab}	31.4	0.33 ± 0.03^{b}	23.1	27.6 ± 0.45^{d}	28.3
	Satya	65 ± 0.6^{ef}	24.6 ± 0.54^{c}	1.10 ± 0.02^{ab}	28.5	0.44 ± 0.01^{c}	23.0	26.5 ± 0.09^{cd}	27.8
Newly bred varieties	MH 124	58 ± 0.3^{cd}	22.5 ± 0.26^{b}	1.19 ± 0.14^{abc}	30.2	0.47 ± 0.03^{c}	25.0	23.5 ± 0.4^{b}	24.4
	MH 125	67 ± 0.2^{f}	28.6 ± 0.15^{e}	1.40 ± 0.12^{c}	31.4	0.66 ± 0.02^{e}	28.1	34.6 ± 0.34^{e}	30.5
	MH 318	54 ± 0.7^{ab}	19.6 ± 0.57^{a}	1.27 ± 0.04^{bc}	29.1	0.37 ± 0.01^{b}	23.3	19.9 ± 0.19^{a}	22.2
	MH 421	59 ± 0.5^{d}	21.8 ± 0.49^{b}	1.17 ± 0.15^{ab}	26.7	0.54 ± 0.01^{d}	26.2	27.6 ± 0.33^{d}	26.2
	MH 539	56 ± 1.1^{bc}	21.6 ± 0.26^{b}	1.02 ± 0.01^{a}	30.5	0.32 ± 0.01^{b}	26.1	19.5 ± 0.95^{a}	24.5
	MH 560	53 ± 1.1^{a}	19.6 ± 0.72^{a}	0.99 ± 0.08^{a}	29.0	0.24 ± 0.01^{a}	20.3	23.6 ± 0.06^{b}	22.4
	MH 564	58 ± 0.4^{d}	22.5 ± 0.26^{b}	1.16 ± 0.03^{ab}	30.8	0.45 ± 0.02^{c}	25.1	25.7 ± 0.22^{c}	27.5

Values are expressed as Mean + Standard Deviation (n=3) on dry matter basis
Means in the same column with the different superscripts are significantly different at $P < 0.05$

and disruption of the native granule starch structure have also been found to increase starch digestibility (Bhama and Sadana, 2004).

In vitro mineral accessibility can be a global index of *in vivo* mineral bioavailability. Mung bean (100 g) should cover 12 - 16 % of iron, 8 - 14 % of zinc and 20 - 29 % of calcium according to the recommended daily intake (RDI) based on the total amount of these minerals. However, due to the lower bioavailability it only covers 3.5 - 5.1 % of iron, 1.6 - 4.4 % of zinc and 4.9 - 8.6 % of calcium of the RDI. Mung bean varieties like MH 318, with a high amount of phytic acid, were found to have the lowest amounts of accessible minerals. The values of the present study support those of Jood *et al.* (1998) in mung bean cultivars. Significant negative correlations of phytic acid and polyphenol were found with *in vitro* mineral accessibility. The differences in mineral accessibility among varieties may be related to their contents of anti-nutrients such as phytic acid, polyphenols as well as dietary fibre; and to their contents of respective minerals, iron, zinc and calcium. As mung beans do not contain any mineral uptake enhancer such as vitamin C, the effects of the anti-nutrients mentioned earlier need to be minimised to achieve a better mineral bioavailability. A possible way to achieve this is by dephytinization. Wet processing such as fermentation and germination was shown to contribute to dephytinization (Hemalatha et al., 2007; Lotika and Bains, 2007; Nout, 2009). Dehulling and cooking can reduce the polyphenol concentrations, thereby increasing the nutritional value of the grain (Madhuri et al., 1996). This also suggests that mung bean products obtained through fermentation, germination and soaking may achieve higher levels of mineral bioavailability.

4. Conclusion and recommendations

Farmers are predominantly interested in the agronomic characteristics of their mung bean varieties as this result in higher yields and revenues. However, agricultural extension services should also pay attention to nutritional characteristics of the mung bean varieties.

We recommend that plant breeders should focus on a combination of crop yield, with nutritional value and consumer preference traits. A low phytic acid content may be a desired property from a nutritional point of view, but it may hamper the growth of the plants when too low (Coelho et al., 2002). Thus, phytic acid contents need to be reduced by appropriate breeding techniques without compromising seed germination (Bohn et al., 2008), or by processing methods such as fermentation. Another target for plant breeding is to improve the mineral content to enhance micronutrient availability. It should be realized that the investigated cultivars were grown under identical conditions on the same plot and during the same season, so the data presented could only be seen as comparative and not absolute, in the absence of performance data in different locations or seasons. However, from this study we conclude that although the newly bred varieties hold promise for better agronomic yields, their nutritional potential is not better than that of established varieties.

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Chapter 5

Nutritional characteristics of mung bean foods

Abstract

Malnourishment in developing counties can be addressed by a food-based approach in which locally produced and consumed foods are improved by applying food processing techniques that benefit the amount and availability of desirable nutrients. To facilitate this approach, this paper reports on the composition and *in vitro* micronutrient accessibility of fourteen traditional mung bean foods from India in relation to their preparation methods. Proximate composition, *in vitro* mineral accessibility, phytic acid and polyphenol contents varied among the range of products. Products requiring either fermentation or germination, had higher *in vitro* iron, zinc and calcium accessibility. Average *in vitro* iron, zinc and calcium accessibility of the mung bean products were 16, 9 and 418 mg kg^{-1} dry weight. Phytic acid and polyphenols averaged 2.1 and 1.8 g kg^{-1} dry weight, respectively, and tended to be negatively correlated with *in vitro* mineral accessibility. Different mung bean products (100 g) cover 12.0 - 59.5 %, 5.2 - 45.6 %, 4.2 - 28.6 % and 1.1 - 7.1 % of the Recommended Dietary Allowance for protein, iron, zinc and calcium, respectively, for 7-9 year old Indian children. The wide range is indicative for differences due to food type and preparation method.

Keywords: *In vitro* mineral accessibility, iron, zinc, calcium, phytate, polyphenols

1. Introduction

Malnutrition is a serious health concern in many developing countries. A major cause is lack of access to nutritious food products. Strategies to tackle malnutrition are fortification of food products and distribution of nutrient supplements, but a food-based approach has the advantage that it is within easy reach, as indigenous foods provide variety, are well-accepted, frequently consumed and readily available.

Among the indigenous foods, mung bean based products are widely consumed in India. Mung bean or green gram (*Vigna radiata* (L.) R. Wilczek) has been cultivated in India since prehistoric times and is believed to be a native crop of India. Its grains have a protein content comparable to that of chick pea (*Cicer arietinum* L.) and contain less anti-nutritional (Chitra et al., 1995) and flatulence causing compounds than soya bean (*Glycine max* (L.) Merr.) (Abdullah et al., 1984). Mung bean is used in India for the preparation of different food products like dhals, sweets, snacks and savoury products. The frequency of consumption of different mung bean products is very high (Grover et al., 2004; Manu and Khetarpaul, 2006), thus offering the possibility for improved products to contribute significantly to the nutritional status of the local people.

Although the nutritional composition of raw mung bean grains of different varieties has been documented (Dahiya et al., 2011), little or no information is available on the proximate, mineral and anti-nutritional composition of the indigenous mung bean food products. Therefore, in the present investigation mung bean food products were analysed to determine the nutritional and anti-nutritional components and their relation with each other. This article is the first to report on the major mung bean foods of north India and on their nutritional potential.

2. Material and methods

2.1 Sampling of mung bean food products

Mung bean food products were collected from rural and urban households or purchased from the market in Hisar district of Haryana state in India. Five samples of approximately 250 g of each product were collected or purchased from the different regions where the foods are known to be representatively processed and consumed. Each sample was collected as ready to eat or ready to cook. In the case of ready to cook products, they were cooked in the laboratory. Food products collected were analysed individually and not with the other products with which they are consumed in a meal. The five samples of food products were then pooled to minimize variation to form one composite food sample. After thorough mixing of the composite sample using a blender for 2 min, three representative portions of each were removed and weighed. The dried samples were ground to fine powder in an electric grinder (Cyclotec M/s Tecator, (Hoganas), Sweden) and passed through a 0.5 mm mesh sieve. Powders were sealed and stored in air-tight plastic containers in a refrigerator at 5º C until analysis (maximum 20 days).

2.2. Analytical methods

2.2.1 Proximate composition

The following AOAC (1990) methods were used to determine proximate composition: drying at 105 ºC for 24 h for moisture (AOAC 925.10), incineration at 550 ºC for ash (AOAC 923.03), defatting in a Soxhlet apparatus using hexane for crude lipids (AOAC 920.39), digestion with NaOH and H_2SO_4 for crude fibre (AOAC 962.09) and the microKjeldahl method for crude protein (AOAC 960.52). For conversion of nitrogen to crude protein, a conversion factor of 6.25 was used. The carbohydrate content was estimated by difference of protein, fibre, ash and fat. Energy was calculated using Atwater energy conversion factors of 4.0, 4.0 and 9.0 kcal g^{-1}, for protein, carbohydrate and fat, respectively, and recalculated to kJ g^{-1}. Proximate composition was determined using dried samples.

2.2.2 Mineral composition

Calcium, iron and zinc contents were determined by first digesting 1 g of sample using 25 ml diacid mixture ($HNO_3/HClO_4$: 5/1, v/v) after which the digested solution was filtered through Whatman no. 42 filter paper. The volume of the solution was made up to 50 ml and then the mineral content was determined by an Atomic Absorption Spectrophotometer 2380, Perkin - Elmer (USA) using the method of Lindsey and Norwell (1969).

2.2.3 *In vitro* mineral accessibility

In vitro iron accessibility was determined by the single enzyme method according to Rao and Prabhavathi (1978). This method is convenient, requires a minimum of chemicals, and is well suited for comparative purposes. Obviously, it does not necessarily predict exactly what will happen *in vivo*, but neither do the more sophisticated *in vitro* approaches. The method involved incubation of 2 g of powdered sample with 25 ml of 5 g L^{-1} pepsin in 0.1 N HCl solution in a water bath of 37 ºC for 90 min, after adjusting the pH to 1.3 using HCl. The mixture was then centrifuged at 3,000 rpm for 45 min and the supernatant was filtered through Whatman no. 44 filter paper. Iron in the filtrate was determined according to the AOAC (1995) method by treating with 1 ml hydroxylamine hydrochloride solution and 5 ml acetate buffer solution and then reacted with α, α′ dipyridyl to yield a colour which was read at 510 nm and used to make a calibration line for calculating the *in vitro* iron accessibility.

In vitro zinc and calcium accessibility were assessed with the multiple enzyme method of Kim and Zemel (1986). The method involved hydration of 2 g sample with 3 ml distilled water. Hydrated samples were then treated with 20 ml pepsin solution (1 g L^{-1} pepsin in 0.1 N HCl). Next the pH was adjusted to 1.5, followed by incubation at 37 ºC for 1 h in a controlled temperature chamber with shaker. After incubation the pH was raised to 6.8 with NaOH and 2.5 ml of a suspension containing 5 g L^{-1} pancreatin and 50 g L^{-1} bile was added and again incubated for 1 h at 37 ºC in a controlled temperature chamber with shaker. Next, the volume was increased to 50 ml with distilled water and immediately centrifuged at 3,000 rpm for 45 min at 5 ºC. Supernatants were removed and again centrifuged at 13,000 rpm for 45 min at 5 ºC. The supernatant was digested with diacid mixture (HNO_3/$HClO_4$: 5/1, v/v) and then dissolved calcium and zinc were determined by an Atomic Absorption Spectrophotometer 2380, Perkin-Elmer (USA) using the method of Lindsey and Norwell (1969).

2.2.4 Phytic acid and polyphenol content

Phytic acid (PA) was estimated colorimetrically by the method of Davies and Reid (1979), by incubating 500 mg of sample with 20 ml of 0.5 M HNO_3 for 3 h with continuous shaking. The suspension was then filtered through Whatman no. 1 filter paper. One ml of this suspension was made up to 1.4 ml using distilled water and then mixed with 1 ml ferric ammonium sulphate solution containing 50 μg of Fe. The test tube containing this suspension was placed in boiling water for 20 min. Next, the suspension was cooled to room temperature and 5 ml iso-amyl alcohol was added followed by 0.1 ml ammonium thiocyanate solution (100 g L^{-1}). The content was mixed well, and centrifuged at 3,000 rpm for 10 min. Colour intensity in alcohol was read at 465 nm using a spectrophotometer and used to make a calibration line for calculating the phytic acid.

Total polyphenols were extracted from 500 mg of defatted sample by refluxing with 50 ml methanol containing 10 g L^{-1} HCl for 4 h. The extract was concentrated by evaporating methanol on a boiling water bath and brought to 25 ml with methanol-HCl solution (Singh and Jambunathan, 1981). Half a millilitre of extract was made up to 8.5 ml with distilled water, mixed with 0.5 ml Folin Denis reagent and shaken. After 3 min, 1 ml of saturated sodium carbonate was added, followed by shaking. After an hour, the absorbance was read at 725 nm. Calculations were done using absorbance and expressed as tannic acid equivalent (Swain and Hills, 1956). The PA : Zn, PA : Ca and PA : Fe molar ratios were calculated by the method of Jane Wyatt and Triana-Tejas (1994).

Pepsin, pancreatin, pancreatic amylase and bile were obtained from Sigma-Aldrich Co. USA. All other reagents used for the analyses were of analytical grade and glassware was acid (10 g L^{-1} HCl) washed.

2.2.5 Statistical analysis

Each composite sample of mung bean product was analysed in triplicate. Mean ± standard deviation values were calculated. Pearson linear correlation coefficients were determined to relate the nutrient digestibility and accessibility with concentrations of anti-nutritional factors. Statistical analyses were performed with PASW Statistics (Version 18.0.2) IBM Co. USA.

3. Results and discussion

3.1 Description of the products

Table 1 presents a brief description of the mung bean products and their major ingredients. They were classified into four groups, namely *dhals*, sweets, snacks and others. *Dhals* are spiced curries of whole or split legumes, with thick soup-like consistency, commonly consumed with cereal products like rice and chapattis (Indian flat bread). Sweets include three types of products like *laddu*, *burfi* and *halwa*, prepared with ghee (clarified butter oil) and sugar along with dehulled split mung bean by shallow frying the mung bean flour or paste. Snacks are salted or spiced products like *namkeen*, *papad*, *bhalle* and *pakore*. *Namkeen* are deep fried spiced dehulled split mung bean grains. *Papad* is a spiced flat roasted product of dehulled split mung bean. *Bhalle* are round balls of deep fried dehulled fermented mung bean paste. *Wadian*, sprouts and *khichadi* products each have distinctive characteristics and thus were combined as a category of other products. *Wadian* are irregular shaped sun-dried dumplings of fermented dehulled mung bean paste, which are cooked with spices. Sprouts are germinated mung bean grains eaten as such or fried to be used in salads. *Khichadi* is prepared by cooking split mung beans with white rice.

