Chapter 2

Review of Literature
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Chapter 2

REVIEW OF LITERATURE

2.1 Introduction

The importance of rapeseed-mustard in Indian agriculture has already been described briefly (Chapter 1). Various aspects of crop that require more detailed consideration are considered below. In addition, some attention has also been given to nitrogen, phosphorus, potassium and sulphur as plant nutrients and to their commonly available sources and to various methods of application of these fertilizers.

2.2 Rapeseed-mustard

In India, rapeseed-mustard, like other crops, has been cultivated from pre-historic times. Since then, efforts have been made to improve their genetic make-up and method of cultivation. As a result, considerable literature is available regarding various aspects of this crop. In the following pages, an effort has been made to review the available literature on general aspects and on the mineral nutrition of these plants.

2.2.1 Nomenclature

Under the names rapeseed and mustard, several oilseeds belonging to the Brassicaceae syn. (Cruciferae) are grown in India. These are divided into four groups to avoid confusion.

1. Brown mustard, commonly called rai (raya or laha). Brassica juncea (L.) Czern. & Coss

2. Sarson

   (a) Yellow sarson – Brassica campestris L. var. sarson Prain

   (b) Brown sarson – Brassica campestris L. var. dichotoma watt

3. Toria (Lahi or Maghi Labi) – Brassica campestris L. var. toria Duth.
4. *Taramira* or *tara* (*Eruca sativa* Mill.):

Sarson and toria are commonly known as rapeseed and rai as mustard. However, in trade, taramira and in world statistics, turnip rape (*Brassica napus* L.) and oilseed rape (*Brassica oleracea* L.) are also included under ‘rapeseed’ (Baranyk and Fabry, 1999; Reddi, 2003).

2.2.2 Botanical description

Rapeseed-mustard includes annual herbs. Root, in general, is long and tapering tap root. Stem is erect, much branched with variable height ranging from 0.45 m to 1.75 m. Lower leaves are petiolate, upper leaves are sessile, variously lobed, more or less entire, glabrous or with few bristly hairs. The inflorescence is a corymbose raceme. Flowers are orange to pale yellow, actinomorphic, hermaphrodite and hypogynous with four petals spread out in the form of a Greek cross. The flowers bear six stamens with *tetradynamous* condition and a bicarpellary syncarpous superior ovary having parietal placentation. The fruit is a siliqua (Reddi, 2003).

2.2.3 Classification

Adopting the system of classification of Bentham and Hooker (1862-1883), all aforesaid oil producing species could be classified as follows:

Kingdom: Plant Kingdom

Division: Phanerogamia

Sub-division: Angiospermae

Class: Dicotyledons

Sub-class: Polypetalae

Series: Thalamiflorae

Order: Parietales

Family: Cruciferae

Genus: *Brassica*
However, it may be added that the current name of the family is *Brassicaceae* (Cronquist, 1981) and the recent classification is therefore:

**Kingdom - Plantae - Plants**

- **Subkingdom** – Tracheobionta – Vascular plants
- **Superdivision** – Spermatophyta – Seed plants
- **Division** – Magnoliophyta – Flowering plants
- **Class** – Magnoliopsida – Dicotyledons
- **Subclass** – Dilleniidae
- **Order** – Capparales
- **Family** – *Brassicaceae* – mustard family
- **Genus** – *Brassica*

### 2.2.4 Origin

*Brassica juncea* L. was originally introduced into North-eastern India from China. It later got extended into Afghanistan via the Punjab. Eastern India is one of the independent centers of origin of *Brassica campestris* L. Taramira, is a relatively recent introduction into India. Taramira is believed to be native of southern Europe and North Africa (Reddi, 2003). *Brassica napus* L. is a latest introduction into India. Its origin is obscure, but were initially proposed to involve natural interspecific hybridization between the two diploid species *Brassica oleracea* L. and *Brassica rapa* L. (syn. *campestris*). Northern Europe is supposed to be the centers of its origin (OECD, 1997).

### 2.2.5 Distribution

The crop is grown both in subtropical and tropical countries. In Asia, it is chiefly grown in China, India and Pakistan. It is also grown in Canada, Europe and Russia, but the forms of rapeseed-mustard grown there are different from those grown in India. India occupies the first position, both with regard to acreage and production of rapeseed-mustard in the world. The chief states
producing them are Assam, Bihar, Haryana, Madhya Pradesh, Orissa, Punjab, Rajasthan, Uttar Pradesh and West Bengal (Reddi, 2003).

2.2.6 Climate and soil

The rapeseed-mustard crop is of the tropical as well as of the temperate zones and requires relatively cool temperatures for satisfactory growth. In India, this is grown in the ‘rabi’ (winter) season from September-October to February – March. The crop grows well in areas having 25-40 cm of rainfall annually and thrives best in light to heavy loams (Reddi, 2003).

2.2.7 Cultivation

A finely prepared seed-bed is required to ensure good germination. When sown pure, 5 kg seeds per hectare are required for direct sowing of varieties of all rapeseed-mustard. Whenever, moisture in the field is inadequate, the seeds are mixed with moist soil and kept overnight. For distributing evenly, seeds are usually mixed with sand before sowing. Seeds are sown at a depth of 4 to 5 cm in line, 30 cm apart with a drill or behind the plough. Thinning is done three weeks after sowing to maintain a plant-to-plant distance of 10 to 15 cm.

The entire quantity of applied fertilizer, particularly nitrogen, is drilled before sowing. Under irrigated conditions, doses of 40, 60 and 80 kg N/ha are considered optimum for toria, sarson and raya respectively. However, under rainfed conditions, 40 kg N/ha is optimum for all rapeseed-mustard varieties. Two irrigations, one at flowering and other at pod formation, result in maximum yield in rapeseed-mustard (Reddi, 2003).

Plants are generally harvested before fruits are fully ripe to reduce shattering. Harvesting is usually performed in early morning. Threshing is done by beating with a wooden stick the seed-bearing part of the plants taken in convenient bundles or by trampling them under the feet of bullocks. Winnowing is done with the help of natural air current by slowly dropping the threshed produce from a basket held shoulder high (Reddi, 2003).
2.2.8 Uses

The leaves of young plants are used as a green vegetable. The seed and oil are used as a condiment in the preparation of pickles and for cooking and flavouring curries and vegetables. Seeds yield oil which is the main cooking medium in northern India and can not be replaced by any other edible oil. The oil may also be used as an illuminant and lubricant, for soap manufacture and in the production of erucic acid used in turn in the manufacture of other chemicals. The oil is also used for massages, among others, in rheumatism and stiff joints.

2.3 Inorganic plant nutrition

Inorganic ions obtained from the soil having specific and essential functions in plants are called mineral nutrients and their absorption, translocation and metabolism refer to as mineral nutrition. In the following pages, a brief idea of history of mineral nutrition and of their sources as well as their main physiological roles in plants, particularly those demanded in relatively large quantities (nitrogen, phosphorus, potassium and sulphur) has been given. Moreover, methods of nutrient application and the effect of the exogenously applied nutrients on performance of rapeseed-mustard are also visualized.

