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# Physio-morphological Response of Erucic acid-Free Genotypes of Rapeseed-mustard to the Application of Graded Combinations of Nitrogen, Phosphorus and Sulphur

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## ABSTRACT

A field experiment was conducted to study the effect of five graded combinations of nitrogen (N), phosphorus (P) and sulphur (S) on growth characters, physio-biochemical parameters and yield characteristics as well as fatty acid composition of the oil of three genotypes of rapeseed-mustard (two erucic acid-free, viz. *Brassica napus* L. cv. 'Hyola PAC-401' and *Brassica juncea* L. Czern. & Coss. cv. 'TERI (0E) M21-Swarna', and one the best performing high-yielding, *B. juncea* cv. 'Rohini' as a check). The nutrient combinations with a uniform dose of 30 kg K ha$^{-1}$ included (i) 0 kg N + 0 kg P + 0 kg S ha$^{-1}$ ($N_0P_0S_0$), (ii) $N_{30}P_{10}S_{17}$, (iii) $N_{60}P_{20}S_{34}$, (iv) $N_{90}P_{30}S_{51}$ and (v) $N_{120}P_{40}S_{69}$. Application of $N_{90}P_{30}S_{51}$ proved best for most parameters studied. 'Hyola PAC-401' surpassed other cultivars in seed and oil yield. The interaction $N_{90}P_{30}S_{51}$ x 'Hyola PAC-401' (also $N_{90}P_{30}S_{51}$ x 'TERI (0E) M21-Swarna') proved superior for most parameters, including seed yield, oil yield and erucic acid content.

**Keywords:** fatty acid composition of oil, NPS application, oil yield, seed yield

## INTRODUCTION

Rapeseed-mustard is the third most important oilseed crop of the world, after soybean and palm (Batra 2000). However, cultivars of this group contain 40-50% erucic acid in their oil (<2% is desired) responsible for cardiac diseases (Pachauri 2001). Keeping this in view, oilseed researchers have been able to develop and introduce several improved quality cultivars including those free from erucic acid. The yield potential of Brassicas, as for others crops, can be realized by proper management of nitrogen (N), phosphorus (P) and sulphur (S) fertilizer. N nutrition has strong regulatory influence on S assimilation and *vice versa* (Duke and Reisenauer 1986; Hawkesford *et al*. 1995). It is well known that when a full dose of N applied basally as a single application, most of it is rendered unavailable to plants due to many factors. For example, up to 50% of the applied N may be lost through leaching, decomposition, volatilization, and conversion to an unavailable form (Dejoux *et al*. 2003). Therefore, it is necessary to understand the plant processes and storage method for N and other nutrients. Once new crop plants are released, it becomes imperative to workout the precise package of farm practices so as to exploit their genetic potential fully. Of these, mineral nutrient management plays an important role in enhancing the productivity of crops. Therefore, in the present study an effort was made to evolve management technology of N along with S and P application for optimal seed as well as oil yield in rapeseed-mustard (two erucic acid-free genotypes were tested and one best-performing, high-yielding genotype as a check).