Table 1 Mung bean derived foods and summary of their preparation

Food type	Product	Main ingredients	Unit operations involved
Dhals	*Whole dhal*	Whole mung bean, red chili powder, salt, cumin seeds, vegetable oil, turmeric powder, garam masala, tomato, onion, coriander leaves garlic and water	Soaking and pressure/open cooking
	Split dhal	Same as whole dhal but with split mung beans instead of whole mung bean	Soaking and pressure/open cooking
	Dehulled split dhal	Same as whole dhal but with dehulled split mung beans instead of whole mung bean	Soaking and pressure/open cooking
Sweets	*Whole laddu*	Whole mung bean, sugar and ghee	Crushing and roasting
	Dehulled split laddu	Dehulled split mung bean flour, powdered sugar, ghee and nuts	Milling, flour roasting
	Burfi	Dehulled split mung bean, crystalline sugar, water, ghee and nuts	Soaking, paste making, cooking and frying
	Halwa	Dehulled split mung bean, sugar syrup, water, ghee and nuts	Soaking, paste making, cooking and frying
Snacks	*Namkeen*	Dehulled split mung bean, vegetable oil, water and salt	Soaking and deep frying
	Papad	Dehulled split mung bean flour, salt, black pepper, cumin seeds, asafoetida*, water and $NaHCO_3$	Milling, dough making, drying, sheeting and roasting
	Bhalle	Dehulled split mung bean, cumin seeds, salt, water and vegetable oil	Fermentation, soaking and deep frying
	Pakore	Dehulled split mung bean, salt and red chili powder, garam masala, mango powder, coriander seed powder, water and vegetable oil	Fermentation, soaking and deep frying
Others	*Wadian*	Dehulled split mung bean, asafoetida*, water and salt	Soaking, fermentation, drying and pressure/open cooking
	Khichadi	White rice and split mung bean, rice, ghee, water and salt	Soaking and open cooking
	Sprouts	Whole mung bean and water	Soaking and germination

*A dried latex (gum oleoresin) exuded from the living underground rhizome or tap root *Ferula foetida.*

Table 2 Proximate composition of mung bean derived foods

Food type	Mung bean food product	Moisture ($g\ kg^{-1}$)	Crude protein ($g\ kg^{-1}$)	Crude fat ($g\ kg^{-1}$)	Crude fibre ($g\ kg^{-1}$)	Ash ($g\ kg^{-1}$)	Carbohydrate* ($g\ kg^{-1}$)	Energy** ($kJ\ kg^{-1}$)
Dhals	*Whole dhal*	737 ± 21	236 ± 5	48 ± 7	20.7 ± 1.2	37 ± 0.4	659 ± 10	16780 ± 132
	Split dhal	827 ± 34	206 ± 2	54 ± 4	13.8 ± 1.0	36 ± 2.2	690 ± 4	17030 ± 53
	Dehulled split dhal	590 ± 18	207 ± 2	96 ± 5	8.5 ± 0.5	42 ± 4.3	647 ± 9	17890 ± 80
Sweets	*Whole laddu*	137 ± 7	111 ± 6	180 ± 5	21.0 ± 1.0	15 ± 0.3	673 ± 8	19900 ± 107
	Dehulled split laddu	120 ± 11	123 ± 5	142 ± 5	7.7 ± 0.6	11 ± 0.6	717 ± 9	19390 ± 98
	Burfi	72 ± 3	154 ± 2	276 ± 10	14.0 ± 1.0	13 ± 0.4	543 ± 11	22070 ± 228
	Halwa	64 ± 5	188 ± 4	348 ± 4	12.9 ± 0.6	21 ± 1.0	431 ± 2	23450 ± 100
Snacks	*Namkeen*	211 ± 8	193 ± 3	190 ± 4	12.8 ± 0.7	18 ± 0.4	586 ± 3	20190 ± 76
	Papad	168 ± 7	168 ± 1	40 ± 9	12.3 ± 0.6	79 ± 0.4	701 ± 8	16060 ± 170
	Bhalle	718 ± 35	176 ± 2	95 ± 5	5.4 ± 1.0	57 ± 0.6	667 ± 2	17670 ± 12
	Pakore	467 ± 16	196 ± 2	173 ± 14	6.5 ± 0.5	39 ± 4.4	586 ± 20	19600 ± 234
Others	*Wadian*	693 ± 28	162 ± 3	32 ± 10	11.4 ± 1.2	15 ± 0.2	779 ± 15	16960 ± 200
	Khichadi	751 ± 7	165 ± 3	13 ± 2	6.7 ± 0.6	32 ± 0.4	783 ± 3	16370 ± 46
	Sprouts	546 ± 16	170 ± 5	02 ± 2	19.0 ± 1.0	43 ± 2.3	766 ± 6	15740 ± 6

Note: values ($g\ kg^{-1}$) are expressed as mean ± standard deviation (n=3) on dry matter basis (except for moisture)
* Calculated by difference from protein, fat, ash, fibre and dry matter
** Energy = (fat (g) x 9.0 + protein (g) x 4.0 + carbohydrate (g) x 4.0) x 4.18

3.2 Proximate composition

The composition of the mung bean foods is presented in Table 2. Among the mung bean products, moisture content varied considerably. The highest moisture content was found in *dhals*, *bhalle*, *wadian* and *khichadi*. The soup-like consistency of *dhals* and the soaking before *bhalle* consumption explain their relatively high moisture content. Sweets like whole *laddu*, dehulled split *laddu* and *halwa* contained less moisture with the least moisture in *burfi*, that has high amounts of fat due to the addition of ghee. *Halwa* contained most fat followed by *burfi*. Among the snacks, *namkeen* and *pakore* had fat contents comparable to that of sweets like whole *laddu* and dehulled split *laddu*; this can be explained as *namkeen* and *pakore* are deep fried, resulting in oil absorption, whereas both types of *laddu* contain ghee as an ingredient. *Dhals*, *papad*, *bhalle* and *wadian* are low in crude fat with the lowest content in sprouts and *khichadi*. The relatively low fat content of *dhals* can be attributed to the use of only small amounts of oil to sauté spices and condiments as well as to the absence of frying as a processing method. *Bhalle* contains less fat than *pakore*, despite the fact that both are fried products; *bhalle* is soaked in water for 2 - 6 hours before consumption which might expel some fat from the product. *Wadian* and *papad* are not fried and also do not contain a lot of fat as an ingredient, which explains why their fat content is lower than that of the sweets.

Dhals contain slightly more crude protein than other products, with the lowest amounts in whole *laddu* and dehulled split *laddu*. Crude protein contents of the products ranged from 111 to 236 g kg^{-1} dry weight. Crude protein content of snacks were very similar to those of *wadian*, *khichadi* and sprouts. It seems that processing methods had no effect on the crude protein content.

Crude fibre was highest in whole *dhal*, whole *laddu* and sprouts, which are made primarily of whole mung bean grains, whereas *bhalle*, *pakore*, *khichadi*, dehulled split *laddu* and dehulled split *dhal* had lower crude fibre contents. The latter products are made of dehulled split mung beans in which the majority of the fibre is removed as husk.

The ash content of mung bean products containing hull, like whole *dhal*, split *dhal* and sprouts, was higher than in sweets made of dehulled split mung beans. *Papad* had the highest ash content although it is made from dehulled split mung beans; this may be caused by the use of black pepper as an ingredient, as it contains a considerable amount of ash (40-50 g kg^{-1}) (Parthasarathy et al., 2008). Moreover, use of asafoetida (a dried latex, gum oleoresin, exuded from the living underground rhizome or tap root *Ferula foetida*) may also have contributed to the relatively high ash content of *papad* as asafoetida contains 50 g kg^{-1} of ash (Pradeep et al., 1993). *Khichadi* contained a considerable amount of ash; here the main contribution is due to the rice and not to the dehulled split mung bean. Fatty products like sweets, *namkeen* and *pakore*, contained slightly less carbohydrate than the other products. Fatty products like *burfi*, *halwa*, *laddu* and *namkeen* provide the highest amounts of calories compared to products like *papad*, *wadian*, *khichadi* and sprouts, that are non-fried nod non-fatty products.

3.3 Mineral composition

Table 3 presents iron, zinc and calcium in the different mung bean foods. The highest mineral concentrations were found for calcium, while iron and zinc were present in lower amounts. There are differences between the mineral levels of the mung bean product composites. The variation in mineral content in products may have several reasons, like the use of whole, split or dehulled split mung bean, or the type of processing, like soaking, which results in loss of minerals. *Dhals* had higher mineral contents than *halwa*, *laddu* and *burfi*, due to the use of various spices, condiments, tomato and onion as ingredients. *Bhalle* had the highest iron content followed by *dhals*; the contents are comparable to previous studies (Pushpanjali and Khokhar, 1995). Less iron and zinc is present in *papad* despite it having the highest ash content. This may be due to the fact that the minerals are determined as elements and the ash contains their salts. Moreover, ash may also contain other elements like sodium and magnesium, which were not determined. Products involving germination, dehulling and fermentation as unit operations, like sprouts, *bhalle*, and *dhals*, had higher iron contents. Calcium contents were higher in dehulled split *dhal*, dehulled split *laddu*, *papad* and *khichadi*.

Table 3 Mineral composition of mung bean derived foods

Food type	Mung bean food product composite samples	Iron (mg kg^{-1})	Zinc (mg kg^{-1})	Calcium (mg kg^{-1})
Dhals	*Whole dhal*	71 ± 0.8	26 ± 0.2	1553 ± 8
	Split dhal	65 ± 0.1	24 ± 4.6	1145 ± 8
	Dehulled split dhal	67 ± 0.1	30 ± 3.2	1953 ± 5
Sweets	*Whole laddu*	53 ± 0.1	27 ± 3.4	1445 ± 5
	Dehulled split laddu	32 ± 2.0	26 ± 1.1	1653 ± 15
	Burfi	32 ± 0.7	21 ± 0.5	1238 ± 18
	Halwa	39 ± 0.5	39 ± 1.3	1298 ± 14
Snacks	*Namkeen*	33 ± 2.7	22 ± 1.6	1141 ± 47
	Papad	26 ± 0.3	19 ± 1.9	1655 ± 10
	Bhalle	79 ± 0.2	31 ± 3.0	1433 ± 10
	Pakore	62 ± 0.6	29 ± 0.1	1093 ± 13
Others	*Wadian*	35 ± 0.5	17 ± 1.2	1398 ± 15
	Khichadi	27 ± 2.5	22 ± 0.3	1705 ± 13
	Sprouts	61 ± 0.4	24 ± 3.5	1355 ± 10

Note: values (mg kg^{-1} dry matter) are expressed as mean ± standard deviation (n=3);

3.4 Phytic acid and polyphenols

Phytic acid and polyphenol contents of mung bean product composites are presented in Table 4. Phytic acid content varied considerably among the various mung bean product composites. There are two distinct categories of mung bean foods in terms of phytic acid content. One category includes dehulled split *dhal*, *namkeen*, *papad*, *bhalle*, *pakore*, *wadian* and sprouts, in which phytic acid ranged from 1.40 – 2.25 g kg^{-1}, whereas another category that includes products like whole *dhal*, split *dhal*, whole *laddu*, dehulled split *laddu*, *burfi*, *halwa*, *khichadi*, had phytic acid contents ranging from 3.51 – 4.46 mg kg^{-1} (Figure 1). The amount was lower in snacks than in sweets and *dhals* except for dehulled split *dhal*, which contained an amount of phytic acid comparable to that of snacks. Products involving fermentation as a processing step, like *bhalle* and *wadian*, and germination, like sprouts, contained lower amounts of phytic acid than products processed by cooking and soaking. The results seem to indicate that the degrading impact of dehulling, germination and fermentation on the phytic acid content of mung bean product composites results in lower phytic acid contents (Jood et al., 1998). However, as the production of these products involves more than one processing step, it is not clear which processing step has the most degrading impact on the phytic acid. The relatively high phytic acid content of sweets, despite the fact that they are made of dehulled split mung bean, can be attributed to two factors. Firstly, sweets are prepared only with sugar, ghee and dehulled split mung bean, in other words, there is no dilution of phytic acid by the addition of significant amounts of other ingredients that are low in phytic acid. Secondly, sweets also contain nuts, like cashews and almonds, which also contain phytates ranging from 1.5 – 3.5 g kg^{-1} of edible portion (Venkatachalam and Sathe, 2006). In contrast, *dhals* need a lower amount of mung bean to prepare and also involve soaking as a processing step, which is known to have a degrading effect on phytic acid (Sattar et al., 1989). The relatively high amount of phytic acid in *khichadi* could be due to the split mung bean used in its preparation instead of dehulled split mung bean.

Polyphenol was found to be higher in products prepared with whole mung bean grains, like whole and split mung bean *dhal* and whole *laddu*, as compared to sweets and snacks prepared with dehulled split mung bean *dhal*. This can be due to the fact that polyphenols are mainly present in the outer seed coat of the grain, which are removed during dehulling. The polyphenol content of fermented products, like *bhalle* and *wadian*, is lower than that of fried products like *pakore*.

Khichadi contains the lowest amount of polyphenols, which may be due to the fact that only small amounts of mung bean are required for its preparation.

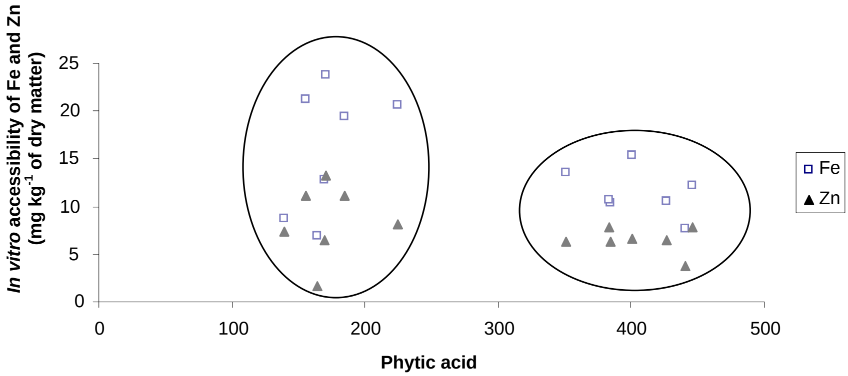

Figure 1 *In vitro* iron and zinc accessibility as a function of phytic acid concentration

Table 4 Phytic acid, polyphenol and molar ratios of phytic acid to minerals of mung bean derived foods

Food type	Mung bean food product composite samples	Phytic acid (mg kg^{-1})	Polyphenol (mg kg^{-1})	PA : Fe Molar ratio	PA : Zn Molar ratio	PA : Ca Molar ratio
Dhals	*Whole dhal*	3510 ± 50	2436 ± 46	4.2 ± 0.08	13.3 ± 0.2	0.13 ± 0.002
	Split dhal	4009 ± 30	2378 ± 27	5.2 ± 0.04	16.7 ± 3.2	0.21 ± 0.002
	Dehulled split dhal	1703 ± 47	1620 ± 68	2.2 ± 0.06	5.6 ± 0.6	0.05 ± 0.001
Sweets	*Whole laddu*	4406 ± 76	2601 ± 40	7.0 ± 0.12	16.0 ± 2.0	0.18 ± 0.003
	Dehulled split laddu	3842 ± 46	1294 ± 60	10.2 ± 0.65	14.9 ± 0.6	0.14 ± 0.002
	Burfi	4264 ± 64	1821 ± 30	11.2 ± 0.31	20.3 ± 0.6	0.21 ± 0.004
	Halwa	4458 ± 173	1720 ± 94	9.7 ± 0.39	11.5 ± 0.6	0.21 ± 0.008
Snacks	*Namkeen*	1646 ± 43	1448 ± 47	4.2 ± 0.36	7.3 ± 0.5	0.09 ± 0.004
	Papad	1395 ± 32	1727 ± 50	4.6 ± 0.12	7.2 ± 0.7	0.05 ± 0.001
	Bhalle	1553 ± 37	1614 ± 35	1.7 ± 0.04	4.9 ± 0.5	0.07 ± 0.001
	Pakore	1850 ± 48	1857 ± 25	2.5 ± 0.07	6.3 ± 0.2	0.10 ± 0.002
Others	*Wadian*	1697 ± 33	1437 ± 35	4.2 ± 0.10	9.9 ± 0.7	0.08 ± 0.001
	Khichadi	3830 ± 56	1337 ± 43	12.1 ± 1.16	17.6 ± 0.4	0.14 ± 0.002
	Sprouts	2249 ± 47	1835 ± 30	3.1 ± 0.07	9.4 ± 1.4	0.10 ± 0.002