2.3.1 Brief history

The antiquity of plant nutrition can be traced back from the time of Democritus of Abdera (460-360 BC). He added: “Mother earth when fructified by rain gives birth to crops for the nourishment of man and beast. But that which came from earth must return to earth and that which came from air to air. Death, however, does not destroy matter but only breaks up the union of its elements which are then recombined into other forms”. Aristotle (384-322 BC) assumed: “Plants assimilate organic matter from the roots”. Pliny (23-79 BC) concluded: “It is universally agreed by all writers that there is nothing more beneficial than to turn up a crop of lupines, before that have podded, either with
the plough or the fork, or else to cut them and bury them in heaps at the roots of trees and vines”. While the use of manure continued in medieval times, there were no theoretical contributions to plant nutrition until the Renaissance. Palissy (1510-1589) proposed the concept that manuring was to replace substances lost by crop removal. Van Helmont (1577-1644) attributed plant growth to water. Woodward (1665-1728) drew the attention to the importance of terrestrial matter for plant growth. Glauber (1604-1655) and Plattes (1600-1655) analyzed salts such as wood ash, limestone and saltpetre (potassium nitrate) on plant growth and invented a chemical fertilizer called “flattening salt” (Russell, 1926; Browne, 1943). Despite the ever-prevalent belief that humus (organic matter) was the entire source of plant nutrients, i.e. in the ‘Humus Theory’ of Aristotle, it was critically examined by de Saussure (1767-1845). He claimed the importance of nitrogen for plant growth. He believed that nitrogen is obtained wholly by absorption of soluble organic substances present in the soil. However, in the early 19th century, Liebig (1803-1873) assumed that nitrogen is absorbed from the air (not from humus). He gave the theory of the mineral nutrition of plants (Browne, 1943; Bould, 1963).

However, more meaningful developments in plant nutrition began in the 1960s with Sachs, Knop, Pfeffer and others, who began the practice of growing plants in artificial media chiefly in water culture, to determine the elements essentially for the growth of plant (Gauch, 1972).

The contribution of plant nutrition as a science bloomed in the 20th century. In due course of time, different researches, using sophisticated analytical techniques, were able to demonstrate the essentiality of seventeen elements for plant growth and development. These essential plant elements are listed below according to their concentration in the tissue of higher plants in decreasing order: hydrogen, carbon, oxygen, nitrogen, potassium, calcium, magnesium, phosphorus, sulphur, chlorine, iron, boron, manganese, zinc, copper, nickel and molybdenum (Salisbury and Ross, 1992; Marschner, 2002).
2.3.2 Physiological roles of nitrogen, phosphorus, potassium and sulphur

Each essential plant nutrient plays a specific role in the plant. As nitrogen, phosphorus and potassium are removed by most crops (as also sulphur, by Brassica crops) in relatively large quantities, they are considered here individually in some detail.

2.3.2.1 Nitrogen

Nitrogen represents the mineral nutrient required in the largest quantities (1-3% on dry weight basis) by plants and is most limiting where maximal biomass production is desired (Salisbury and Ross, 1992; Hell and Hillebrand, 2001). It is taken by plants as nitrate ions ($\text{NO}_3^-$), ammonium ions ($\text{NH}_4^+$) and urea (Samuel et al., 1997; Forde and Clarkson, 1999; van Wieren et al., 2000). Nitrogen is reduced and incorporated into many essential compounds, such as amino acids, proteins, enzymes, nucleic acids, plant growth regulators, vitamins and chlorophyll (Bandurski, 1965; Beevers and Hageman, 1969; Devlin and Witham, 1986; Marschner, 2002). Under conditions of nitrogen deficiency, characteristic phenotypes result with pale mature leaves and after an elongation of roots which in turn decreases shoot:root ratio. The leaves and young fruits tend to drop prematurely (Salisbury and Ross, 1992; Hell and Hillebrand, 2001).

Excess supply of nitrogen leads to delayed ripening by encouraging more vegetative growth. The leaves acquire dark green colour and become thick and leathery. Root system is feebly developed and results in low shoot:root ratio. It delays reproductive growth and may affect adversely fruit and grain quality. The plants become more liable to attack of pests and diseases (Black, 1973; Devlin and Witham, 1986; Salisbury and Ross, 1992; Scheible et al., 1997; Zhang et al., 1999; Marschner, 2002).
2.3.2.2 Phosphorus

Phosphorus occurs in plants at 0.1 - 0.4% on dry weight basis. It is absorbed by plants from the soil as monovalent \((\text{H}_2\text{PO}_4^-)\) and divalent \((\text{HPO}_4^{2-})\) ions. Phosphorus is an essential structural constituent of metabolically active compounds, like nucleic acids, phospholipids, phytin, nicotinamide adenine dinucleotide, nicotinamide adenine dinucleotide phosphate, adenosine triphosphate, pyridoxal phosphate, nucleoproteins, purine and pyrimidine nucleotides and flavin nucleotide (Devlin and Witham, 1986; Hell and Hillebrand, 2001; Salisbury and Ross, 1992; Marschner, 2002). It plays an important role in photosynthesis, respiration, regulation of a number of enzymes and disease resistance (Tamhane et al., 1970; Raghothama, 1999).

Deficiency of phosphorus leads to increased root: shoot ratio, changes in root morphology and architecture, increased root hair proliferation, root hair elongation, accumulation of anthocyanin pigments, proteoid root formation and increased association with mycorrhizal fungi, shedding of prematurity leaves and delay in flowering and fruiting (Raghotama, 1999). It also causes a decrease in photosynthesis (Hewitt, 1963). Excess supply of phosphorus results in increased root growth compared with shoot growth (Tamhane et al., 1970).

2.3.2.3 Potassium

Potassium \((\text{K}^+)\) is the most abundant cation in plants (up to 10% on dry weight basis). It plays a role in basic functions, such as osmoregulation, electrical neutralization of anionic groups and control of cell membrane polarization (Clarkson and Hanson, 1980; Maathuis and Sanders, 1996). A large number of enzymes is either completely dependent on or stimulated by potassium (Sueltter, 1970). It is also essential for most metabolic processes, including glycolysis, oxidative phosphorylation and adenine synthesis (Evans and Sorger, 1966). Potassium plays an important role in tissue hydration and thus helps in opening and closing of stomata (Fischer and Hsiao, 1968; Humble and Hsio, 1969; Webb and Mansfield, 1992).
Potassium-deficient plants exhibit chlorosis (loss of green colour) along the leaf-margins or tips starting with the bottom leaves and progressing up the plant. The plants are stunted with little vigour and branches have weak stalks. This is accompanied by reduced grain size and yield. It also causes a decrease in photosynthesis and protein synthesis (Hewitt, 1963; Marschner, 2002).

2.3.2.4 Sulphur

Sulphur is required at 0.1-1.0% (on a dry weight basis) for growth and development. Sulphur is mainly taken up by plants via the roots from the soil solution and translocated symplastically through endodermal cells to the stele for distribution to the various plant tissue (Cacco et al., 1980; Grossman and Takahashi, 2001). Plant canopies are a strong sink for deposition of atmospheric sulphur dioxide, which enters mainly through the stomatal apertures (Faller, 1972; Taylor and Tingey, 1983; Olszyk and Tingey, 1985; Baldocchi, 1993).

Up to 90 per cent of the total sulphur is present in most plants as cysteine and methionine that in turn are predominantly bound in protein (Giovanelli, 1990). Reduced sulphur is required in the function of cofactors, such as acetyl coenzyme A, thiamine, biotin and lipoic acid. The sulphur containing tripeptide glutathione is involved in the regulation of protein synthesis (Kranner and Grill, 1996) and in the compensation of various forms of stress (Rennenberg and Brunold, 1994). Both functions of glutathione are highly significant for the survival of plants in a stressful environment. Sulphur-containing plant secondary compounds, like allin and isothiocyanate derivatives can be important for phytomedical applications (Fahey and Talaly, 1995; Sendle, 1995; Stoner, 1995).