## MATERIALS AND METHODS

A field experiment was conducted according to a factorial randomized block design at the Farm/Botanical Garden of the Aligarh Muslim University, Aligarh (27° 52′ N latitude, 78° 51′ E longitude and 187.45 m asl), India. The soil of the experimental field was a sandy loam with a pH (1: 2; soil: water) -8.00, E.C. (1: 2; soil: water) -0.65 dS m$^{-1}$; available minerals: N (181 kg N ha$^{-1}$), P (22 kg P ha$^{-1}$), and K (308 kg K ha$^{-1}$). Five graded combinations of soil-applied N, P and S were applied to three cultivars of rapeseed-mustard (two erucic acid-free genotypes, viz. *Brassica napus* L. cv. 'Hyola PAC-401' and *Brassica juncea* L. Czern. & Coss. cv. 'TERI (0E) M21-Swarna', and one best-performing, high-yielding *B. juncea* cv. 'Ronini' as a check) grown in 10 m$^2$ plots. The nutrient combinations with a uniform 30 kg K ha$^{-1}$ included (i) 0 kg N + 0 kg P + 0 kg S ha$^{-1}$ ($N_0P_0S_0$), i.e. control, (ii) $N_{30}P_{10}S_{17}$, (iii) $N_{60}P_{20}S_{34}$, (iv) $N_{90}P_{30}S_{51}$ and (v) $N_{120}P_{40}S_{69}$. The source of N was urea and of P and S, single superphosphate. The half dose of N and full of P, K and S was applied at the time of sowing and the remaining half dose of N was top-dressed after 30 days after sowing (DAS). The experimental field was irrigated at 30, 60 and 90 DAS, and weeding was undertaken twice at 30 and 60 DAS. There were three replicates for each treatment. The performance of the crop was assessed in terms of growth characteristics (shoot length plant$^{-1}$, leaf number plant$^{-1}$, area leaf$^{-1}$, leaf area index (LAI), fresh weight plant$^{-1}$ and dry weight plant$^{-1}$) and physio-biochemical parameters (net assimilation rate, leaf carbonic anhydrase activity and leaf NPK content) at 45 and 60 DAS and yield characters (pods plant$^{-1}$, seeds pod$^{-1}$, 1000-seed weight, seed yield ha$^{-1}$, oil content and oil yield ha$^{-1}$) and fatty acid composition of the oil at harvest. Leaf area was measured by the gravimetric method and LAI, according to Watson (1958). Net assimilation rate was calculated using the formula of Milthorpe and Moorby (1979). Carbonic anhydrase activity was measured by the titration method of Dwivedi and Randhawa (1974). Leaf N and P contents were determined according to the method of Lindner (1944) and Fiske and Subba Row (1925), respectively. Leaf K content was estimated by flame photometry (Fotoflame, AIMIL Ltd. New Delhi, India). Oil of the seeds was extracted by taking 25 g meal of ground seeds and transferring into a Soxhlet apparatus to which 100 mL pure petroleum ether was added. The apparatus was kept on a water bath at 60°C for ~6 h. At the end of each extraction process, the petroleum extract of seeds was left in air to evaporate the petroleum ether. The oil left after the evaporation of petroleum ether was weighed and expressed as percentage of the mass of the

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seeds. The percentage of oil was calculated by the following formula:

$$\text{Percentage of oil} = \frac{m \times 100}{m_0}$$

where m = mass of the oil in g and $m_0$ = mass of seed sample in g. Oil yield was computed on the basis of oil percentage and seed yield. Fatty acid composition of the oil was determined by adopting the method of Kaushik and Agnihotri (1997).

Data were analyzed statistically with SPSS-11 statistical software (SPSS Inc., Chicago, IL, USA). For the F test, the error due to replicates was also determined. The F value was found to be significant at the 5% level of probability.

## RESULTS AND DISCUSSION

### Morphological and physiological analysis

The effect of treatments and their interactions with cultivars on almost all parameters, as also cultivar differences were significant (**Tables 1-4**).

Increasing levels of nutrient combinations up to

**Table 1** Effect of graded combinations of soil-applied N, P and S on growth parameters of three cultivars of rapeseed-mustard at 45 and 60 DAS (mean of three replicates).