Note: values are expressed as Mean ± Standard Deviation (n=3) on dry matter basis

3.5 *In vitro* mineral accessibility

Differences were observed in *in vitro* mineral accessibility of iron, zinc and calcium among product composites (Table 5), which may be related to the presence of anti-nutrients such as phytic acid, polyphenols as well as dietary fibre, and to the contents of minerals themselves. The highest amount of *in vitro* accessible iron was found in dehulled split *dhal* followed by *bhalle* and sprouts, whereas whole *laddu*, *namkeen* and *papad* had the lowest *in vitro* accessible iron. Products involving fermentation and germination and dehulling as processing method have relatively higher *in vitro* accessible iron as compared to fried and fatty products. This may be due to degradation of phytic acid present in the testa of mung bean grains during the fermentation and germination processes (Barakoti and Bains, 2007). As most of the phytic acid is present in the hull of whole mung bean grains, dehulling reduces its amount (Ghavidel and Prakash, 2007), imparting a positive effect on *in vitro* iron accessibility in split dehulled *dhal*. Whole *laddu* and whole *dhal* had the lowest *in vitro* iron accessibility, which may be due to presence of phytic acid in the hull of whole mung bean grain used to prepare these products, which has an inhibitory effect on the *in vitro* iron accessibility. *In vitro* iron accessibility in the mung bean product composites is high in comparison to what is expected for iron absorption in human beings. The results show *in vitro* iron accessibility in the same range as found in different cereals and legume-based foods by previous authors (Rao and Prabhavathi, 1978). Moreover, it is expected that *in vitro* iron accessibility tends to increase at low pH values due to a greater extent of dissociation of the phytic - mineral complex.

Similarly, *in vitro* accessible zinc is highest in dehulled split *dhal* followed by the fermented product *bhalle* and the germinated product, sprouts. Whole mung bean product composites had lower *in vitro* accessible zinc. *In vitro* accessible calcium was highest in dehulled split *dhal* followed by *wadian* and *bhalle*. The relatively high *in vitro* zinc accessibility in dehulled split *dhal* is due to the fact that dehulled grains contain less phytic acid than whole grains and thus have a lower inhibitory effect on bivalent ions like zinc (Ghavidel and Prakash, 2007). *In vitro* accessible calcium in snacks was considerably higher than in sweets and whole mung bean product composites (Crea et al., 2008).

Phytic acid to mineral molar ratios (Table 4) are used as an indicator for the bioaccessibility of divalent mineral ions. The average PA : Fe, PA : Zn and PA : Ca of the mung bean product composites are 5.9, 11.5 and 0.13, respectively. Critical values of molar ratios of phytic acid to a mineral for adequate mineral absorption have been reported as < 0.24 for phytate/calcium (Morris and Ellis, 1980), < 1 for phytate/iron (Hallberg et al., 1989) and < 10 for phytate/zinc (Morris and Ellis, 1980). However, in mung bean product composites phytic acid to mineral molar ratios are quite high, whereas the percentage *in vitro* mineral accessibility is also high, which might be due to the fact that the effect of phytic acid on minerals not only depends on the amount of phytic acid but also on the presence of *in vivo* iron absorption enhancers, like vitamin C, and the processing techniques used. Moreover, it has been reported that the effect of phytic acid on minerals is also governed by the pH (Crea et al., 2008). Mung bean product composites have lower phytic acid to mineral ratios as compared to raw mung bean (Dahiya et al., submitted), indicating the degradation effect of different processing methods on phytic acid.

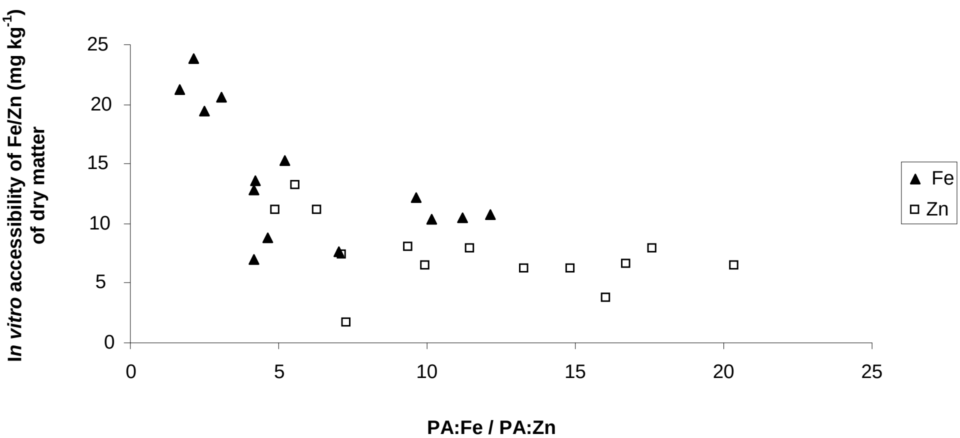

Figure 2 *In vitro* accessibility of Fe and Zn as a function of PA:Fe and PA:Zn molar ratios, respectively

Table 5 *In vitro* mineral accessibility of mung bean derived foods

Food type	Mung bean food product composite samples	*In vitro* iron accessibility		*In vitro* zinc accessibility		*In vitro* calcium accessibility	
		(mg kg^{-1})	(%*)	(mg kg^{-1})	(%*)	(mg kg^{-1})	(%*)
Dhals	*Whole dhal*	13.6 ± 0.5	19.2	6.3 ± 1.0	23.9	315 ± 47	20.3
	Split dhal	15.3 ± 0.2	23.6	6.6 ± 0.8	27.9	388 ± 20	33.9
	Dehulled split dhal	23.8 ± 0.6	35.6	13.2 ± 0.6	43.6	680 ± 16	34.8
Sweets	*Whole laddu*	7.6 ± 0.8	14.4	3.7 + 0.3	13.6	292 ± 52	20.2
	Dehulled split laddu	10.3 ± 0.6	32.3	6.3 ± 0.8	24.5	276 ± 23	16.7
	Burfi	10.5 ± 0.4	32.8	6.5 ± 0.5	31.3	359 ± 12	29.0
	Halwa	12.2 ± 0.1	31.4	7.9 ± 0.6	20.4	345 ± 34	26.6
Snacks	*Namkeen*	7.0 ± 0.5	20.9	1.7 ± 0.7	7.5	431 ± 19	37.8
	Papad	8.8 ± 0.3	34.5	7.3 ± 0.5	38.0	514 ± 59	31.0
	Bhalle	21.3 ± 0.9	26.8	11.1 ± 1.2	35.6	465 ± 47	32.5
	Pakore	19.5 ± 0.9	31.3	11.2 ± 1.0	38.5	380 ± 13	34.7
Others	*Wadian*	12.8 ± 0.6	37.1	6.5 ± 1.0	38.6	501 ± 36	35.9
	Khichadi	10.7 ± 0.4	40.2	7.9 ± 0.9	36.5	292 ± 2	17.1
	Sprouts	20.6 ± 0.4	33.6	8.1 ± 0.7	34.0	354 ± 31	26.1

Note: values are expressed as mean ± standard deviation (n=3) on dry matter basis
*% = % of the content present

The ratios vary considerably among mung bean product composites, showing that products with lower phytic acid to mineral ratios have comparatively higher mineral accessibility. The values of PA : Ca are much lower than PA : Fe and PA : Zn due to the presence of higher amounts of calcium in the mung bean product composites. *In vitro* iron and zinc accessibility seem not to be affected by PA : Fe and PA : Zn in the mung bean product composites (Figure 2), indicating other possible factors like pH, presence of other anti-nutritional components and minerals affecting *in vitro* mineral accessibility. Therefore, in the case of mung bean foods, PA : Fe and PA : Zn cannot be effectively used to predict mineral bioavailability. If it is assumed that calcium binds more with phytic acid due to its large amounts and forms many phytic acid - calcium complexes, then this will create a sparing effect on the iron and zinc, as the concentration of calcium is higher than iron and zinc in the products. Figure 3 indicates the possible sparing action of phytic acid - calcium on the iron and zinc accessibility in the majority of mung bean product composites. However, it seems that in case of split mung bean *dhal*, whole *laddu*, *burfi* and *halwa* there is still enough phytic acid to bind with Fe and Zn. This is also evident from the fact that the percentage of *in vitro* iron and zinc accessibility is higher in mung bean product composites than the percentage *in vitro* calcium accessibility. Figure 4 indicates PA : Ca as potential factor determining the *in vitro* calcium accessibility.

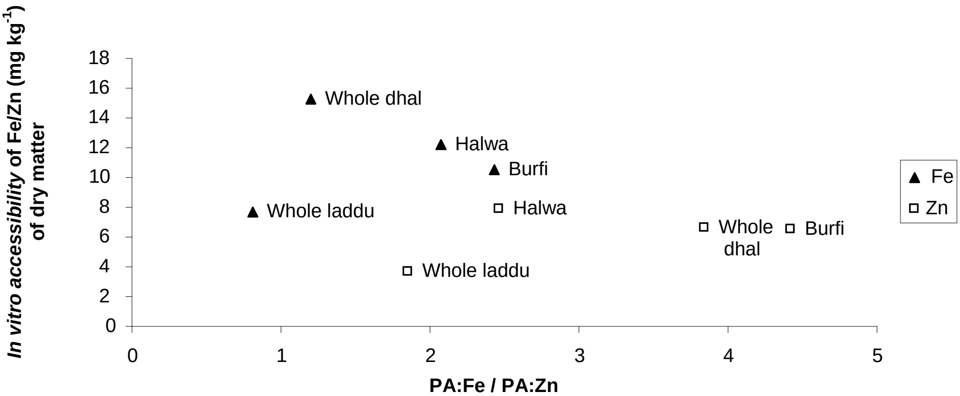

Figure 3 *In vitro* accessibility of Fe and Zn as a function of PA:Fe and PA:Zn molar ratios, respectively, in split *dhal*, whole *laddu*, *burfi* and *halwa* (as calculated by phytic acid assuming that all calcium present is bound to phytic acid)

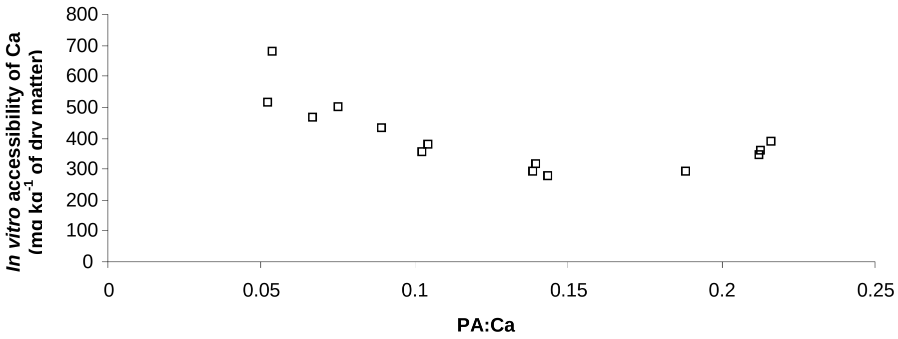

Figure 4 *In vitro* calcium accessibility as a function of PA:Ca molar ratio

3.6 Contribution to Recommended Dietary Allowance

The percentage of recommended dietary intake of protein, iron, zinc and calcium covered by different mung bean food products for children of 7-9 years is given in Table 6 (calculated on the fresh weight of product consumed on the basis of the recommendations of the Nutrition Society of India, Hyderabad). Different mung bean product composites (100 g) cover 12.0 - 59.5 %, 1.6 - 7.2 %, 1.4 - 9.1 % and 1.1 - 7.1 % of the Recommended Dietary Allowance (RDA) for protein, iron, zinc and calcium, respectively, for 7 - 9 year old Indian children. There is a large difference in the % of RDA covered for protein, iron, zinc and calcium between products. Percentage of RDA covered for protein is highest in the sweets, as well as snacks, except *bhalle*, which covered RDA in lower amounts than *wadian*, split *dhal* and *khichadi*. *Halwa*, *burfi*, dehulled split *dhal* and *pakore* cover relatively higher % of RDA for iron, whereas *khichadi*, whole *dhal*, split *dhal* and *wadian* cover relatively lower % RDA for iron.

Table 6 Percentage of recommended dietary intake* of protein, iron, zinc and calcium covered by mung bean derived foods for children of 7-9 years (calculated for 100 fresh weight on the basis of total protein and *in vitro* mineral accessibility)

Food type	Products	% RDA protein	% RDA iron	% RDA zinc	% RDA calcium
Dhals	*Whole dhal*	21.1	2.2	2.1	1.4
	Split dhal	12.1	1.7	1.4	1.1
	Dehulled split dhal	28.7	6.1	6.8	4.7
Sweets	*Whole laddu*	32.6	4.1	4.0	4.2
	Dehulled split laddu	36.6	5.7	6.9	4.1
	Burfi	48.3	6.1	7.5	5.6
	Halwa	59.5	7.2	9.2	5.4
Snacks	*Namkeen*	51.6	3.4	1.7	5.7
	Papad	47.4	4.6	7.6	7.1
	Bhalle	16.8	3.7	3.9	2.2
	Pakore	35.4	6.5	7.5	3.4
Others	*Wadian*	16.9	2.5	2.5	2.6
	Khichadi	14.0	1.7	2.4	1.2
	Sprouts	26.2	5.8	4.6	2.7

*RDA used are 29.5 g protein, 16 mg iron, 8 mg zinc and 600 mg calcium

4. Conclusion

Information on nutrients and anti-nutritional factors of traditional food products is important for food composition databases (Khalil, 2000), to know the nutritional intake of populations and to select foods for product and process design and development. In the case of mung bean product composites, it seems that fermented and germinated products have higher amounts of *in vitro* accessible minerals and lower anti-nutritional compounds as compared to fried ones. This indicates the possibility to improve the non-fermented foods like *khichadi* and whole *dhal* by incorporating these processing steps. However, due to multiple processing steps it is not clear which processing step has the largest impact on the *in vitro* mineral accessibility. Therefore, controlled experiments are needed to evaluate the relative impact of the different processing methods on the mineral accessibility in mung bean foods.