The deficiency of sulphur leads to pale-green young leaves, while mature leaves remain dark-green. This phenomenon is different from the symptoms of nitrogen and phosphorus deficiency. Stems become abnormally long and develop woodiness. Sulphur deficiency leads to amino acid, as well as other nitrogen containing compounds and starch accumulation in the tissues,
increased proteolytic activity, decreased protein and oil production and photosynthetic process and delay in flowering (Burke et al., 1986; Devlin and Whitham, 1986; Dietz, 1989; Hell, 1997; Marschner, 2002).

2.3.3 Sources of nitrogen-, phosphorus-, potassium- and sulphur-containing fertilizers

In modern agriculture system, it has imperative to add a sufficient amount of these nutrients every year for raising agricultural production. For nitrogen, anhydrous ammonia, ammonium sulphate, ammonium chloride, ammonium nitrate-sulphate, ammonium nitrate with lime, ammonium phosphate-sulphate, ammonium polyphosphate solution, ammonium thiosulphate solution, calcium nitrate, potassium nitrate, sodium nitrate, urea, urea-sulphate, urea-ammonium nitrate, urea-ammonium phosphate and urea phosphate are the chief sources. Single superphosphate, nitric phosphate, diammonium phosphate, apatite and calcium phosphate are dominant sources of phosphorus. Inositol phosphate (esters of orthophosphoric acid), phospholipids, nucleic acids, phosphate sugars are applied as organic phosphorus sources. Muriate of potash (potassium chloride), potassium sulphate, potassium magnesium sulphate, potassium nitrate, potassium phosphate, potassium carbonate, potassium hydroxide, potassium thiosulphate and potassium polysulphate are the principal potassium fertilizers. The sources of sulphur comprise ammonium bisulphite, ammonium nitrate-sulphate, ammonium phosphate sulphate, ammonium polysulphide, ammonium sulphate, ammonium thiosulphate, ferrous sulphate, gypsum, magnesium sulphate, potassium sulphate, pyrite, potassium-magnesium sulphate, potassium thiosulphate, potassium polysulphide, sulphuric acid (100%), sulphur, sulphur dioxide, single super phosphate, triple superphosphate, urea-sulphur, urea-sulphuric acid and zinc sulphate (Miller and Donahue, 1990; Tandon, 1993; Tisdale et al., 1993).
2.3.4 Methods of fertilizer application

Under natural conditions, plants grow in soil and obtain nutrients from it through their root system. However, continuous cultivation results in depletion of nutrients in soil. Under such conditions, application of nutrients to soil becomes inevitable to ensure good harvest. Nutrients may also be applied through foliage, when immediate demand of a particular nutrient to the crop is apparent. The various methods of nutrient application to soil and foliage are briefly described below.

2.3.4.1 Soil application

Nutrients are applied to the soil in various ways irrespective of position of seed, seedling or the growing plant before, at or after sowing or on transplantation. The important ones, as described by Miller and Donahue (1990), are summarized below.

2.3.4.1.1 Gaseous fertilizer application

Anhydrous ammonia, which supplies nitrogen, is the only gaseous fertilizer used. Anhydrous ammonia is typically stored in a liquid form, most commonly under pressure, and to a lesser degree, under refrigeration. Anhydrous liquefied ammonia is applied to the soil at 10 to 15 cm depth (or even deeper in sandy soils). It vaporizes quickly but is captured by several components in the soil, including water, clay and other minerals.

2.3.4.1.2 Fertilizer application in irrigation water

Gaseous and solid fertilizers could be metered into the irrigation water. Sprinkler irrigation system is suitable and encourages better use of fertilizers dissolved in water.

2.3.4.1.3 Banding

In this method, fertilizer is applied slightly below and to one side of the seed. This method is best for those crops that are grown in rows.
2.3.4.1.4 Broadcasting

Fertilizers are applied uniformly across the entire soil surface.

2.3.4.1.5 Strip placement

Over-application of fertilizers and poor application methods have an adverse effect on our environment. Strip fertilizer placement can help producers improve conservation while increasing the efficiency and effectiveness of their fertility programme. This method of fertilizer management can ensure higher levels of production and profitability as it ensures maximum uptake and crop response.

2.3.4.1.6 Top-dressing

In this method, supplemental fertilizer is applied to the soil surface after the crop has grown to a pre-determined stage.

2.3.4.1.7 Side dressing

Fertilizer is applied to the growing crop either as a surface placement or a shallow banding.

2.3.4.2 Foliar application

This method of nutrient application refers to the spraying on leaves of growing plants suitable dilute solution of nutrient/s. Foliar application may be preferred under conditions, including nutrient deficiencies observed during early stage, unfavourable physical and chemical condition of soil and drought during.

2.3.5 Applied nutrients and rapeseed-mustard performance

Rapeseed-mustard, like other crops, responds to exogenously applied inputs, including nutrients. In the following pages, relevant available recent publications on performance of rapeseed-mustard to nutrients related to absorption and utilization of nitrogen, phosphorus, potassium and sulphur, applied through soil and foliage, have been reviewed. As the present study is
planned to be carried out in India, most of the references included are of Indian origin.

Bali et al. (1992) conducted a field experiment on *Brassica juncea* cv., KOS 1 and EC 132142 at Shalimar (Jammu and Kashmir). They applied N:P:K rates of 30:6.5:8.5, 60:13:17 or 90:20:25 kg/ha. Of these N:P:K combinations, 60:13:17 kg/ha proved best as far as seed yield was concerned.

Ghatak et al. (1992) performed a field experiment on *Brassica juncea* cv. RW 85-59 at Mohanpur (West Bengal). They applied three levels of nitrogen (0, 80, 160 kg N/ha). They reported highest seed yield with 160 kg N/ha. Applied nitrogen also increased seed oil content.

Mohan and Sharma (1992) performed a field experiment on *Brassica juncea* cv. Pusa Bold at Sabour (Bihar). They applied 0, 25, 50, 75 or 100 kg N/ha and 0, 25, 50, or 75 kg S/ha. They reported that seed yield increased up to 75 kg N/ha and 50 kg S/ha. A further addition of 25 kg N/ha and 25 kg S/ha decreased seed yield. Oil yield followed a similar pattern.

Prasad and Shukla (1992, 1993) carried out a field experiment on *Brassica juncea* cv. Varuna at Varanasi (Uttar Pradesh). They applied three doses each of nitrogen (0, 40, or 80 kg N/ha) and potassium (0, 30 or 60 kg K₂O, i.e. 0, 25 or 50 kg K/ha) either all at sowing or in 2 equal splits, at sowing and 40 days after sowing (DAS). They noted that seed yield increased with increase in nitrogen rate and was highest with application of 80 kg N + 60 kg K₂O (50 kg K/ha). Nitrogen, phosphorus and potassium yields in seed and straw were also higher with 80 kg N + 50 kg K/ha.

Rathore and Manohar (1992) studied the effect of graded levels of nitrogen and sulphur (0, 30, 60, 90, 120, 150 or 180 kg N/ha and 0, 80, 160, 240, 320, or 400 kg S/ha) on nitrogen content in different plant parts of mustard (*Brassica juncea* cv. T-59) at Jobner (Rajasthan). They found that nitrogen concentration in whole plant, leaf 2-3, leaf 4-5 and in top one-third of the plant increased with increase in applied nitrogen and sulphur.
Tripathi and Singh (1992) conducted a field experiment on two cultivars of *Brassica juncea*, viz. Varuna and NDR 8501 at Faizabad (Uttar Pradesh). They applied four levels of nitrogen (0, 40, 80, or 120 kg N/ha). Nitrogen, phosphorus and potassium uptake and seed protein content generally increased with nitrogen rate, while seed oil content decreased. Generally NDR 8501 proved superior to Varuna.