Moreover, other ingredients used in mung bean product composites seem to play a significant role in *in vitro* mineral accessibility, as some might be acting as mineral enhancers and others as inhibitors. *Khichadi* has low amounts of *in vitro* accessible minerals and other nutrients, and therefore needs to be consumed with mineral-rich vegetables. Products with relatively high amounts of anti-nutrients, like whole and split *dhal*, can be consumed along with food products containing enhancers of mineral absorption *in vivo*, like ascorbic acid (Jin et al., 2009). In terms of *in vitro* mineral accessibility, dehulled split mung bean grains are a better ingredient for mung bean foods than whole or split mung bean grains. *In vitro* mineral accessibility in mung bean product composites can also be increased by using mung bean varieties with high levels of total minerals, like iron and zinc, and lower levels of anti-nutritional compounds like phytic acid and polyphenols.

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Chapter 6

General discussion and future perspectives

1. Introduction

Redesigning traditional foods for alleviating malnutrition requires cautious consideration of all the possible factors that affect their nutritional potential and acceptance. Therefore, in the present thesis, an integrated approach was followed to study factors affecting nutritional intake from mung bean foods. Thus, the hypothesis of the present project was that mung bean foods could be optimised for their nutritional value, and could constitute a suitable vehicle for the enrichment of the diet with micronutrients that are deficient in the majority of the Indian population. So far, the best technologies to that avail have not yet been established and technological possibilities have not yet been tested for consumer acceptance of the resulting foods. Thus, this project was framed to achieve the following research objectives:

1. To review the technological and nutritional potential of mung bean
2. To determine the nutritional value of mung bean varieties
3. To determine the nutritional significance of indigenous mung bean foods
4. To determine consumer choices and underlying factors
5. To identify options to redesign traditional mung bean products

To what extent the above objectives were reached and what needs to be done next in terms of further research is discussed in this chapter.

2. Factors affecting the nutritional potential of mung bean

The factors affecting the nutritional potential of mung bean are located at various levels in the mung bean food network (*i.e.*, production, processing and consumption) in terms of technical and social parameters (Figure 1). At production level, the important factors relating to the product (here: the mung bean grain) are agronomical techniques, genetic differences and local growing conditions. These factors affect the composition of mung bean grains at the time of harvesting. The choice of a particular variety is determined by farmers' knowledge, perception and preferences for seed characteristics. Chapter 2 and 4 address these issues.

Technical and social factors also play a role at processing level and affect the nutritional composition of mung bean. One of the important factors is the effect of processing operations on the nutritional quality of mung bean varieties and the use of other ingredients, such as spices and vegetables. Different processing operations influence the nutrients in the foods in their specific way, and affect the nutritional value of the consumed dish. The choices of processors choices for certain unit operations and mung bean varieties depend on their knowledge and perception of the

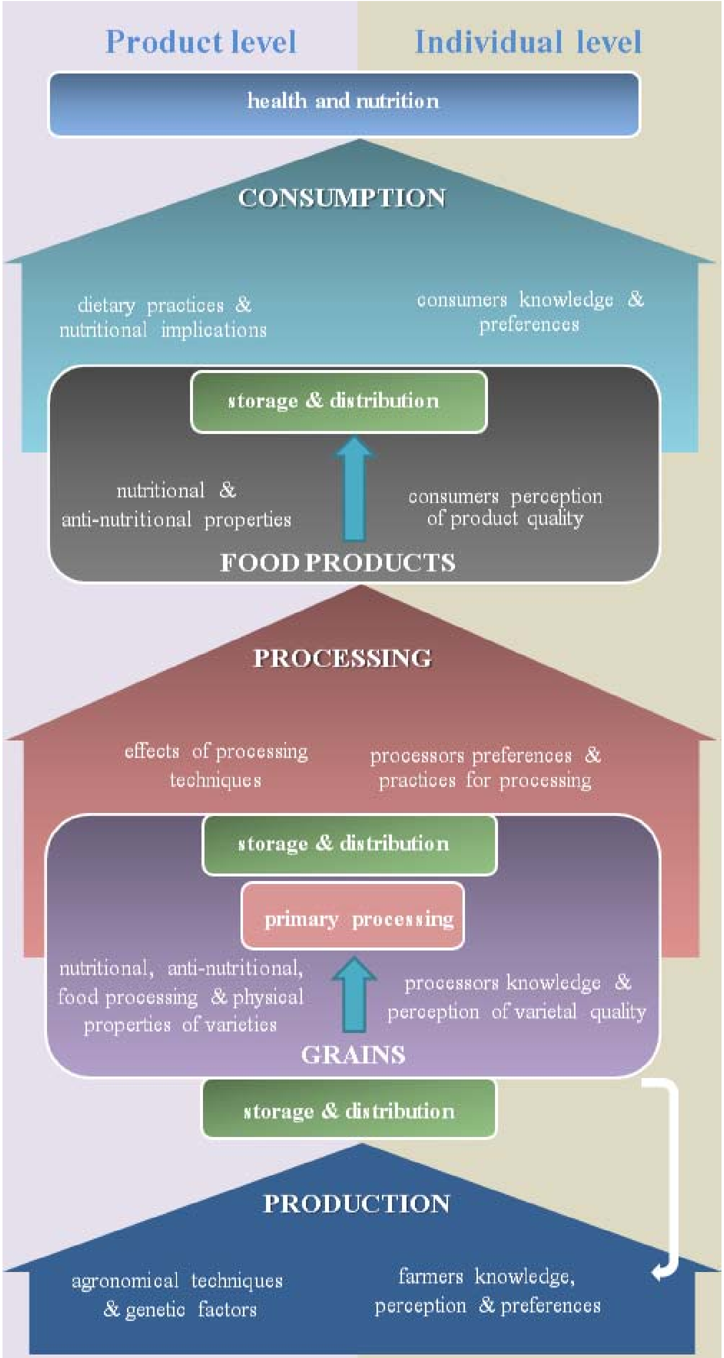

Figure 1. Mung bean food network and associated factors affecting nutritional potential

impact of processing on quality, and their preferences for particular unit operations. Chapter 5 deals with the nutritional value of prevailing mung bean dishes and illustrates how this is impacted by processing.

At consumption level, the dietary practices and food choice for consumption affect nutrient intake. Food choice depends on consumer's knowledge of mung bean and its derived dishes, and consumer's quality perception and preferences. Chapter 3 addresses these factors. In this thesis, most of the above mentioned factors were analysed by experimentation, whereas some others were investigated on the basis of meta-analysis of available literature data.

3. Technological options for redesigning mung bean foods

Apart from providing protein and energy, mineral nutrition is one of the major functions of mung bean food dishes. However, as discussed in the previous section, the nutritive potential of mung bean foods is not realised in practice. Mineral uptake is predominantly influenced by the total mineral content and the presence of enhancers and/or inhibitors of mineral uptake. This section deals with these factors at production, processing and consumption level.

3.1 At production level

Composition of the grain is an important determining factor for its potential nutritional value. Specifically, the area of origin (Trung and Yoshida, 1983), genetic makeup (Babu et al., 1988), agronomical practices like use of fertilizers (Coelho et al., 2002) and effect of location (Coelho et al., 2002) affect the nutritional composition. Therefore, changes in these factors may lead to changes in the amounts of inhibitors of mineral uptake, like phytic acid and polyphenols, and in enhancers of mineral uptake, like vitamin C, which later may affect the mineral bioavailability.

Among the enhancers of mineral uptake, vitamin C is one of the most important. Vitamin C was reported to range from 0 to 10 mg/100 g dw (Prabhavat, 1990) with an average of 3.1 mg/100 g dw in mung bean. This variation could be due to experimental variation or genetic differences; the author did not provide an explanation. Increasing the vitamin C content in mung bean grains using breeding techniques seems be beneficial, depending on the food product. For example, in the case of *ankurit dhal*, the absence of any thermal treatment during processing permitted vitamin C to act as an enhancer of mineral uptake. For other dishes increasing the vitamin C in the mung bean grain will not be of interest as it will be lost almost completely during food processing.

Removing the inhibitors of mineral uptake, such as phytic acid, seems to be the next option for increasing the nutritional value of mung bean. However, it was reported that reducing the phytic acid content may hamper the growth of the plants (Coelho et al., 2002). Moreover, use of fertilizer increases the phytic acid content in the grains, suggesting that the use of fertilizer may have an adverse impact on mineral bioavailability in foods prepared from these grains (Coelho et al., 2002). Since fertilizers are necessary for the growth of the plant and crop yield, and similarly, germination is also vital for the next growing cycle, decreasing the phytic acid content in the grains by breeding techniques or changing the agronomical practise of using fertilizer, cannot be used to increase mineral bioavailability.

Consequently, the option left to increase mineral availability through breeding is by increasing the total content of minerals in the grain. This can be achieved by selecting among existing nutrient-rich varieties, which should preferably be local, so-called "*desi*" varieties as preferred by consumers for mung bean products (Chapter 3). Selection can be based on chemical composition, genetic makeup, agronomical and physical properties like colour, since colour of the grains is a function of genetic make-up of the variety (Paroda and Thomas, 1988).

Mung beans have high levels (34.0 mg of catechin/g) of polyphenols in their testa (Barroga et al., 1985). Muhammed et al. (2010) suggested that, being bioactive molecules, seed coat polyphenols can protect the seed against pathogens and improve seed viability. Dark coloured mung bean grains contained higher polyphenol levels than light-coloured grains (Muhammed et al., 2010; Salunkhe et al., 1982). Thus, as polyphenols have been reported to reduce the protein digestibility and mineral bioavailability, products made of light coloured mung bean varieties are likely to have a higher protein digestibility and mineral bioavailability. It would be interesting to investigate the predictive value of the seed coat colour of mung beans for their mineral bioavailability. Moreover, yellow mung bean varieties contained higher quantities of polyphenols in their seed coats than green varieties (Muhammed et al., 2010), which indicates effective removal of polyphenols in yellow varieties by dehulling.

Difference in colour in mung bean varieties is also related to different carotenoid contents. Green coloured mung bean grains contained higher amounts of carotenoids (0.9 mg/100 g) than yellow varieties (0.7 mg/100 g), which was attributed to higher amounts of carotenoids in the seed coat of green coloured varieties (41.5 %) than in those of yellow varieties (16.2 %) (Harina and Ramirez, 1978). Colour of grain is also important from a consumer point of view. It imparts colour to food products like *whole dhal*, *split dhal*, *dehulled dhal* and *ankurit dhal* prepared by using whole or dehulled mung beans. Mung bean varieties that impart odd colours to a product are not acceptable (chapter 3). Dark coloured varieties or a dark colour in green grains are disliked by consumers in India (chapter 3).

Another physical property that is correlated with chemical composition and could be used for selection of varieties for breeding purposes is the grain size. Consumers expressed an aversion to consume large-sized mung bean grains in India (chapter 3). They like *desi* (meaning local) varieties, which have small grains. Bhadra et al. (1991) reported a negative correlation between protein content and grain size; varieties with small sized grains and low yield were found to have high protein content. However, Trung and Yoshipa (1983) reported a positive correlation between seed size and protein content (r = 0.555). Therefore, research needs to be done to validate the correlation between seed size and protein content. If grain size is negatively correlated to protein content, then breeding should focus on small-sized varieties.

In terms of chemical composition, Philippine varieties have higher protein contents (23.4 %) as compared to Indian varieties, which have an average protein content of 19.8 % (Trung and Yoshida, 1983). Use of these varieties might be effective in breeding for nutrient-rich grains but these may not be ecologically adapted. Moreover, these varieties may lead to a change in food processing requirements and sensory properties, which may not be accepted by local consumers.

The consumer survey (chapter 3) elucidated the consumption of different mung bean varieties in the research locale. Therefore, established and newly bred mung bean varieties were analysed for their nutritional and anti-nutritional properties as reported in chapter 4. Although the nutrient content of raw grains does not give the nutrient availability after processing, it is a first indication of differences between varieties. Varieties were compared based on proximate composition, minerals, anti-nutrients and *in vitro* mineral accessibility. Variety MH 125 had the highest contents of iron, calcium, magnesium and sodium and might thus be of nutritional interest. Polyphenol contents were highest in variety MH 318 and lowest in variety MH 125. *In vitro* protein digestibility of varieties showed significant differences among varieties, ranging from 53.1 % in variety MH 560 to 67.1 % in variety MH 125. *In vitro* starch digestibility was found to be lowest (19.6 mg maltose released/g) in variety MH 560 and highest (28.6 mg maltose released/g) in variety MH 125. On the basis of lowest phytate to mineral ratios, breeding seems to have improved the nutritional value of variety MH 125. However, phytate to mineral ratios are fully reliable as indicators of mineral accessibility, as other factors like the amount of calcium also impact mineral accessibility. Moreover, on the basis of agronomical characteristics, there is no significant improvement due to the lower yield of variety MH 125 as compared to varieties MH 560 and MH 564. Variety MH 125 is a green coloured variety and thus seems promising in terms of consumer acceptance (chapter 5). However, more research is needed on mineral bioavailability of MH125 when used in various local foods.

3.2. At processing level

People in northern India process and consume mung bean in numerous forms (chapter 3). Different mung bean foods require diverse processing steps, which influence the nutrient composition differently. Information on nutrients and anti-nutritional factors of traditional food products is important for food composition databases (Khalil, 2000) to be able to calculate the nutrient intake of populations and to select foods for product and process design and further development. The most popular mung bean foods were analysed to know the total and available nutrient contents. Our research reported on the composition and *in vitro* micronutrient accessibility of fourteen traditional mung bean foods from India in relation to their preparation methods (chapter 5).

Food processing techniques like fermentation and germination were reported to help in dephytinisation (Barakoti and Bains, 2007; Hemalatha et al., 2007). Germination and soaking lower the trypsin inhibitor activity (Chandrashekar et al., 1989); trypsin inhibitors are low molecular weight proteins and thus they are likely to leach during soaking. Trypsin inhibitor activity is also reduced by heat treatments. Furthermore, processes like dehulling and cooking can reduce the amount of polyphenols, thereby increasing the nutritional value of the grain (Madhuri et al., 1996). Obviously, increasing the iron content in mung bean will not be effective if anti-nutrients affecting its bioavailability are present in large quantities. Polyphenols were found to be higher in products prepared with whole mung bean grains, like *whole* and *split mung bean dhal* and *whole laddu*, compared with sweets and snacks prepared with *dehulled split mung bean dhal.* The highest amount of *in vitro* accessible iron was found in dehulled split *dhal* followed by *bhalle* and *ankurit dhal*, whereas *whole laddu*, *namkeen* and *papad* had the lowest *in vitro* accessible iron (chapter 5).

Consequently, processing methods like fermentation, germination, dehulling, soaking and cooking, which improve the nutritional value significantly, can be used to redesign traditional foods. However, incorporating such steps can lead to unintended quality changes. Therefore, more research is required to study the impact of redesigning foods on nutritional value and consumer preferences. Moreover, since multiple processing steps are used for the preparation of a single food, it is not clear which processing step has the largest impact on the *in vitro* mineral accessibility. Controlled experiments are needed to evaluate the relative impact of the different processing steps on the mineral accessibility in mung bean foods. In the case of mung bean products, it seems that fermented and germinated products have higher amounts of *in vitro* accessible minerals and lower anti-nutritional compounds as compared to fried products. This indicates the possibility to improve the foods that are prepared with non-germinated grains, like *khichadi* and *dhals*, by incorporating this processing step.

When considering the effect of processing on nutrient composition of mung bean foods, spatial distributions of nutrients in the grain play an important role. Singh et al. (1968) reported the distribution of different minerals in the anatomical parts of the mung bean. They reported that calcium is primarily present in the seed coat (30 to 50 %, i.e. 812 mg/100 g dw), iron in the embryo (23 mg/100 g dw) and seed coat (17 mg/100 g dw) and phosphorus in the embryo (756 mg/100 g dw) and cotyledons (341 mg/100 g dw). The average crude fibre content is 4.6 g/100 g dw and it is correlated with seed hardness due to the fact that hard seeds have a thick seed coat (Felicito and Mendoza, 1990). Singh et al. (1968) reported that 80 - 93 % of the crude fibre in mung bean is present in the seed coat, whereas the embryo contains only 2 - 3 % crude fibre. This explains why products made of dehulled mung bean like dehulled *dhal* contain lower amounts of crude fibre, namely 8.5 g/ 100 g dw (chapter 4) as compared to whole *dhal* (20.7 g/ 100 g dw). Removal of the embryo and seed coat during dehulling and milling will not affect the nutritive value of mung bean grain much, as these only account for a small proportion of whole mung bean grain (Singh et al., 1968). Most of the protein in mung bean is present in the cotyledons, with the majority of protein as salt soluble storage globulins. Therefore, dehulling also has little effect on the protein content.

Apart from the effect of processing steps, use of other ingredients to prepare mung bean products potentially plays a role in *in vitro* mineral accessibility, as some might act as enhancers of mineral uptake and others as inhibitors (chapter 5). For example, nuts used in the sweets also contain phytates that increase the total phytic acid content in the product. On the contrary, vegetables like tomato and coriander used in *dhals*, increase the vitamin C content. *Dhals* had higher mineral contents than *halwa*, *laddu* and *burfi*, due to the use of various spices, condiments, and vegetables as ingredients. This shows that recipes of *dhals* can be redesigned to increase the *in vitro* nutrient bioavailability. *Khichadi* has low amounts of *in vitro* accessible minerals and other nutrients, and therefore its recipe could be changed to incorporate locally available mineral-rich vegetables to increase the mineral bioavailability. Products with relatively high amounts of anti-nutrients, like whole and split *dhal*, can be consumed along with food products containing enhancers of mineral absorption *in vivo*, like ascorbic acid (Jin et al., 2009). In terms of *in vitro* mineral accessibility, *dehulled split mung bean* grains are a better ingredient for mung bean foods than whole or split mung bean grains.

There are a number of aspects to consider when selecting nutritionally rich food products, like nutrient content, anti-nutritional content, nutrient accessibility and their molar ratios. However, the phytic acid : mineral ratios are not a fool-proof index for bio-availability and thus are not to be strictly taken into account. The ration of PA : Fe and PA : Zn could not be used effectively to predict mineral accessibility in mung bean foods; phytic acid to mineral molar ratios were quite high, but so was the *in vitro* mineral accessibility. It seems that there are other factors that increase the mineral accessibility. If it is assumed that calcium binds more readily with phytic acid due to its large amounts and forms many phytic acid - calcium complexes, this will create a sparing effect on the iron and zinc (chapter 4). However, it seems that in the case of split mung bean *dhal*, whole *laddu*, *burfi* and *halwa* there is still enough phytic acid to bind with Fe and Zn. This is also evident from the fact that the percentage of *in vitro* iron and zinc accessibility is higher in mung bean products than the percentage *in vitro* calcium accessibility. Moreover, there are other factors that affect the mineral bioavailability in the human gastrointestinal tract like other anti-nutritional factors in the food matrix.

3.3 At consumption level

The literature review on mung bean (chapter 2) indicated that the impact of consumer choices on the nutrient intake of mung bean foods has not been studied so far. Consumer choice is an important factor that determines the nutritional contribution of a food product regardless of its composition. Therefore, it was important to decide the relative importance of traditional mung bean food products in terms of consumer choice, which depends primarily on three aspects, i.e. consumer perception, preferences and practices. Consequently, comparative research was conducted to understand these aspects and their influencing factors.

Dietary practices play an important role in the nutritional status of an individual. Dietary practices for mung bean foods show two underlying factors that influence nutrient intake through mung bean foods. These are the accompanying foods and frequency of consumption. Differences in frequency of consumption were due to various reasons. Seasonal eating of certain mung bean foods is one of these reasons. Food products like sweets, for instance, are mainly consumed in wintertime. However, *dhals* and *khichadi* were consumed weekly or monthly by most consumers. Mung bean snacks were consumed at least once per month or seasonally. Moreover, the presence of other legume products with similar characteristics also influenced the frequency of consumption of mung bean foods. A relatively low frequency of consumption of legume foods is in line with results previously published (Arlappa et al., 2010).

Apart from the frequency of consumption, the use of accompanying products also influences the potential of food products to contribute to the nutritional status of its users. *Bhalle* and *khichadi* are the only two products that were consumed with cold food products like curd and *lassi* (buttermilk). *Dhals* and *wadi* were consumed with staple products like rice, *chapatti,* and *parantha* (shallow fried *chapatti).* Consumers eat *dhal* with many variations in its recipe. One of the important variations is spinach mung bean *dhal*. This product might not be a good source of minerals as oxalates in spinach hinder mineral absorption in the human intestine (Gupta et al., 2006). Sweets and snacks were consumed with hot drinks like tea and coffee. This dietary habit causes an ineffective use of total minerals present in these mung bean foods, as tea contains tannins that potentially bind with minerals, thereby reducing their bioavailability (Hurrell, 1999; Temme and Van Hoydonck, 2002).

In contrast, there are other mung bean dietary patterns in which consumers add lemon juice to *dhals* prior to consumption, which is a promising combination, as ascorbic acid in lemon enhances iron absorption through solubilisation by reduction of ferric to ferrous iron (Fidler et al., 2003). The combination of these products is expected to improve nutrient bioavailability. From a nutritional point of view, combinations of mung bean foods with foods high in sulphur-containing amino acids are advisable, since mung bean lacks methionine (Mendoza et al., 2001). Consumption of *dhals* with cereal products like Indian bread and rice indicate promising combinations in terms of amino acid nutrition. This consumption pattern provides a balanced amount of lysine, a limiting amino acid in cereals, and methionine, a limiting amino acid in legumes. Therefore, cereal-based mung bean products like *khichadi* and *dhal parantha* (Indian bread prepared with cooked *dhal* and wheat flour) can be considered good in terms of a balanced amino acid intake. Accompanying foods seem to have a large impact on the overall nutritional uptake from mung bean foods. Consequently, research on the effects of mung bean product combinations on the overall nutritional profile of dishes is advocated.

Several mung bean products seem to offer potential as a vehicle to alleviate malnutrition on the basis of nutritional composition (e.g. mineral contents and their accessibility), consumer characteristics (i.e. knowledge, perception, preference and practices) and socio-economic factors. Affordability, ease of processing, storage methods used, product procurement, time of consumption, temperature during consumption and pre-consumption requirements govern the accessibility aspect of the mung bean products. However, sensory liking, positive health perception, nutrient content, food preference, frequency of consumption and accompanying food products determine the nutritional contribution of the products to the overall food intake. These factors interact and lead to a final food choice. In the case of mung bean foods, consumers prefer products with a high sensory quality. Thus, they prefer to consume sweets like *halwa* and *laddu,* although they perceive *khichadi* as the healthy choice. Nonetheless, consumers choose *dhals* for daily consumption. This indicates that in certain circumstances food choice is influenced more strongly by social-economic restrictions than by consumer perception and preferences (Hoefling and Strack, 2010).

In order to get a complete picture of these influences on food choice, the selected factors were ranked and used to outline different scenarios. These scenarios provide insight in the options for using mung bean foods to alleviate malnutrition while staying as close as possible to local food uses and preferences. Results show that *dhals* are the most promising products but also that different factors favour diverse products. Increasing the weight for certain factors may give different outcomes. This is relevant because certain factors can be adjusted by dedicated technological research, i.e. they can be improved to match consumer wants. The flexible factors that determine the innovation potential are nutrient content, frequency of consumption and accompanying products. Interestingly, all scenarios lead to the same conclusion, namely that *dhals* are the most promising product for improving the nutritional status of its users.

Apart from product development, redesigning is also required at consumption level. As discussed earlier, different accompanying foods can lead to different nutritional values, and therefore it is needed to choose the accompanying foods wisely. Food-based dietary guidelines need to be designed to ensure proper awareness through extension activities (Brown et al., 2011). Thus, when deciding about the choice of any food product as a vehicle to alleviate malnutrition among relevant populations, we advocate to not merely rely on sensory appreciated products but to take into account other factors that govern food choice as well. In short, indigenous mung bean consumption patterns possess constraints, which can be improved by using outcomes of a multi-disciplinary research approach.

4. Implications for future research

In conclusion, this research has shown that mung bean food products play an important role in the local food networks in northern India. In general, there is diversity of mung bean foods that are integrated with region specific eating habits, processing patterns and cropping systems. There was a number of options where improvement is required to fully benefit from their nutritional potential (Figure 2). At production level, plant breeders need to focus more on increasing the total mineral content instead of increasing enhancers of mineral uptake or decreasing the content of anti-nutritional compounds. Local varieties are liked by the consumer and are thus require to be improved in terms of agronomical and nutritional value through traditional breeding or biotechnological techniques. At processing level, operations like fermentation, soaking, dehulling and germination were found to help in increasing the mineral accessibility. These processing steps need where possible to be incorporated in the process of redesigning foods in conjunction with consumer acceptance. Moreover, incorporation of vitamin C rich ingredients like coriander and tomato after the thermal processing steps might also increase mineral bioavailability. At consumption level, accompanying foods and frequency of consumption are the two important factors that affect the nutritional uptake of mineral from mung bean foods. Taking convenience-related factors into account, *dhals* were selected as the most promising products to increase the mineral uptake through mung bean.

The fact that options for improvement exist at different levels of the mung bean food network, made it necessary to analyse them from more than a single scientific discipline. Therefore, an interdisciplinary approach was used in this project called TELFUN (Tailoring Food Sciences to Endogenous Patterns of Local Food Supply for Future Nutrition). The results of each discipline in this project acted as supportive information for the formulation of further research objectives. For example, the importance of accompanying foods in the mung bean dishes as indicated by the consumer study in this thesis was investigated by human nutrition research. Similarly, the selection of *dhals* as the most promising food to alleviate malnutrition lead to this food being chosen as a test mung bean product in conjugation with guava (*Psidium guajava*) as a source of vitamin C in the school feeding experiments. The potential of *dhal* milling in a small village using the women self-help groups was also analysed by the social scientist of the multidisciplinary team. Moreover, the social scientist investigated the possibilities to promote the consumption of mung bean dhals accompanied by foods containing enhancers of mineral uptake. These experiments included the formation of functional women self-help groups in the research locale and the installation of a small-scale milling machine in one of the villages. Milling and the primary processing of the *dhals* were done by the women of the self-help groups. The potential of this small-scale entrepreneurship as a source of income and an option to support food sovereignty was analysed. The plant breeder of the team selected potential mung bean varieties based on the agronomical characteristics in conjugation with farmers preferences. The nutritional and anti-nutritional properties of these mung bean varieties were reported in this thesis and compared with those of established varieties.

Mung bean is ecologically adapted to India and this thesis has shown its derived products like *dhals* to be socially accepted and nutritionally significant. However, economic suitability in terms of contribution to income and availability at a low price are also important for a food to contribute to food sovereignty in a resource-poor locality. Changing food habits in the rural and urban areas are a potential threat to food sovereignty. Moreover, a change in women's roles in the society in the sense that they want to spend less time as housewives, also impacts food processing patterns. So, industrialization of traditional foods manufacturers at small- or medium-scale is important to prevent that *dhals* disappear from the dietary pattern of local people. Research is required into the mechanization and modernization of *dhal* processing. *Dhals* of legumes lentils, chick pea and urd beans are available in a packaged form in the Indian market. Retort pouching and canning are a few potential industrial techniques that are used by Indian food companies for preserving *dhals*. This indicates that *dhal* processing has the potential to be mechanized to keep up with the changing food processing and consumption patterns. However, some of these technologies are expensive and require sophisticated machinery, making it difficult for the local small-scale mung bean processors to install and use. Therefore, technologies have to be developed for processing and packaging *dhals* at a small- or medium-scale scale level.

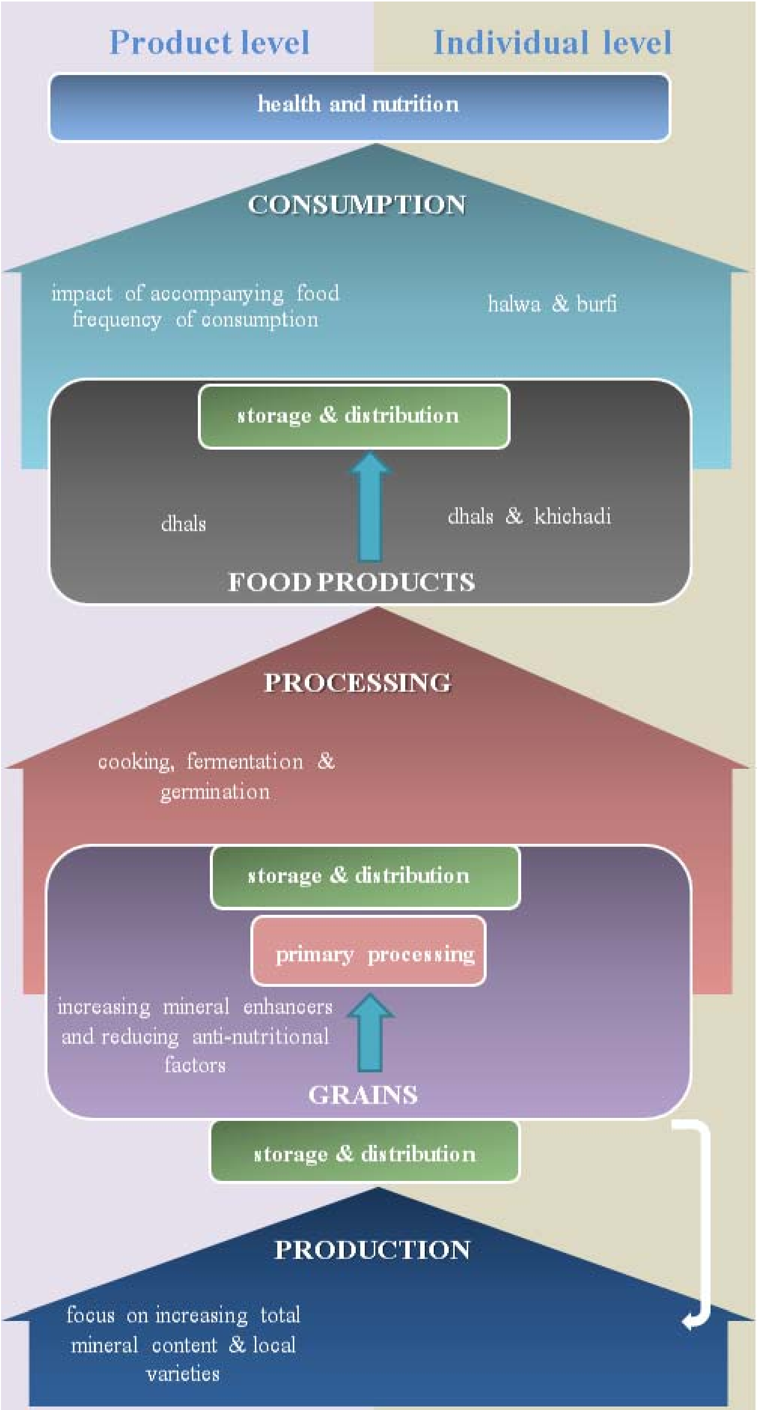

Figure 2. Technological options in the mung bean food network for redesigning foods

This thesis presents various technological options like breeding of nutrient-rich mung bean varieties, incorporation of improved food processing and reformulation of recipes with local nutritious ingredients for redesigning foods, which still require more research. As such, this study reflects the use of an interdisciplinary approach with integration of technological options at production, processing and consumption levels in conjugation with product quality and consumer wishes for better nutrition.