Dubey and Khan (1993a, b) and Dubey *et al.* (1994) conducted a field trial on *Brassica juncea* cv. Varuna at Powarkheda (Madhya Pradesh). They applied four doses of nitrogen (0, 30, 60 or 90 kg N/ha) and six levels of sulphur, viz. 0, 10, 20, 30, 40 or 50 kg S/ha. They noted that dry matter production per plant, plant nitrogen content and uptake, seed sulphur content and total sulphur, seed yield and seed protein content increased with increasing levels of nitrogen. Oil content was decreased by nitrogen application. Increasing levels of sulphur up to 30 kg S/ha increased dry matter production per plant, plant nitrogen content and seed yield and up to 20 kg S/ha, nitrogen uptake. Sulphur application up to 40 kg S/ha improved seed-sulphur and oil content. Increasing levels of sulphur enhanced total sulphur and protein content linearly.

Khanpara *et al.* (1993a, b) carried out a field experiment on *Brassica juncea* cv. Kranti at Udaipur (Rajasthan). They gave nitrogen at 0, 20, 40 or 60 kg N/ha and sulphur at 50, 100, 150 or 200 kg S/ha. Sulphur was applied as a full rate of elemental sulphur 21 days before sowing or as 50 kg gypsum + the remaining as elemental sulphur at the time of sowing. Dry matter production per plant, leaf area index at 50% flowering, number of primary and secondary branches per plant and seed yield per hectare increased with increasing rate of nitrogen application. Addition of sulphur up to 100 kg S/ha increased leaf area index, plant height, number of primary and secondary branches per plant and seed yield. They also noted that growth parameters and seed yield were not affected by source or time of sulphur application.
Shukla and Kumar (1993), working at Pantnagar (Uttaranchal), applied four levels of nitrogen (0, 40, 80 or 120 kg N/ha) to six cultivars of Brassica juncea viz., Kranti, Krishna, Pusa Bold, Rohini, Vardan and Varuna. Application of nitrogen increased crop growth rate, relative growth rate, leaf area ratio, leaf area index, seed yield but decreased oil content. Relative growth rate and leaf area ratio were not significantly different between cultivars, while net assimilation rate was highest in Vardan. Cultivars Kranti, Vardan and Krishna accumulated more dry matter in stem. Nitrogen content in stem and seeds was highest in Vardan, with remaining cultivars being at par. Cultivar Vardan proved superior in seed yield, whereas Rohini and Pusa Bold gave the lowest seed yield. Seed oil content was highest in Vardan and lowest in Rohini.

Arora et al. (1994) conducted a field experiment on Brassica juncea cv. Varuna at Gwalior (Madhya Pradesh). They applied four levels each of nitrogen (0, 30, 60 or 90 kg N/ha) and sulphur (0, 20, 40 or 60 kg S/ha) in all possible combinations. Of these, 90 kg N + 40 kg S/ha proved best for seed yield. Seed oil content increased significantly up to 30 kg N/ha and further raise caused a reduction up to 90 kg N/ha. However, a linear increase in oil content was observed with increasing levels of sulphur. Seed allylisothiocynate content increased steadily with each increase in level of nitrogen and sulphur. Iodine value of mustard oil increased with increasing levels of nitrogen and decreased with every increase in the level of sulphur.

Bikram et al. (1994 a, b, c) performing a field trial at Hisar (Haryana), applied four levels of nitrogen (0, 40, 80 or 120 kg N/ha) to Brassica juncea cv. RH-30, Brassica carinata cv. HC2 and rape cv. Midas 2. Leaf area index, leaf area duration, crop growth rate, yield and yield components, protein concentration, iodine value, sinigrin and glucosinolate increased with increasing nitrogen rate. Oil yield increased with up to 80 kg N/ha. However, oil concentration decreased with increase in nitrogen rate. Regarding Brassica species, Brassica carinata followed by rape, proved superior. Rape had the highest concentration of oil but lowest oil yield. Protein concentration and
iodine value were highest in *Brassica carinata* and lowest in rape. Sinigrin and glucosinolate concentration was in the order *Brassica carinata* > *Brassica juncea* > rape.

Mohammad (1994) conducted a field experiment on *Brassica juncea* cv. Varuna at Aligarh (Uttar Pradesh). He applied foliar spray of phosphorus at 2 kg P/ha as sodium dihydrogen orthophosphate, diammonium phosphate or monocalcium superphosphate, in 2 equal splits at 70 and 90 DAS. Phosphorus spray enhanced seed and oil yield, but no significant difference in the effect of the three sources of phosphorus was noted. He concluded that the less expensive and easily available commercial-grade monocalcium superphosphate could be preferred for spray to increase profits.

Pradhan et al. (1994) performed a field experiment at Cooch Behar (West Bengal). They applied nitrogen at 0, 40, 80 or 120 kg N/ha and phosphorus at 0 or 40 kg P₂O₅ (17 kg P)/ha to three cultivars of rape, viz. B 9, B 85 and RW 351. Seed yield increased significantly up to 90 kg N and by the application of 17 kg P/ha. Seed yield was positively correlated with plant height, number of primary branches per plant, LAI, CGR, number of siliquae per plant and number of seeds per siliqua. There were no yield differences between cultivars, but RW 351 had maximum number of siliquae per plant and B 9 excelled in number of seeds per siliqua.

Arthamwar et al. (1995, 1996 a, b) performed a field experiment at Parbhani (Maharashtra). They applied three levels each of nitrogen (0, 50 or 100 kg N/ha) and phosphorus (0, 40 or 80 kg P₂O₅ i.e. 0, 17 or 35 kg P/ha) to four cultivars of *Brassica juncea*, viz. Pusa Bold, PR 18, T 59 and Local. They noted that leaf area, dry matter, nitrogen and phosphorus uptake, yield components, seed yield and oil yield increased with increase in the rate of nitrogen and phosphorus fertilizers. Graded levels of phosphorus application also increased oil content linearly. Regarding cultivars, it was noted that leaf area was higher in improved cultivars than in the Local cultivar. Pusa Bold proved best for most parameters, including seed and oil yield.
Thakral et al. (1995, 1997), working at Hisar (Haryana), applied 75, 100 or 125% of the recommended nitrogen and phosphorus rates of 80 kg N + 30 kg P$_2$O$_5$ (13 kg P)/ha to Brassica juncea cv. RH 781, Brassica napus cv. N 20-7-1 and Brassica carinata cv. C 6YS-7-B. In general, leaf area index, leaf area duration and crop growth rate increased with increasing rate of nitrogen and phosphorus application and they were higher in Brassica carinata. They also found that, the increasing levels of fertilizers significantly affected the fatty acid composition. Fatty acid content varied between species.

Dalai et al. (1996), working at Bhubaneswar (Orissa), studied the effect of four levels of nitrogen (0, 25, 50 or 75 kg N/ha) on Brassica juncea cv. Pusa Bahar. They found that 75 kg N/ha gave the highest seed yield and seed protein content increased and seed oil content decreased with increasing nitrogen levels.

Kakatia and Kalita (1996) performed a field trial at Jorhat (Assam) to study the effect of nitrogen fertilizer application (0, 25, 50, 75 or 100 kg N/ha) on yield components of three cultivars of Brassica juncea, viz. Varuna, Tm 2 and Tm 3. They noted that all yield components and nitrogen uptake and seed and stover-nitrogen concentration increased with increasing nitrogen fertilizer levels, whereas seed oil concentration decreased and 1000-seed weight and seeds per siliqua remained unchanged. They also noted that Varuna was the highest yielding cultivar.