The implications of the present thesis are as follows:

1. Research on digestibility and bioavailability of nutrients in mung bean foods is needed as the factors that affect them are many and their interactive behaviour is not well understood. Moreover, functional properties need to be determined, as literature on these parameters is limited.
2. Extensive studies related to the effects of processing on the essential nutrients and functional properties are required to standardise processing, for a better mung bean food quality in terms of nutrition and process efficiency.
3. Plant breeders should focus on a combination of crop yield, nutritional value and consumer preference traits. Emphasis should be on increasing the total mineral content of the grains.
4. Food choice is sometimes more strongly influenced by social-economic restrictions than by consumer perception and preferences. Therefore, increasing the frequency of consumption of nutrient-rich products and the use of accompanying foods that enhance the nutrient uptake should be promoted through extension or through the use of these products in community food based nutritional interventions like mid-day meal programmes in schools.
5. Re-modifications of mung bean recipes should be done by careful alteration of processing steps or by varying ingredients to increase the enhancers of mineral uptake and/or reduce inhibitors.
6. *Dhals* have the potential to contribute significantly to the nutrient intake, but their sensory acceptability needs to be improved.

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Summary

Malnutrition is one of the most critical food related problems in resource-poor communities. So far, none of the approaches aimed to alleviate malnutrition provided a sustainable solution. Food sovereignty is a relatively recent concept that comprises the right of people to determine food production, processing and consumption. It thus has the potential to facilitate sustainable development of local food systems. Indigenous foods can be important factors enhancing food sovereignty. Though indigenous traditional foods have many advantageous features, their actual presence is not sufficient to prevent malnutrition. This gap requires investigation to identify which indigenous foods are candidates for innovation or redesigning in order to contribute to alleviation of malnutrition. The present thesis deals with various technological options in mung bean (*Vigna radiata* L. Wilczek) food systems in northern India for redesigning traditional foods for better nutrition. Redesigning traditional foods requires evaluation of factors affecting the nutrient intake through their consumption. Such quality related factors include adequate consumption, high nutrient bioavailability and consumer satisfaction, which were studied in an interdisciplinary setting.

This research aimed at (i) reviewing the physical, food processing, nutritional and anti-nutritional properties of mung beans; (ii) determining consumer awareness, knowledge, perception, preferences and practices related to mung bean foods and their impact on nutritional potential; (iii) determining the nutritional characteristics of newly bred and established mung bean varieties; (iv) determining the nutritional characteristics of the indigenous mung bean foods, and (v) critically evaluating all the possible factors affecting nutritional potential and identifying technological options to redesign traditional mung bean products.

The review (chapter 2) on the technological and nutritional potential of mung beans showed that the composition of grains depends primarily on three factors i.e. agronomical practices, genetic diversity and site specific growing conditions. Mung bean is a rich source of protein (14.6 to 33.0 g/100 g) and iron (5.9 - 7.6 mg/100 g). However, the mineral accessibility is low due to the presence of anti-nutritional factors like phytic acid (441.5 mg/100g) and polyphenols (462 mg/100g). Options to increase the mineral accessibility at the production level include increasing the total mineral content, decreasing the content of anti-nutritional compounds, and increasing the presence of enhancers of mineral uptake such as vitamin C. The latter, however, will not be an effective approach as vitamin C will be destroyed by the heat during traditional processing. Similarly, decreasing the phytic acid content also may be ineffective due to the importance for plant for germination and growth. Therefore, increasing the total mineral content by breeding or biotechnical techniques is probably the best approach in the case of mung bean. This requires selection of existing nutrient rich varieties based on chemical composition, genetic makeup, agronomical and physical properties.

Seven newly bred and three established varieties of mung bean were analysed for proximate composition, minerals, anti-nutrients and *in vitro* mineral accessibility (chapter 4). They contained 18 - 23 g protein, 4.0 - 5.6 g crude fibre and 2.5 - 4.1 g ash per 100 g dry sample. Iron, zinc, calcium, sodium and potassium ranged from 3.4 - 4.6, 1.2 - 2.3, 79 - 115, 8.1 - 13.5 and 362 - 415 mg/100 g dry weight, respectively. Phytic acid and polyphenols averaged 769 and 325 mg/100 g dry weight, respectively. Phytic acid and polyphenols were negatively correlated with *in vitro* mineral accessibility and nutrient digestibility. Average molar ratios of phytic acid to iron and zinc were 16.8 and 52.7, respectively. Differences in *in vitro* iron and zinc accessibility could not be explained by phytic acid to calcium nor magnesium molar ratios. We expect that other factors such as the amount of calcium, affect mineral accessibility. Variety MH 125 had the highest contents of iron, calcium, magnesium and sodium and might thus be of nutritional interest. However, more research is needed on mineral bioavailability of MH125 when used in various local foods.

The preparation of mung bean products necessitates diverse processing steps, which also influence the nutrient composition. A study of 14 mung bean products was conducted to analyse proximate composition, *in vitro* mineral accessibility, phytic acid and polyphenol contents (chapter 5). Average *in vitro* iron, zinc and calcium accessibility of the mung bean products were 1.6, 0.9 and 41.8 mg/100 g dry weight. Phytic acid and polyphenols averaged 210 and 180 mg/100 g dry weight, respectively, and were negatively correlated with *in vitro* mineral accessibility. Polyphenols were found to be higher in products prepared with whole mung bean grains, such as *whole* and *split mung bean dhal* and *whole laddu*, compared with sweets and snacks prepared with *dehulled split mung bean dhal.* The highest amount of *in vitro* accessible iron was found in *dehulled split dhal* (2.4 mg/100 g) followed by *bhalle* (2.1 mg/100 g) and *ankurit dhal* (2.1 mg/100 g), whereas *whole laddu* (0.8 mg/100 g), *namkeen* (0.7 mg/100 g) and *papad* (0.9 mg/100 g) had the lowest *in vitro* accessible iron. Results showed that fermented or germinated mung bean foods had higher *in vitro* iron, zinc and calcium accessibility. The incorporation of fermentation or germination in the redesigning of traditional products might increase mineral bioavailability. Apart from the effect of processing steps, use of other ingredients during processing could have a significant impact on mineral nutrition. For example, nuts used in the sweets also contain phytates that increase the total phytic acid content in the product. Vegetables like tomato and coriander used in *dhals*, increase the vitamin C content, which acts as an enhancer of mineral uptake.

Our study on the habits of mung bean consumers (chapter 3) showed that their food choices vary with the circumstances; the type of mung bean food consumed is mainly influenced by socio-economic conditions rather than by perception and preferences. Amongst the important factors at consumption level that influence nutrient intake are the foods that are consumed as an accompaniment, and the frequency of mung bean food consumption. Increasing the frequency of consumption can be one of the effective ways of increasing mineral uptake through mung bean. Addition of ingredients like lemon juice or coriander leaves enhance mineral accessibility. On the contrary use of tea and coffee seems to diminishes mineral accessibility. Certain mung bean products can be regarded as candidate vehicles to alleviate malnutrition on the basis of their nutritional composition (e.g. mineral contents and their accessibility), consumer characteristics (i.e. knowledge, perception, preference and practices) and socio-economic factors.

Scenario analysis based on consumer perception, preferences, practices and nutritional value of products revealed that *dhals* are the most promising food with respect to nutrient content, ease of processing and frequency of consumption. *Dhals* can be redesigned by nutrition-based plant breeding, use of mineral enhancing traditional processing, and better dietary practices at consumption level. *Dhals* are valuable because they are highly nutritious, deliver sustenance and are easy to digest. *Dhals* contribute significantly in terms of protein, iron and zinc to the Indian vegetarian population with frequent dietary deficiencies. *Dhals* can have higher mineral contents when various spices, condiments, tomato and onion are used in their preparation. In terms of convenience, these products are also suitable to resource-poor people as *dhals* are relatively cheap compared with other mung bean products. Moreover, they are easily available and have convenient processing. Culturally, *dhals* play a significant role in Indian dietary habits. Improvements should address the poor sensory attributes of *dehulled dhal* e.g. by inclusion of local vegetables or spices. Furthermore, *dhals* could be made more convenient to prepare, e.g. by reducing cooking time. It is concluded that mung bean *dhals* can be a good vehicle for alleviation of mineral malnutrition. This research as a part of interdisciplinary project called 'TELFUN' conceptualised the options for redesigning traditional mung bean foods for better nutrition taking into consideration their production, processing and consumption.

Samenvatting (Summary in Dutch)

Ondervoeding is een van de belangrijkste voedingsproblemen voor arme bevolkingsgroepen. Tot nu toe hebben pogingen om ondervoeding uit te bannen niet geleid tot duurzame oplossingen. Voedselsoevereiniteit is een betrekkelijk nieuw begrip dat het recht toekent aan mensen om hun eigen voedselproductie, verwerking en consumptie te bepalen. Dit biedt de kans op duurzame ontwikkeling van lokale voedselketens. Inlands traditioneel voedsel kan in belangrijke mate bijdragen aan voedselsoevereiniteit. Hoewel inlandse voedselproducten voordelen bieden, is hun aanwezigheid in het dieet echter ontoereikend om ondervoeding te voorkomen. Deze lacune vraagt te onderzoeken welk inlands voedsel geschikt zou zijn om door innovatie of herformulering een bijdrage te leveren aan de vermindering van ondervoeding. Dit proefschrift behandelt technologische mogelijkheden om de voedingswaarde van traditionele voedselproducten door herformulering te verbeteren, in de context van de lokale voedselketen van mungbean (*Vigna radiata* L. Wilczek) in noord India. Dit vraagt een studie van de factoren die de inname van nutriënten door voedselconsumptie bepalen. Kwaliteit gerelateerde factoren zoals voldoende consumptie, grote nutriëntenbeschikbaarheid, en consumenttevredenheid, werden onderzocht in een interdisciplinair kader.

Het doel van dit onderzoek was om (i) overzicht te krijgen van de fysische-, verwerkings-, voedings- en anti-nutritionele eigenschappen van mungbeans; (ii) van consumenten de bekendheid, kennis, perceptie, voorkeur en gebruik van mungbeanproducten te meten en te bepalen hoe deze factoren de bijdrage aan de voedingstoestand beïnvloeden; (iii) van recent veredelde, en reeds langer gebruikte mungbeanvariëteiten de nutriëntensamenstelling te vergelijken; (iv) de nutriëntensamenstelling te onderzoeken van inlandse mungbeanproducten; en (v) alle mogelijke factoren die de voedingswaarde beïnvloeden kritisch te beschouwen, en technologische mogelijkheden voor te stellen voor de herformulering van traditionele mungbeanproducten.

Het overzicht (hoofdstuk 2) van technologische en voedingskundige mogelijkheden van mungbeans gaf aan dat de samenstelling van de bonen van drie factoren afhangt, nl. teeltmethoden, genetische diversiteit en specifieke groeiomstandigheden. Mungbeans zijn een goede bron van eiwit (14,6 – 33,0 g/100g) en ijzer (5,9 - 7,6 mg/100g). De beschikbaarheid van mineralen is echter laag door de aanwezigheid van antinutritionele factoren zoals fytinezuur (441,5 mg/100g) en polyfenolen (462 mg/100g). Om tijdens de teelt de mineralenbeschikbaarheid te verhogen, zou het totaal gehalte aan mineralen kunnen worden verhoogd, het gehalte antinutritionele stoffen kunnen worden verlaagd, en het gehalte van opnamestimulerende stoffen, zoals vitamine C, kunnen worden verhoogd. De laatstgenoemde optie zal niet effectief zijn omdat vitamine C tijdens traditionele bereidingsprocessen zal worden geïnactiveerd. Ook het verlagen van antinutritionele gehalten van bijvoorbeeld fytinezuur is niet raadzaam vanwege de belangrijke rol die deze stof speelt bij de zaadkieming en plantengroei. Daarom is verhoging van het mineralengehalte door veredeling of biotechnologische methoden mogelijk de beste aanpak voor mungbeans. Hiervoor zou een selectie kunnen worden gemaakt van reeds bestaande nutriëntrijke variëteiten, op basis van criteria zoals chemische samenstelling, genetische eigenschappen, teeltmogelijkheden en fysische eigenschappen.

Zeven recent veredelde, en drie gebruikelijke mungbeanvariëteiten werden onderzocht op chemische samenstelling, mineralen, antinutriënten en in-vitro mineralenbeschikbaarheid (hoofdstuk 4). Zij bevatten 18 - 23 g eiwit, 4,0 - 5,6 g ruwvezel en 2,5 - 4,1 g as per 100 g drogestof. IJzer, zink, calcium, natrium en kaliumgehalten waren respectievelijk 3,4 - 4,6, 1,2 - 2,3, 79 - 115, 8,1 - 13,5, en 362 - 415 mg/100 g drogestof. Fytinezuur- en polyfenolengehalten waren gemiddeld respectievelijk 769 en 325 mg/100g drogestof. Gehalten aan fytinezuur en polyfenolen waren negatief gecorreleerd met in-vitro mineralenbeschikbaarheid en nutriëntenverteerbaarheid. Molaire verhoudingen van fytinezuur t.o.v. ijzer en zink waren respectievelijk 16,8 en 52,7. Verschillen in in-vitro mineralenbeschikbaarheid konden niet worden verklaard uit molaire verhoudingen van fytinezuur t.o.v. calcium of magnesium. Verwacht wordt dat andere factoren, zoals het calciumgehalte, de mineralenbeschikbaarheid kunnen beïnvloeden. Variëteit MH125 had de hoogste gehalten aan ijzer, calcium, magnesium en natrium en zou daarom van voedingskundig belang kunnen zijn. Het is echter eerst nodig om de mineralenbeschikbaarheid van MH125 te bepalen als ingrediënt van diverse lokale mungbeanproducten.

De bereiding van mungbeanproducten vereist verschillende bewerkingen, die ook van invloed zijn op de nutritionele samenstelling. Veertien mungbeanproducten werden onderzocht op hun chemische samenstelling, in-vitro mineralenbeschikbaarheid en fytinezuur- en polyfenolengehalten (hoofdstuk 5). De gemiddelde in-vitro beschikbaarheid van ijzer, zink en calcium in de mungbeanproducten was respectievelijk 1,6, 0,9 en 41,8 mg/100 g drogestof. Fytinezuur- en polyfenolengehalten bedroegen gemiddeld respectievelijk 210 en 180 mg/100 g drogestof, en waren negatief gecorreleerd met de in-vitro mineralenbeschikbaarheid. De hoeveelheid polyfenolen was hoger in producten die waren bereid met hele mungbeans, zoals *whole* en *split mung bean dhal* en *whole laddu*, in vergelijking tot zoetigheden en snacks waarvoor ontvliesde *split mung bean dhal* was gebruikt. Het hoogste gehalte aan in-vitro beschikbaar ijzer werd gevonden in ontvliesde *split dhal* (2,4 mg/100 g) gevolgd door *bhalle* (2,1 mg/100 g) en *ankurit dhal* (2,1 mg/100 g), terwijl *whole laddu* (0,8 mg/100 g), *namkeen* (0,7 mg/100 g) en *papad* (0,9 mg/100 g) het laagste gehalte aan in-vitro beschikbaar ijzer hadden. De resultaten toonden aan dat gefermenteerde of gekiemde mungbeanproducten een relatief hoge in-vitro beschikbaarheid van ijzer, zink en calcium hadden. De integratie van fermentatie of kieming in het herformuleren van traditionele producten zou de mineralenbeschikbaarheid wellicht kunnen verhogen. Naast het effect van de verschillende bereidingswijzen kan het gebruik van andere ingrediënten tijdens bereiding een significant effect hebben op de minerale samenstelling. Noten, die bij de bereiding van zoetigheden worden gebruikt, bevatten bijvoorbeeld fytaten, die het totale gehalte aan fytinezuur in een product verhogen. Groenten, zoals tomaat en koriander die worden gebruikt in *dhals,* verhogen het gehalte aan vitamine C, die de opname van mineralen bevordert.

Onderzoek naar het gebruik van mungbeanproducten door consumenten (hoofdstuk 3) toonde aan dat hun keuze afhangt van de omstandigheden; de keuze voor een bepaald mungbeanproduct wordt voornamelijk bepaald door sociaal-economische omstandigheden en minder door perceptie en voorkeur. Belangrijke factoren die de inname van nutriënten tijdens consumptie bepalen, zijn de begeleidende gerechten en de frequentie van de consumptie van mungbeanproducten. Verhogen van de consumptiefrequentie zou een effectieve manier zijn om de inname van mineralen van mungbean te vergroten. Toevoeging van ingrediënten zoals citroensap of korianderblad verbetert de mineralenbeschikbaarheid. Gelijktijdige consumptie van thee of koffie, daarentegen, lijkt de mineralenbeschikbaarheid te verslechteren. Bepaalde mungbeanproducten kunnen worden gezien als geschikte kandidaten voor het tegengaan van ondervoeding vanwege hun nutritionele samenstelling (bijvoorbeeld de gehalten aan mineralen en hun beschikbaarheid), consumentenaspecten (bijvoorbeeld kennis, perceptie, voorkeur en gebruik) en sociaal-economische factoren.

Scenarioanalyse, die werd uitgevoerd op basis van consumentenperceptie, voorkeur, gebruik en nutritionele waarde van producten, liet zien dat *dhals* de meest veelbelovende producten zijn ten aanzien van nutriëntengehalte, bereidingsgemak en consumptiefrequentie. *Dhals* kunnen worden geherformuleerd door veredeling die gebaseerd is op voedingswaarde, het toepassen van traditionele bereidingswijzen die de mineralenbeschikbaarheid stimuleren, en een betere samenstelling van de maaltijd. *Dhals* zijn waardevol omdat ze zeer voedzaam zijn, makkelijk verteerbaar en goed verzadigen. *Dhals* leveren een significante bijdrage aan de inname van eiwit, ijzer en zink door de Indiase vegetarische bevolking, die dikwijls lijdt aan deficiënties. *Dhals* kunnen hogere gehalten aan mineralen hebben wanneer tijdens hun bereiding gebruik wordt gemaakt van verschillende specerijen, kruiden, tomaat en ui. Bovendien zijn *dhals* ook geschikt voor minder draagkrachtige mensen aangezien ze relatief goedkoop zijn in vergelijking met andere mungbeanproducten. Verder zijn *dhals* makkelijk verkrijgbaar en gemakkelijk klaar te maken. Vanuit cultureel oogpunt bezien, spelen *dhals* een belangrijke rol in de voedingsgewoonten in India. Verbeteringen zouden zich moeten richten op de povere sensorische eigenschappen van dehulled *dhal*, bijvoorbeeld door het toevoegen van lokale groenten of kruiden aan de receptuur. Verder kunnen *dhals* nog eenvoudiger te bereiden worden gemaakt, bijvoorbeeld door het verkorten van de benodigde kooktijd.

De conclusie is dat mungbean *dhals* een geschikt product zijn voor het bestrijden van mineralen deficiënties. Dit onderzoek, dat deel uitmaakte van het interdisciplinaire 'TELFUN' project, heeft de opties in kaart gebracht voor het herformuleren van traditionele mungbeanproducten op basis van hun productie, bereiding en consumptie ten behoeve van een betere voeding.

सारांश (Summary in Hindi)

संसाधन–गरीब समुदायों में कुपोषण भोजन सम्बन्धित महत्वपूर्ण समस्याओं में से एक है। अब तक के दृष्टीकोण से कोई भी कुपोषण को कम करने के लिए एक स्थाई समाधान प्रदान करने के उद्देश्य से असमर्थ रहा है। खाद्य संप्रभुता एक अपेक्षाकृत नई अवधारणा है जिसके तहत लोगों को खाद्य उत्पादन, प्रसंस्करण और उपभोग का अधिकार शामिल है। इसमें स्थानीय खाद्य प्रणाली के सतत विकास को सुविधाजनक बनाने की क्षमता है। स्वदेशी खाद्य पदार्थ खाद्य संप्रभुता को बढ़ाने में महत्वपूर्ण कारक हो सकते है। हालांकि स्वदेशी पारम्परिक खाद्य प्रणाली में कई लाभप्रद विशेषताएं हैं, परन्तु उनकी वास्तविक उपस्थिति कुपोषण को रोकने के लिए प्रयाप्त नहीं है। इस अन्तर को अनुसंधान की आवश्यकता है, जिससे यह जाना जा सकता है कि कौन सा स्वदेशी खाद्य पदार्थ नवीनीकरण व पुनः रचना के लिए उम्मीदवार है, जिससे कुपोषण के उन्मूलन में योगदान हो सकता है। वर्तमान शोध बहतर पोषण के लिए पारम्परिक खाद्य पदार्थों की पुनः रचना द्वारा उत्तर भारत के मूंग खाद्य प्रणाली में तकनीकी विकल्पों से सम्बन्धित है। पारम्परिक खाद्य पदार्थों की पुनः रचना के लिए पोषक तत्वों की खुराक को प्रभावित करने वाले कारको की आवश्यकता है। इस तरह की गुणवत्ता सम्बन्धि कारकों में प्रयाप्त खपत, उच्च पोषक तत्व, जीवप्राप्यता और उपभोक्ता संतुष्टी शामिल है, जो एक अंतविर्षयक सेंटिंग में अध्ययन किया गया है।

इस अनुसंधान के मुख्य उद्दश्य है (1) मूंग के भौतिक खाद्य प्रसंस्करण, पोषण और पोषण–विरोधी गुणों की समीक्षा करना (2) मूंग खाद्य पदार्थों सम्बन्धित उपभोक्ता जागरूकता, ज्ञान धारणायें, वरीयतायें और पोषक तत्वों की क्षमता पर उनके प्रभाव से सम्बन्धित प्रथाओं का निर्धारण करना (3) नव नसल व स्थापित मूंग किस्मों में पोषक तत्वों की विशेषताओं का निर्धारण (4) स्वदेषी मूंग खाद्य पदार्थों की विशेषताओं का निर्धारण, और (5) पोषण क्षमता को प्रभावित करने वाले सभी कारकों का गंभीरतापूर्वक मूल्यांकन और पारम्परिक मूंग उत्पादों की पुनः रचना के लिए तकनीकी विकल्पों की पहचान करना।

मूंग की तकनीकी और पोषण क्षमता पर समीक्षा से पता चला है कि अनाज की संरचना कृषि शास्त्रीय प्रथाओं, अनुवांषिक विविधता और भूमि विशिष्ट अवस्थाओं जैसे तीन कारकों पर मुख्य रूप से निर्भर करता है। मूंग प्रोटीन (14.6–33.0 ग्राम प्रति 100 ग्राम) और लोहे (6.9–7.6 मिलीग्राम प्रति 100 ग्राम) का एक समृद्ध स्त्रोत है। हालांकि, फायटिक अमल (441.5 मिलीग्राम प्रति 100 ग्राम) और पौलीफिनौल (462 मिलीग्राम प्रति 100 ग्प्रम) जैसे विरोधी पोषक कारकों की उपस्थिति की वजह से खनिज प्राप्यता कम है। कुल खनिज सामग्री में वृद्धि करना, विरोधी पोषण यौगिकों की सामग्री में कमी करना, और विटामीन–सी जैसे खनिज प्राप्यता को बढ़ाने वाले यौगिकों की उपस्थिति बढाना, उत्पादन स्तर पर खनिज प्राप्यता बढ़ाने के विकल्पों में शामिल हैं। तथापि, आखिरी विकल्प प्रभावी नहीं होगा क्योंकि विटामीन–सी पारम्परिक प्रक्रिया के दौरान गर्मी से नष्ट हो जायेगा। इसी तरह पौधों के अंकुरण और विकास में महत्व के कारण फायटिक अमल में कमी करना भी अप्रभावी विकल्प हो सकता है। इसलिए प्रजनन या बॉयोटेकनोलोजीकल तकनीकों द्वारा कुल खनिज सामग्री को बढ़ाना मूंग के मामलें में शायद सबसे अच्छा तरीका है। इसके लिए मौजूदा पोषक किस्मों की रासायनिक संरचना, अनुवांशिक

संरचना, कृषि शास्त्रीय और भौतिक गुणों के आधार पर चयन करने की आवश्यकता है। मूंग की सात नई नसलों और तीन स्थापित किस्मों का आसन्न रचना, खनिज–विरोधी पोषक तत्वों और इन–विट्रो खनिज प्राप्यता के लिए विषलेषण किया गया (अध्याय –4) । इनमें 18–25 ग्राम प्रोटीन, 4.0 – 5.6 ग्राम रेशा और 2.5–4.1 ग्राम राख प्रति 100 ग्राम सूखे नमूने में निहित है। इनमें लोहे, जिंक, कैल्शियम, सोडियम और पोटैशियम की मात्रा क्रमशः 3.4–4.6, 1.2–2.3, 79–115, 8.1–13.5 और 362–415 मिलिग्राम प्रति 100 ग्राम सूखे नमूने में है। फायटिक अमल और पौलीफिनौल की औसत मात्रा 769 और 325 मिलिग्राम प्रति 100 ग्राम सूखे नमूने में है। फायटिक अमल व पौलीफिनौल इन–विट्रो खनिज प्राप्यता और पोषक तत्वों की पाचन शक्ति के साथ नकारात्मक सह–सम्बन्ध रखते थे। फायटिक अमल का लोहे और जिंक के साथ आणविक अनुपात क्रमषः 16.8 और 52.7 है। इन–विट्रो लोहें और जिंक प्राप्यता में अन्तर न तो फायटिक अमल के कैल्शियम के साथ आणविक अनुपात से समझाया जा सकता है और न ही फायटिक अमल के मैगनीशियम के आणविक अनुपात से। हम उम्मीद करते हैं कि कैल्शियम की मात्रा जैसे अन्य कारण भी खनिज प्राप्यता को प्रभावित करते हैं। MH 125 किस्म में सबसे अधिक लोहें, कैल्शियम, मैगनीशियम और सोडियम है जिससे यह पोषणता के अनुसार रूचिकर है। हालांकि विभिन्न स्थानीय खाद्य पदार्थों में इस्तेमाल करने के लिए MH 125 किस्म में खनिज जीवप्राप्यता पर अधिक अनुसंधान की आवश्यकता है।

मूंग उत्पादों की तैयारी में विभिन्न प्रसंस्करण कदम अनिवार्य हैं जो कि पोषण तत्वों की संरचना को प्रभावित करते हैं। 14 मूंग उत्पादों में आसन्न संरचना, इन–विट्रो खनिज प्राप्यता, फायटिक अमल और पौलीफिनौल सामग्री का विशलेषण करने के लिए अध्ययन का आयोजन किया गया (अध्याय–5)। मूंग उत्पादों में औसत इन–विट्रो लोह, जिंक और कैल्शियम प्राप्यता क्रमशः 1.6, 0.9 और 41.8 मिलिग्राम प्रति 100 गम्रम सूखे नमूने में हैं। फायटिक अमल और पौलीफिनौल की औसतन मात्रा क्रमशः 210 और 180 मिलिग्राम प्रति 100 ग्राम सूखे नमूने में है तथा ये इन–विट्रो खनिज प्राप्यता के साथ नकारात्मक सह–सम्बन्ध रखते हैं। पौलीफिनौल की मात्रा साबुत मूंग से बने उत्पादों जैसे साबुत दाल, धुली दाल व साबुत लड्डू में ज्यादा पाई गई। इन–विट्रो लोह प्राप्यता की सबसे ज्यादा मात्रा धुली दाल (2.4 मिलिग्राम प्रति 100 ग्राम) में थी और उसके बाद भल्ले व अंकुरित दाल में पाई गई, जबकि साबुत लड्डू, नमकीन और पापड़ में इन–विट्रो प्राप्यता सबसे कम थी। परिणाम से यह पता चला है कि किण्वित व अंकुरित मूंग खाद्य पदार्थों में इन–विट्रो लोह, जिंक और कैल्ष्शियम प्राप्यता सबसे उच्च थी। पारम्परिक उत्पादों की पुनः रचना में किण्विन और अंकुरण के समावेष से खनिज प्राप्यता में वृद्धि हो सकती है। प्रसंस्करण कदमों के प्रभाव के अलावा, उत्पादों की तैयारी के दौरान अन्य सामग्री के उपयोग का खनिज पोषण पर एक महत्वपूर्ण प्रभाव भी हो सकता है। उदाहरण के लिए, मिठाई में इस्तेमाल होने वाले मेवों में फायटिक अमल होता है जो कि उत्पाद में कुल फायटिक अमल को बढ़ा देते हैं। दालों में प्रयोग होने वाली

सब्जियां जैसे टमाटर और धनिया, विटामीन–सी की मात्रा को बढ़ाते है जो कि खनिज प्राप्यता को बढाने में सहायक है।

मूंग उपभोक्ताओं (अध्याय–3) की आदतों पर हमारे अध्ययन से पता चला है कि उनके भोजन विकल्प परिस्थितिओं के साथ बदलते हैं। मूंग उत्पादों के प्रकार का ग्रहण, धारणा और वरीयताओं की बजाय मुख्य रूप से सामाजिक–आर्थिक परिस्थितियों से प्रभावित है। संगत के रूप में सेवन करने वाले खाद्य पदार्थ व मूंग भोजन की आवृर्ति, खपत के स्तर पर पोषक तत्वों की खुराक पर प्रभाव डालने वाले महत्वपूर्ण कारक है। मूंग के माध्यम से खनिज प्राप्यता को बढ़ाने के लिए उपभोग की आवृर्ति को बढ़ाना एक प्रभावी तरीका हो सकता है। नींबू के रस और धनिये जैसी सामग्री के इस्तेमाल से खनिज प्राप्यता को बढ़ाया जा सकता है। इसके विपरित चॉय व कॉफी का उपयोग खनिज प्राप्यता को कम करता हैं। कुपोषण को कम करने के लिए कुछ मूंग उत्पाद पोषण संरचना (जैसे खनिज सामग्री और उनकी प्राप्यता), उपभोक्ता विशेषताओं (अर्थात ज्ञान धारणा, वरीयतायें और प्रथायें) और सामाजिक– आर्थिक कारको के आधार पर उम्मीदवार हो सकते हैं।