Patil et al. (1996) conducted a field experiment at Akola (Maharashtra) and applied four levels of nitrogen (0, 40, 80 or 120 kg N/ha) to Brassica juncea cv. Pusa Bold and Brassica campestris cv. Pusa Kalyani. Data revealed that nitrogen supply up to 120 kg N/ha increased seed yield linearly in both the species. However, it exerted a negative effect on partitioning of assimilates from pod wall to seed. The study also indicated that Brassica juncea was superior to Brassica campestris as far as seed yield was concerned.

Singh et al. (1996) conducted a field experiment at Pantnagar (Uttaranchal). They applied three levels of nitrogen (60, 90 or 120 kg N/ha) to
four cultivars of *Brassica juncea*, viz. Kranti, C 552, PR 8903 and RW 85-59. They found that seed and oil yield increased with increasing rates of nitrogen. Cultivars did not vary in respect of seed yield.

Singh and Kumar (1996) conducted a field experiment on *Brassica juncea* cv. NDR 8501 at Faizabad (Uttar Pradesh). They applied four levels of nitrogen (0, 30, 60 or 90 kg N/ha) and three levels of sulphur (0, 20 or 40 kg S/ha). They reported that increasing rates of nitrogen and sulphur application resulted in significant increases in plant height, siliquae/plant and 1000-seed weight, with 40 kg S/ha giving maximum values for growth and yield components. Seed and stover yields increased with increasing levels of nitrogen up to 60 kg N/ha and of sulphur up to 40 kg S/ha. On average, seed oil content was maximum with 60 kg N/ha or 40 kg S/ha.

Sugawe *et al.* (1996), working at Parbhani (Maharashtra), applied four levels of nitrogen (0, 40, 80 or 120 kg N/ha) to *Brassica juncea* (cv. not mentioned). They noted that nitrogen content in leaf, stem and seed was more with 120 kg N/ha than with other levels of nitrogen. Similarly, 120 kg N/ha proved best for protein content and oil yield. However, oil content in seeds was not affected significantly due to nitrogen application.

Tomer *et al.* (1996), conducting a field experiment at Baraut (Uttar Pradesh), applied four combinations of nitrogen + phosphorus + potassium [0 kg N + 0 kg P + 0 kg K, 40 kg N +20 kg P₂O₅ (8.7 kg P) + 20 kg K₂O (16.6 kg K), 80 kg N + 40 kg P₂O₅ (17.5 kg P) + 40 kg K₂O (33.2 kg K) or 120 kg N + 60 kg P₂O₅ (26.2 kg P) + 60 kg K₂O (49.8 kg K)/ha] to four cultivars of *Brassica juncea*, viz. Varuna, Pusa Bold, Prakash and RH 8113. They noted that plant height, number of branches, dry matter accumulation, number of siliquae per plant, 1000-seed weight, seed yield and oil yield increased with increasing levels of fertilization. All these growth and yield attributes were significantly higher in Varuna and Pusa Bold than Prakash and RH 8113. The interactions of Varuna and Pusa Bold with higher levels of fertilization gave maximum seed yield and dry matter accumulation respectively.
Thakuria and Gogoi (1996), working at Jorhat (Assam), applied four levels of nitrogen (0, 40, 80 or 120 kg N/ha) to three cultivars of *Brassica juncea*, viz. TM 2, TM 4 and Varuna. Seed yield and yield components increased significantly with increasing nitrogen fertilizer application up to 80 kg N/ha. Cultivars did not vary with regard to seed yield and yield attributes, except 1000-seed weight, which was maximum in Varuna.

Chand et al. (1997 a, b), conducting a field experiment at Jobner (Rajasthan), studied the effect of soil-applied sulphur and foliar spray of urea on *Brassica juncea* cv. T 59. They applied three levels of sulphur (0, 30 or 60 kg S/ha) to the soil. In addition, five levels of foliar spray of urea, viz. 0, 1, 2, 3 or 4% urea solution, each at the rate of 1000 L/ha were applied at two stages (30 DAS and 60 DAS). They found that increasing levels of sulphur increases chlorophyll content, nitrogen and sulphur content in seeds and straw and their uptake, number of siliquae per plant, seeds per siliqua, test weight, seed and straw yield, oil content and oil yield linearly. As far as effect of urea spray was concerned, 3% solution proved best for most parameters.

Deekshitulu and Subbiah (1997, 1998) conducted a field experiment on *Brassica juncea* cv. Seeta at Bapatla (Andhra Pradesh). They applied four levels of nitrogen (0, 50, 100 or 150 kg N/ha) and three levels of sulphur (0, 25 or 50 kg S/ha). The data revealed that number of siliquae per plant, 1000-seed weight and seed nitrogen uptake increased significantly up to 150 kg N/ha, while the number of seeds per siliqua increased significantly up to 100 kg N/ha only. Similarly, the number of seeds/siliqua, 1000-seed weight and seed-sulphur uptake increased significantly up to 50 kg S/ha, while the number of siliquae per plant increased significantly up to 25 kg S/ha only. The highest seed and oil yields were realized at the highest application rates of nitrogen (150 kg N/ha) and sulphur (50 kg S/ha). Oil content peaked with 100 kg N/ha and then decreased. Increasing levels of sulphur increased oil content.

Gurjar and Chauhan (1997) studied the effect of five levels of nitrogen + phosphorus [0 kg N + 0 kg P, 25 kg N + 16.6 kg P$_2$O$_5$ (7.2 kg P), 50 kg N + 33
kg P₂O₅ (14.4 kg P), 75 kg N + 50 kg P₂O₅ (21.8 kg P) or 100 kg N + 66.4 kg P₂O₅ (29 kg P)/ha on two cultivars of *Brassica juncea*, viz. Kranti and Pusa Bold at Gwalior (Madhay Pradesh). They found that seed yield and yield attributes increased up to 75 kg N + 21.8 kg P/ha. They also found that cultivars did not vary in respect of seed yield.

Jaggi and Sharma (1997) performed a field experiment on *Brassica juncea* cv. Varuna at Palampur (Himachal Pradesh). They applied four levels of sulphur (0, 30, 60, or 90 kg S/ha) and three levels of phosphorus (0, 13.1 or 26.2 kg P/ha). They noted that seed yield increased with increasing sulphur and phosphorus rates. Highest seed yield and highest sulphur and phosphorus uptake was obtained with 90 kg S + 26.2 kg P/ha. They also found that sulphur and phosphorus had synergistic effect on yield parameters.

Khafi *et al.* (1997), performing a field experiment at Udaipur (Rajasthan), studied the effect of nitrogen, phosphorus and leaf-applied sulphuric acid and thiourea on *Brassica juncea* cv. Kranti. They applied nitrogen at 0, 20, 40, 60 or 80 kg N/ha, phosphorus at 0 or 30 kg P₂O₅ (13.1 kg P)/ha and sulphuric acid and thiourea spray each at 0.1%. They reported that seed yield increased up to the highest nitrogen rate of 80 kg N/ha and by the application of 13.1 kg P/ha. Foliar application of sulphuric acid or thiourea also increased yield significantly.

Mohammad *et al.* (1997) conducted a pot experiment on *Brassica juncea* cv. Rohini at Aligarh (Uttar Pradesh). They applied three levels of nitrogen at 0, 2 or 4 kg N per 4 kg of soil. They noted that carbonic anhydrase activity and net photorynthetic rate in leaves of 50 day old plants and yield attributes at harvest increased with increasing nitrogen rates. Stomatal conductance was unaffected. Oil content decreased with increasing nitrogen rates.

Patil *et al.* (1997), conducting a field experiment at New Delhi, studied the effect of nitrogen on *Brassica juncea* cv. Pusa Bold and *Brassica campestris* cv. Pusa Kalyani. They applied four levels of basal nitrogen (0, 40,
80 or 120 kg N/ha). Nitrogen supply up to 120 kg N/ha significantly enhanced leaf area index, leaf area duration, crop growth rate and seed yield in both cultivars. Pusa Bold had higher dry matter accumulation and seed yield than Pusa Kalyani. They also found highly significant correlation between seed yield versus leaf area index, leaf area duration and crop growth rate.

Sharma et al. (1997), working at Hisar (Haryana), studied the effect of graded levels of nitrogen (0, 30, 60 or 90 kg N/ha) on two cultivars of Brassica juncea, viz. RH 30 and RH 819 and one cultivar of Brassica campestris, namely TCH 2. They reported that seed yield increased up to 60 kg N/ha. They also noted that the seed yield of Brassica juncea cultivars was at par but higher than that of Brassica campestris.

Shukla and Kumar (1997) performed a field trial on six cultivars of Brassica juncea, viz. Kranti, Krishna, Pusa Bold, Rohini, Vardan and Varuna. They applied four levels of nitrogen (0, 40, 80 or 120 kg N/ha). They reported that nitrogen application at rates up to 120 kg N/ha significantly increased seed yield, maturity period, harvest index and nitrogen uptake, whereas a decreasing trend was observed in the case of oil content with increases in nitrogen fertilization. They also noted that differences among the cultivars were non-significant for seed weight per plant and harvest index. Oil content was significantly higher in Vardan and Krishna, as was nitrogen uptake.

Singh et al. (1997), carrying out a field trial on Brassica juncea cv. Varuna at Bulandshahar (Uttar Pradesh), applied three levels each of nitrogen (0, 40 or 80 kg N/ha) and phosphorus, viz. 0, 30 or 60 kg P₂O₅ (0, 13.1 or 26.2 kg P)/ha. They observed that yield and yield attributes increased with increasing levels of nitrogen and phosphorus.

Tomar et al. (1997) conducted a field trial on Brassica juncea cv. Krishna at Gurkul Narsan (Uttar Pradesh). They applied three levels each of nitrogen (60, 120 or 180 kg N/ha), phosphorus (0, 40 or 80 kg P₂O₅, i.e. 0, 17.5 or 35.0 kg P/ha) and sulphur (0, 40 or 80 kg S/ha). They found that growth attributes (plant height, branches per plant and dry matter accumulation per
plant) yield attributes (pods per plant, seeds per pod and 1000-seed weight and stover yield per hectare) increased significantly with increasing levels of nitrogen, phosphorus and sulphur up to 180, 35 and 80 kg/ha respectively. Oil content of seeds decreased with increase in levels of nitrogen and phosphorus, whereas it increased with increasing levels of sulphur.

Ahmad et al. (1998) conducted a field experiment on Brassica juncea cv. Pusa Jai Kisan and Brassica campestris cv. Pusa Gold at New Delhi. They applied sulphur at 0, 40 or 60 kg S/ha and nitrogen at 60, 100 or 150 kg N/ha. They noted that application of sulphur and nitrogen increased yield components, seed and oil yield, with the highest yield being given by 40 kg S and 100 kg N/ha, respectively. Oil content of seed was highest with 60 kg S and 100 kg N/ha in both cultivars. However, application of 150 kg N/ha decreased the oil content but did not significantly affect seed and oil yield.

Jaggi (1998) and Jaggi and Sharma (1999) performed a field trial on Brassica juncea cv. Varuna at Palampur (Himachal Pradesh). They applied four levels of sulphur (0, 30, 60 or 90 kg S/ha) and three levels of phosphorus, viz., 0, 30 or 60 kg P$_2$O$_5$ (0, 13.1 or 26.2 kg P)/ha in all possible combinations. A combined application of 90 kg S and 26.2 kg P/ha proved best for seed, straw and oil yield. Oil content was minimum at the highest level of sulphur added without phosphorus and was maximum when no sulphur or phosphorus was applied as well as with the highest rates of their application.

Singh et al. (1998) and Singh and Yashwant (1998) performed a field experiment at Varansi (Uttar Pradesh). They applied three levels of nitrogen (0, 40 or 80 kg N/ha) to four cultivars of Brassica juncea, viz. Kranti, Krishna, PR 45 and Varuna. Data revealed that uptake of nitrogen, phosphorus and potassium in seed and stalk, seed yield and oil yield increased significantly with increasing nitrogen rates. As far as cultivars were concerned, it was found that seed and oil yields and yield component values were highest in PR 45.

Abraham (1999, 2000) studied the effect of sulphur and nitrogen on Brassica juncea cv. Pusa Jai Kisan at New Delhi. He applied sulphur at 40 or
60 kg S/ha and nitrogen at 100 or 150 kg N/ha. He found that 60 kg S + 100 kg N/ha proved best for chlorophyll and soluble protein content, photosynthetic rate and oil content.

Ahmad et al. (1999a) and Ahmad and Abdin (2000), performing a field experiment at New Delhi, applied five combinations of nitrogen and sulphur, viz. (i) 0 kg S + 100 kg N, (ii) 40 kg S + 60 kg N, (iii) 40 kg S + 100 kg N, (iv) 60 kg S + 100 kg N and (v) 60 kg S + 150 kg N/ha to Brassica juncea cv. Pusa Jai Kisan and Brassica campestris cv. Pusa Bold. They noted that highest nitrate reductase activity, ATP-sulphurylase activity and photosynthetic rate in leaves, protein, nitrogen and sulphur content in seeds, seed yield, oil content and oil yield were achieved with 40 kg S + 100 kg N/ha in both species. They also noted an increase in oleic acid and linoleic acid content as also a decrease in eicosenoic acid and erucic acid content with the application of sulphur with nitrogen when compared with nitrogen alone.

Ahmad et al. (1999b) conducted a field experiment at New Delhi. They applied three combinations of sulphur and nitrogen to Brassica juncea cv. Pusa Jai Kisan and Brassica campestris cv. Pusa Gold. 40 kg S/ha was applied either in a single basal application (S1) or in two (S2) or three (S3) split applications and 100 kg N/ha was applied in two (N2) or three (N3) splits. Thus treatments were (i) S1N2, (ii) S2N2 or (iii) S3N3. Split application of sulphur and nitrogen (S2N2 or S3N3) resulted in significant improvement in growth and yield of both crops compared with S1N2. They also noted that Brassica juncea responded better to S2N2 than to S1N2 or S3N3. Brassica campestris with S3N3 responded best.

Kachroo and Kumar (1999) studied the effect of nitrogen and sulphur on Brassica juncea cv. Kranti at Pantnagar (Uttaranchal). They applied five levels of nitrogen (0, 40, 80, 120 or 160 kg N/ha) and four levels of sulphur (0, 20, 40, or 60 kg S/ha). They noted that seed weight per plant increased up to 120 kg N/ha and 40 kg S/ha. Seed oil concentration decreased with increasing
nitrogen rates and increased with increasing sulphur doses, whereas protein concentration was increased by both nitrogen and sulphur.