उपभोक्ता धारणा, वरीयतायें, प्रथायें और उत्पादों के पोषण के महत्व के आधार पर किये गये परिदृश्य विषलेषण से पता चला है कि दालें पोषक तत्व सामग्री, सुविधाजनक प्रसंस्करण और उपभोग की आवृर्ति के आधार पर सबसे उत्तम विकल्प है। पोषण आधारित प्रजनन, खनिज बढ़ाने वाले पारम्परिक प्रसंस्करण और बेहतर आहार प्रथाओं के आधार पर दालों की पुनः रचना की जा सकती है।

दालें मूल्यवान हैं क्योकि वे बेहद पौष्टिक, संवहनीय और पचाने में आसान हैं। दालें प्रोटीन, लोह और जिंक के मामले में अकसर आहार की कमी वाले भारतीय शाकाहारी आबादी के भोजन में योगदान करती है। दालों को बनाने के दौरान विभिन्न मसालों, टमाटर और प्याज के इस्तेमाल से खनिज सामग्री को बढाया जा सकता है। सुविधा के मामले में दालें संसाधन–गरीब लोगों के लिए उपयुक्त हैं। क्योंकि ये अन्य मूंग उत्पादों को तुलना में अपेक्षाकृत सस्ती होती हैं। इसके अलावा वे आसानी से उपलब्ध हैं और इनका प्रसंस्करण सुविधाजनक है। सांस्कृतिक तौर पर भारतीय आहार की आदतों में दालें एक महत्वपूर्ण भूमिका निभाती हैं। सुधार के लिए स्थानीय सब्जियों व मसालों के इस्तेमाल से धुली दाल की संवेदी विशेषताओं को बढाना चाहिए। इसके अलावा दालों को पकाने के समय को कम करने जैसे विकल्पों पर काम करने से दाल प्रसंस्करण को ज्यादा सुविधाजनक बनाया जा सकता है।

यह निश्कर्ष निकाला जा सकता है कि दालें खनिज कुपोषण के उन्मूलन के लिए एक अच्छा वाहन हो सकती है। अतः अंतर्विषयक टलफन (TELFUN) परियोजना के एक हिस्से के रूप में यह शोध उत्पादन, प्रसंस्करण व खपत के आधार पर पारम्परिक मूंग खाद्य पदार्थों की पुनः रचना के विकल्पो का मनसचित्रण करता है।

Acknowledgements

The writing of this thesis has been an insightful journey. Along the way, the benevolence of many influenced, in innumerable ways, this offering placed before you. In all good conscience, I cannot do without acknowledging the names of those most essential to its completion. This is an impossible task, given the many people who have contributed to design, implement, apply, assess and support the work. I am going to try anyway, and if some names are not listed, rest assured that my gratitude is not less than for those listed below.

My deepest thankfulness is to my supervisors, Dr. ir. M.A.J.S van Boekel, Dr. ir. Anita Linnemann, and Dr. ir. Rob Nout, whose expertise, understanding and search for perfection in addition to constructive criticism, constant co-operation and encouragement, added considerably to my looking forward to things practically beyond the boundaries of literature. I have been amazingly fortunate to have mentors who gave me the freedom to explore on my own and at the same time the direction to recover when my steps faltered. I bow my head to express profound sense of gratitude to my Indian co-supervisors, Dr. (Mrs.) R. B. Grewal; Centre of Food Science and Technology, C.C.S Haryana Agricultural University, Hisar and Dr. Neelam Khetarpaul; Department of Foods and Nutrition for their kind guidance, constant encouragement, valuable suggestions, and pain-taking efforts during the course of investigation. Their valuable advice and extended vital help during the course of work to facilitate me focused my ideas and widened my knowledge. I want to express my thanks to all my supervisors for giving me great zeal, strength, wisdom, courage and perseverance besides walking all along my footsteps to overcome every obstacle in the drive to carry out this study.

I appreciatively acknowledge the financial support from the Department of Biotechnology (DBT), Ministry of Science and Technology, Government of India, from Wageningen University through the Interdisciplinary Research and Education Fund (INREF) via the TELFUN programme and from the International Foundation of Science (IFS) (Grant No. - A E/21294).

I wish to convey my heartiest appreciation for round the clock help extended to me by staff of the Food Quality and Design and Laboratory of Food Microbiology, of Wageningen University. I am grateful to my colleagues who gave a wonderful work environment. The help and cooperation from the members of technical staff of both the departments, viz. Charlotte van Twisk, Geert Meijer, Frans Lettink, Xandra Bakker-de Haan, Ingrid Maas and Harry Baptist played an important role in conducting experiments. Members of scientific staff of these departments, viz. Ruud Verkerk, Pieternel Luning and Matthijs Dekker, offered insights during departmental presentations, which helped in one or the other way to improve my scientific thinking.

This thesis, being part of the project called 'TELFUN', has given me the platform to reflect my thoughts and understanding on the global issue of malnutrition. This project has given me opportunities to play a significant role in an interdisciplinary manner. I would like to thank the PhD members of this project *viz.* Razak, Kwadwo, Wilhelmina, Renu, Yann, Varsha, Shweta, Francisco, Maria-Elisa, Cesar and Alexandra for providing an interdisciplinary stage and assistance at all levels of the research project. Their insightful suggestions and discussions during TELFUN workshops and different stages of my research were thought-provoking. I thank Prof. Ram Kumar of the Department of Plant Breeding of CCS Haryana Agricultural University, Hisar, India, who provided the mung bean varieties under investigation, along with the relevant information on status and characteristics of the varieties. I also want to convey my gratitude to the other members of the Indian TELFUN supervisor's *viz.* Dr. Nishi Sethi, Dr. Sushma Kaushik, Dr. R.C. Yadav, Dr. Sudesh Jood and Dr. R.S. Dalal for their insights and precious help.

Appreciation also goes out to the non-teaching staff of the Centre of Food Science and Technology, Mr. S.L. Sharma, Mr. Umed Singh, Mr. Hari Yadav, Mr. Bhala Ram, Mr. Mahavir, Mr. Patanjli, Mr. Ranjeet, Mrs. Naresh, and Mrs. Santosh and all others for lending a cooperative hand during research work. I am highly grateful to the non-teaching staff members of Department of Food and Nutrition, especially Mr. Karnail Singh, Mr. Sita Ram, Mr. Dalbir Singh, Mr. Surender Kumar and Mr. Satbir for their ever willing help.

Words fail to express my deepest sense of gratitude that I owe to my loving parents who struggled throughout to provide me the best of everything in life. Their foresight and values paved the way for a privileged education and the support they provided me through my entire life made me the person I am. My siblings Deepti, Poonam, Jyoti and Gagan have been a constant support always. Their innovative ideas also contributed in deciding my research topic. Thanks for the love, the encouragement and the unwavering confidence in your brother. I adorably remember my sister Nisha here, whom we lost 8 years back.

Life blessed me with the opportunity to meet my wife Sakshi; in her I found a wonderful blend of hard work, determination and true grit; as any good genius knows, she is as good as the root. Without her tireless, wholehearted and unique contributions along with the much needed moral support, this investigation would not have taken shape the way it has. Her name could easily be mentioned on the cover alongside mine and I express my deep appreciation in this regard. She saw the light at the end of the tunnel and encouraged me to see it also, even in those darkest moments. Her faith in all my endeavours, constant motivations and care helped me to overcome setbacks; to stay focused and encouraged me each day to get going.

I can look back to incredible days and special memories of friends like Denisse, Vaida, Laura, Susan, Saskia, Roan, Vinod, Jan Bus, Desiree, Nidhi and Mannu. The warm support of all of them enabled me to complete this investigation and have a wonderful time along the way. Although named in a row, they are appreciated for their individual contributions. I greatly value their friendship and am deeply glad about their belief in me.

Fervent thanks to many, many other people who have helped in immeasurable ways. I have to express my gratitude to special people who were with me in space and time giving me moral and emotional support to inspire the completion of this study. In conclusion, I would like to recognize all good beings of the universe whose teachings, dynamism and affection paved way for my years of life.

Bibliography and curriculum vitae of the author

List of publications

Accepted papers

Dahiya, P. K., Linnemann, A. R., Nout, M. J. R., van Boekel, M. A. J. S., Khetarpaul, N., and Grewal, R. B. (2013). Mung bean: technological and nutritional potential. *Critical Reviews in Food Science and Nutrition*.

Submitted papers

Dahiya, P. K., Linnemann, A. R., Nout, M. J. R., van Boekel, M. A. J. S., Khetarpaul, N., and Grewal, R. B., Consumption habits and innovation potential of mung bean foods.

Dahiya, P. K., Linnemann, A. R., Nout, M. J. R., van Boekel, M. A. J. S., and Grewal, R. B., Nutrient composition of selected newly bred and established mung bean varieties.

Dahiya, P. K., Linnemann, A. R., Nout, M. J. R., van Boekel, M. A. J. S., Khetarpaul, N., and Grewal, R. B., Nutritional characteristics of mung bean foods.

Posters

Dahiya, P. K., Linnemann, A. R., Nout, M. J. R., van Boekel, M. A. J. S., Khetarpaul, N., and Grewal, R. B. (2009). Food Sovereignty as a function of sustainability in consumption of indigenous foods & their processing methods: a case of mung bean. *EFFoST Annual meeting "New challenges in food preservation: Processing- Safety- Sustainability",* 10-13 November 2009, Budapest, Hungary.

Curriculum vitae

Pradeep Kumar Dahiya was born on November 7th 1980 in Rohtak, India. He attended primary and secondary school in Bhiwani and Rohtak and graduated from the Maharishi Dayanand University, Rohtak, India in 2003. In July of the same year, he joined the Government College of Education in Bhiwani and did his Bachelor of Education. During 2004–06, he pursued his M.Sc. degree in Food Science & Technology from the Center of Food Science & Technology, Chaudhary Charan Singh Haryana Agricultural University, Hisar (Haryana), India. In 2007, he obtained a research grant from Wageningen University through the Interdisciplinary Research and Education Fund (INREF), to undertake a Ph.D. research project. From April 2007 to December 2012 he carried out the research presented in this thesis entitled 'Towards redesigning indigenous mung bean foods' at Chaudhary Charan Singh Haryana Agricultural University in India and at Wageningen University in The Netherlands. This thesis presents the results of scientific research, which have been published in or submitted to peer-reviewed journals and presented at international workshops and conferences.

Overview of completed training activities

Discipline specific activities

Food Fermentation, VLAG, Wageningen, The Netherlands	2008
Food Risk Analysis: An integrated approach combining insights from natural and social sciences, Graduate School Mansholt, Wageningen, The Netherlands	2009
Reaction kinetics in food sciences, VLAG, Wageningen, The Netherlands	2009
Food perception and food preference, VLAG, Wageningen, The Netherlands	2011

Scientific meetings

19th Indian Convention of Food Scientists and Technologists, CFTRI, Mysore, India	2008
Lectures: Food sovereignty: origins, meaning and relation with other discourses; Techn. for sustainable food networks: do locally matters? Wageningen, The Netherlands	2008
National Seminar on Non-biological contaminants in food, feed & their safety standards. New Delhi, India	2008
Second TELFUN Workshop in Quito, Ecuador (Oral Presentation)	2008
Food Safety & Quality, Guru Jhambeshaver University, Hisar, India (poster presentation)	2008
Third TELFUN Workshop in Hisar, India (Oral Presentation)	2009
EFFoST conference: New challenges in Food preservation: Processing, Safety and Sustainability, Budapest, Hungary (poster presentation)	2009
Home Economics & Nutritional Science, CCS Haryana Agricultural University, Hisar, India	2009
Biodiversity & Agri-biotechnology, Jaypee Institute of Information Techn. University, India	2009
Legal requirements for setting up food processing industries & its scope in Haryana through cluster approach, Ministry of MSME, CCS Haryana Agri. University, Hisar, India	2009
Prospect & problems in production, processing & marketing of medicinal & aromatic plants in Haryana, National Medicinal Board at CCS Haryana Agric. Univ., Hisar, India	2009
Various aspects of WTO, Ministry of MSME at CCS Haryana Agric. Univ., Hisar, India	2009
Micronutrients and Child Health, All India Institute of Medical Sciences, New Delhi, India	2009
Mini symposium on sustainable food production & consumption: Will Novel Protein Foods Beat Meat?, VLAG, Wageningen, The Netherlands	2010
Fourth TELFUN Workshop in Tamale, Ghana	2010
Emerging Challenges: Medicinal Plants, CCS Haryana Agricultural Univiversity, Hisar, India (poster & oral presentation)	2010
Recent Trends in Horticultural Crops-Issues and Strategies for Research and Development, CCS Haryana Agricultural University, Hisar, India (poster presentation)	2010
Processed Foods & Beverages for Health, International Life Sciences Institute, New Delhi, India	2011
Indo-Dutch Consumer Driven Innovation in Food Processing & Retail, New Delhi, India	2011
Nutrition & lifestyle: Emerging NCD challenges, International Life Sciences Institute, India	2012
Food Industry Regulation, Confederation of Indian Food Trade and Industry, Delhi, India	2012
Sustainable Agriculture & Food Security, CCS Haryana Agricultural University, Hisar, India	2012

General courses

Information literacy including introduction Endnote, Wageningen University, The Netherlands 2007

Presentation skills, Wageningen University, Wageningen, The Netherlands 2008

Intellectual Property, World Intellectual Property Organization, Switzerland 2009

Scientific and technical writing program (distance learning course), Nano Science & Technology Consortium, Noida, India 2009

Advanced course guide to scientific artwork, Wageningen University, Wageningen, The Netherlands 2010

Statistical Modeling for Data Analysis, Indian Institute of Technology, Kharagpur, India 2010

Nutrition Security and Sustainable Development, I.G. National Open University, New Delhi, India 2010

Science communication through print media, NICSAIR, New Delhi, India 2010

Post Graduate One Year Online Training Course in Science Journalism, Indian Science Communication Society, Lucknow, India 2010

Data Analysis using SPSS, Kurukshetra University, Kurukshetra, India 2012

ISO 22000:2005 Food Safety Management System Lead Auditor, Nigel Bauer & Associates, United Kingdom 2012

ISO 9001:2008 Quality Management System Lead Auditor, Nigel Bauer & Associates, United Kingdom 2012

Optional

Preparation PhD research proposal 2007

PhD day of Mansholt Graduate School (MGS) 2007

PhD tour to Canada, Laboratory of Food Microbiology, Wageningen University 2008

Group colloquiums, Food Microbiology and PDQ 2009-12

Cover design & lay out Pradeep Kumar Dahiya
Printed by GVO drukkers & vormgevers B.V., Ponsen & Looijen