Kumar et al. (1999) conducted a field experiment at Hisar (Haryana). They applied four levels of nitrogen (0, 40, 60 or 80 kg N/ha) to five cultivars of *Brassica juncea*, viz. CS 52, GJM 9056, Kranti, RH 30 and RH 8814 and to one cultivar of *Brassica napus*, namely GSH 1. They reported that phenological development was delayed by the application of increasing nitrogen rates, while leaf area index, growth rate and seed yield increased. They also noted that *Brassica juncea* cultivars performed better than the *Brassica napus* cultivar.

Prakash et al. (1999), conducting a field experiment at Lakhaoti (Uttar Pradesh), studied the effect of four levels of nitrogen (0, 40, 80 or 120 kg N/ha) on *Brassica juncea* cv. Varuna, *Brassica napus* cv. ISN 706 and *Brassica carinata* cv. DLSC 1. They noted that values of yield components and seed, stover and oil yields increased with increasing nitrogen rates, although response for most yield components was significant up to 80 kg N/ha only. *Brassica carinata* had significantly more pods per plant than *Brassica juncea* or *Brassica napus*, while pod length and seeds per pod were significantly greater in *Brassica napus*. *Brassica juncea* recorded significantly greater values for 1000-seed weight and seeds per plant than the other two species, resulting in significantly higher seed yield, harvest index and oil yield.

Singh and Brar (1999) performed a field experiment on *Brassica juncea* at Bhatinda (Punjab). They applied four rates each of nitrogen (0, 50, 100 or 150 kg N/ha) and phosphorus (0, 15, 30 or 45 kg P₂O₅, i.e. 0, 6.5, 13.1 or 19.7 kg P)/ ha. They found that seed yield increased up to 100 kg N/ha and up to 13.1 kg P/ha.

Thakur (1999), performing a field experiment at Kangra (Himachal Pradesh), studied the effect of three levels of nitrogen (45, 60 or 75 kg N/ha) on two Indian mustard cultivars, viz. RCC 4 and Varuna. Yield attributes, as well
as seed yield, significantly increased with increasing rates of nitrogen up to 60 kg N/ha. As far as cultivars were concerned, RCC 4 proved better than Varuna.

Bhari *et al.* (2000) conducted a field experiment on *Brassica juncea* cv. Varuna at Rozari (Rajasthan). They applied four levels each of nitrogen (30, 60, 90, or 120 kg N/ha) and phosphorus (0, 15, 30 or 45 kg P₂O₅, i.e. 0, 6.5, 13.1 or 19.7 kg P/ha). They observed that plant height, primary and secondary branches, siliqueae per plant and seed yield increased significantly up to 120 kg N/ha. Both 90 and 120 kg N/ha were at par for seeds per siliqua and 1000-seed weight. Phosphorus application up to 19.7 kg P/ha resulted in significant increase in plant height, secondary branches, siliqueae per plant and seed yield.

Majumdar and Pingnoliya (2000) conducted a field experiment on Indian mustard (*Brassica juncea*) cv. T 59 at Jobner (Rajasthan). They applied three sulphur sources (pyrite, elemental sulphur or gypsum) each at three levels (20, 40 or 60 kg S/ha). They noted that all sources of sulphur proved equally effective for seed nitrogen content. Sulphur through gypsum at 60 kg S/ha proved best for phosphorus and sulphur content in seeds and stover and nitrogen, phosphorus and sulphur uptake by seeds.

Patidar *et al.* (2000) conducted a field experiment at Jodhpur (Rajasthan). They applied three combinations of nitrogen + phosphorus + sulphur, viz. control, 60 kg N + 40 kg P₂O₅ (17.5 kg P) or 60 kg N + 40 kg P₂O₅ (17.5 kg P) + 15 kg S/ha to three cultivars of *Brassica juncea*, namely Local, Pusa Bold and T 59. Application of 60 kg N + 17.5 kg P + 15 kg S/ha proved best for growth and yield parameters, including seed yield. Regarding cultivars, they noted that Pusa Bold and T 59 were at par and significantly superior to Local cultivar.

Singh *et al.* (2000), performing a field experiment at Bawal (Haryana), applied four levels of sulphur (0, 15, 30 or 45 kg S/ha) to six cultivars of *Brassica juncea* (BIO 902, RH 30, RH 781, RH 8812, RH 8814 and T 59), to one cultivar of *Brassica carinata*, viz. HC 2 and to one cultivar of *Eruca vesicaria*, i.e. T 27. Application of sulphur up to 45 kg S/ha significantly
increased oil content, seed yield and yield attributes (siliquae per plant, seeds per silique, but not test-weight) compared with the lower levels. Cultivar BIO 902 performed better than the others.

Abraham (2001), conducting a field experiment at New Delhi, studied the effect of split application of sulphur on the growth and yield of Indian mustard (*Barssica juncea*) cv. Pusa Jai Kisan. The treatments included (i) 0 kg S + 30 kg N + 30 kg N/ha, (ii) 10 kg S + 10 kg S + 30 kg N + 30 kg N/ha and (iii) 10 kg S + 5 kg S + 5 kg S + 30 kg N + 30 kg N/ha. A uniform dose of 40 kg P$_2$O$_5$ (17.5 kg P) + 40 kg K$_2$O (33.2 kg K)/ha was also applied. Application of 10 kg S + 5 kg S + 5 kg S + 30 kg N + 30 kg N/ ha proved best for pods per plant, seeds per pod, 1000-seed weight, seed yield and oil yield.

Kumar et al. (2001a) performed a field experiment on *Brassica juncea* cv. RH 30 at Bawal (Haryana). They applied five levels of nitrogen (0, 30, 60, 90 or 120 kg N/ha) and four levels of phosphorus (0, 12.5, 24.9 and 37.4 kg P/ha). Leaf area index, number of siliquae per plant and number of siliquae on main shoot were maximum at 120 kg N/ha and 37.4 kg P/ha. Among other parameters, 1000-seed weight, oil yield and seed yield were maximum at 90 kg N/ha and 24.9 kg P/ha.

Kumar et al. (2001b) performed an experiment at Bawal (Haryana). They applied four levels of nitrogen (0, 40, 60 and 80 kg N/ha) to five cultivars of *Brassica juncea* (CS 52, GJM 9056, Kranti, RH 30 and RH 8814) and one cultivar of Swede rape (*Brassica napus* cv. GSH 1). The data revealed that 80 kg N/ha proved best for growth and yield parameters, including seed yield and harvest index. The differences in seed yield among Indian mustard cultivars were non-significant but all of them were significantly superior to rape cv. GSH 1. Cultivar RH 30 had better harvest index than the other genotypes.

Kumar et al. (2001c) and Singh and Singh (2002) carried out a field experiment at Faizabad (Uttar Pradesh). They applied three sources of sulphur (elemental sulphur, gypsum or pyrite) each at 0, 20, 40 or 60 kg S/ha to three cultivars of *Brassica juncea*, namely Narendra Rai 1, Vardan and Varuna.
Application of 40 kg S/ha proved best for plant height, branches per plant, siliquae per plant, seeds per siliqua, 1000-seed weight, seed and stover yield, harvest index, sulphur uptake and oil and protein content in seed. All three sources of sulphur proved equally effective. Regarding cultivars, it was noted that Narendra Rai 1 and Varuna were at par and superior to Vardan.

Chaubey et al. (2001) conducted a field experiment on mustard (Brassica juncea cv. Rohini) at Ujhani (Uttar Pradesh). They applied three levels of phosphorus, viz. 0, 40 or 60 kg P₂O₅ (0, 17.5 or 26.2 kg P/ha) and five levels of sulphur (0, 15, 30, 45 or 60 kg S/ha) along with a uniform dose of 120 kg N + 33.2 kg K/ha. They noted that the growth attributes (plant height, number of branches per plant) and seed attributes (siliquae per plant, length of siliqua, seeds per siliqua and 1000-seed weight) increased significantly with increasing levels of phosphorus and sulphur up to 26.2 kg P/ha and 30 kg S/ha respectively.

Davaria et al. (2001) carried out a field experiment on Brassica juncea cv. Gujarat Mustard 1 at Junagadh (Gujarat). They applied phosphorus at 0, 25 or 50 kg P₂O₅ (0, 10.9 or 21.8 kg P)/ha and sulphur at 0, 25, 50 or 100 kg S/ha. They reported that primary and secondary branches per plant, siliquae per plant, seeds per siliqua, 1000-seed weight, seed yield, stover yield, leaf chlorophyll content, phosphorus and sulphur content of seeds were highest with 21.8 kg P/ha. There were no observed differences in oil, protein, oleic and linoleic acid content of seeds. Sulphur had no significant effect on growth and yield, except seed yield which was highest at 50 kg S/ha. Sulphur significantly increased leaf chlorophyll content, whereas seed composition of oil, protein, fatty acid, nitrogen, phosphorus and sulphur did not change.

Hotmode et al. (2001) and Rathod et al. (2001) performed a field experiment at Nagpur (Maharashtra). They applied three combinations of nitrogen and phosphorus, viz. 40 kg N + 30 kg P₂O₅ (13.1 kg P)/ha, 50 kg N + 40 kg P₂O₅ (17.5 kg P)/ha or 60 kg N + 50 kg P₂O₅ (21.8 kg P)/ha to two cultivars of Brassica juncea, namely Pusa Bold and ACN 9. They noted that
application of 60 kg N + 21.8 kg P/ha resulted in maximum plant height, leaf number, primary branches, dry matter production, leaf area, leaf chlorophyll, nitrogen, phosphorus and potassium content, number of siliquae per plant, seeds per siliqua, harvest-index and seed yield. However, 40 kg N + 13.1 kg P/ha gave maximum oil content. Regarding cultivars, they reported that Pusa Bold was superior to ACN 9.

Sharma and Jalali (2001) performed a field experiment on Brassica juncea cv. RLM 198 at Rajouri (Jammu). They applied four levels each of phosphorus, viz. 0, 20, 40 or 60 kg P₂O₅ (0, 8.7, 17.5 or 26.2 kg P)/ha and sulphur (0, 20, 40 or 60 kg S/ha). They noted that seed and straw yield increased with increasing levels of phosphorus and sulphur. Phosphorus uptake increased with increasing doses of phosphorus and sulphur up to 40 kg S/ha. Sulphur uptake increased with increasing doses of phosphorus up to 17.5 kg P/ha and of sulphur. Application of phosphorus decreased the oil content but increased oil yield. Increasing levels of sulphur increased oil content.

Bohra and Srivastava (2002) conducted a field experiment on Brassica juncea cv. Pusa Bold at Varanasi (Uttar Pradesh). They applied four levels of combined nitrogen, phosphorus and potassium, viz. 25, 50, 75 and 100% of recommended doses (80 kg N + 40 kg P₂O₅ + 40 kg K₂O/ha, i.e. 80 kg N + 17.5 kg P + 33.2 kg K/ha) and two levels of sulphur at 20 or 50 kg S/ha through gypsum and elemental sulphur. They observed that crop yield and yield attributes (siliquae per plant, test weight, siliqua length and seed yield per plant were significantly improved with increasing levels of combined nitrogen, phosphorus and potassium from 25 to 100% of the recommended dose. Sulphur application positively influenced the yield and yield attributes. Both sulphur sources though remained at par but gypsum showed superiority over elemental sulphur in general. Output-input ratio was highest with 100% of the recommended dose and 50 kg S/ha through gypsum.

Singh et al. (2002) studied the effects of four fertilizer rates, i.e. 50, 75, 100 or 125% of the recommended dose 60 kg N, 40 kg P₂O₅ (17.5 kg P) or 20
kg K₂O (8.7 kg K)/ha on the yield and quality of two cultivars of *Brassica carinata*, namely DLSC 1 and PBC 9221 and three cultivars of *Brassica juncea*, viz. BIO 772, Kranti and PR 8988 at Pantnagar (Uttaranchal). They noted that generally, leaf area index, crop growth rate, net assimilation rate, branch and siliqua number, 1000-seed weight, seed yield, oil yield, protein content, nitrogen content and nitrogen uptake increased with increase in fertilizer rate, whereas seed oil content decreased with fertilizer level. As far as cultivars were concerned, PBC 9221 proved superior to the other two.

Punia *et al.* (2002a) laid out a field experiment on two improved Indian mustard (*Brassica juncea*) cultivars (Varuna and Pusa Kranti) at Udaipur (Rajasthan). They applied three levels of phosphorus, viz., 20, 40 or 60 kg P₂O₅ (8.7, 17.5 or 26.2 kg P)/ha. Application of 17.5 kg P/ha proved best for siliquae per plant, seed yield and oil yield. Regarding cultivars, it could be added that Varuna surpassed Pusa Kranti.

Punia *et al.* (2002 b) laid out a field experiment on *Brassica juncea* cv. Varuna at Udaipur (Rajasthan). They applied three levels of phosphorus, viz. 20, 40 or 60 kg P₂O₅ (8.7, 17.5 or 26.2 kg P)/ha through diammonium phosphate, gypsum, single superphosphate. They found that 17.5 kg P/ha applied through diammonium phosphate proved best for seed and oil yield.

Singh (2002) conducted a field experiment on *Brassica juncea* cv. Varuna at Azamgarh (Uttar Pradesh). He applied five levels each of nitrogen (0, 30, 60, 90 or 120 kg N/ha) and of phosphorus, viz. 0, 15, 30, 45 or 60 kg P₂O₅ (0, 6.5, 13.1, 19.7 or 26.2 kg P)/ha. Increasing levels of nitrogen up to 120 kg N/ha and of phosphorus up to 19.7 kg P/ha increased siliqua length, siliquae number per plant, seeds per siliqua, seed yield and 1000-seed weight. However, oil content was not affected significantly by nitrogen or phosphorus application.

Dhake and Kumar (2003), conducting a field experiment at Hisar (Haryana), studied the effect of nitrogen and phosphorus on *Brassica juncea* cv. RH 30. The treatments included: control, 40 kg N/ha, 80 kg N/ha and 80 kg
N/ha + 30 kg P/ha. They noted that seed yield and grain yield increased with increasing nitrogen rates up to 80 kg N/ha. Combined nitrogen and phosphorus (80 kg N + 30 kg P/ha) gave maximum yields. They also noted that oil content decreased, whereas oil protein content and oil yield increased with increasing nitrogen levels.

2.4 Concluding Remarks

A survey of the foregoing literature reveals that traditional cultivars of rapeseed-mustard responded variably to the applied nutrient/s under various agro-climatic conditions of India. Moreover, different sources of nutrient/s had variable effect on this crop. However, little work has been done on human friendly “00” type Brassicas (free from both erucic acid and glucosinolate). Also, not much work has been done on their response to supplemental foliar application of nutrients, that has been established at Aligarh and elsewhere to elicit better utilization of nutrients which results in comparatively higher productivity and has proved economical for many crops. It was, therefore, considered justified to perform an in-depth study of the response of the newly released “00” type of rapeseed-mustard to various combinations and sources of nutrients applied partly through soil and partly through foliage under the agro-climatic conditions of western Uttar Pradesh.