| Treatments | Cultivars | Shoot length plant$^{-1}$ (cm) | | Leaf number plant$^{-1}$ | | Area leaf$^{-1}$ (cm$^2$) | | Leaf area index | | Fresh weight plant$^{-1}$ (g) | | Dry weight plant$^{-1}$ (g) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | DAS | | | | | | | | | | | |
| | | 45 | 60 | 45 | 60 | 45 | 60 | 45 | 60 | 45 | 60 | 45 | 60 |
| $N_0P_0S_0$ | Rohini | 85.61 | 120.83 | 21.33 | 30.00 | 35.28 | 59.29 | 3.23 | 4.19 | 122.33 | 245.21 | 16.67 | 21.55 |
| | Hyola PAC(401) | 49.81 | 87.51 | 20.00 | 29.33 | 51.68 | 89.53 | 4.12 | 5.48 | 124.00 | 275.81 | 16.51 | 20.57 |
| | TERI(0E) M21-Swarna | 81.29 | 122.13 | 23.66 | 35.66 | 37.21 | 46.11 | 3.27 | 4.37 | 230.33 | 247.82 | 14.80 | 21.30 |
| | Mean | 72.24 | 110.15 | 21.66 | 31.66 | 41.39 | 64.97 | 3.54 | 4.68 | 158.89 | 256.28 | 15.99 | 21.14 |
| $N_{30}P_{10}S_{17}$ | Rohini | 99.28 | 125.21 | 23.33 | 31.33 | 37.62 | 56.82 | 3.55 | 4.52 | 128.00 | 261.53 | 17.53 | 22.79 |
| | Hyola PAC(401) | 61.27 | 92.67 | 22.00 | 31.33 | 53.20 | 95.56 | 4.29 | 5.59 | 131.66 | 311.23 | 16.31 | 22.12 |
| | TERI(0E) M21-Swarna | 98.37 | 131.47 | 26.33 | 36.33 | 39.81 | 50.68 | 3.39 | 4.35 | 231.66 | 283.38 | 18.08 | 23.6 |
| | Mean | 86.31 | 116.45 | 23.88 | 32.99 | 43.54 | 67.69 | 3.74 | 4.82 | 163.77 | 285.38 | 17.30 | 22.83 |
| $N_{60}P_{20}$ $S_{34}$ | Rohini | 106.32 | 137.01 | 24.33 | 35.66 | 40.81 | 66.25 | 3.83 | 4.66 | 136.00 | 297.11 | 19.31 | 24.03 |
| | Hyola PAC(401) | 69.32 | 105.31 | 25.00 | 33.66 | 59.11 | 99.81 | 4.82 | 5.79 | 141.33 | 347.37 | 18.55 | 24.41 |
| | TERI(0E) M21-Swarna | 107.25 | 139.33 | 27.33 | 38.66 | 42.73 | 55.54 | 3.84 | 4.52 | 233.66 | 301.53 | 20.67 | 25.29 |
| | Mean | 94.30 | 127.21 | 25.55 | 35.99 | 47.55 | 73.87 | 4.16 | 4.99 | 170.33 | 315.34 | 19.51 | 24.57 |
| $N_{90}P_{30}$ $S_{51}$ | Rohini | 111.57 | 141.52 | 30.66 | 36.33 | 45.73 | 69.09 | 4.07 | 4.78 | 140.66 | 330.79 | 21.27 | 26.04 |
| | Hyola PAC(401) | 81.22 | 109.89 | 24.33 | 34.33 | 63.33 | 108.11 | 5.06 | 5.82 | 142.00 | 371.65 | 22.25 | 25.74 |
| | TERI(0E) M21-Swarna | 112.78 | 145.29 | 29.33 | 40.33 | 46.41 | 66.73 | 4.13 | 4.80 | 242.66 | 342.05 | 22.01 | 26.13 |
| | Mean | 101.86 | 132.23 | 28.11 | 36.99 | 51.82 | 81.31 | 4.42 | 5.13 | 175.12 | 348.16 | 21.84 | 25.97 |
| $N_{120}P_{40}$ $S_{69}$ | Rohini | 104.57 | 139.62 | 31.33 | 36.66 | 49.28 | 60.12 | 4.36 | 4.65 | 141.66 | 301.68 | 19.68 | 23.58 |
| | Hyola PAC(401) | 62.68 | 103.25 | 24.33 | 36.66 | 65.81 | 101.23 | 5.38 | 5.72 | 143.00 | 335.28 | 18.21 | 22.88 |
| | TERI(0E) M21-Swarna | 108.44 | 135.67 | 29.33 | 41.33 | 51.21 | 51.28 | 4.21 | 4.55 | 243.33 | 289.63 | 19.49 | 25.46 |
| | Mean | 91.90 | 126.18 | 28.33 | 38.21 | 55.43 | 70.88 | 4.65 | 4.97 | 176.00 | 308.86 | 19.12 | 23.97 |
| LSD | T | 6.90 | 10.32 | NS | 1.89 | NS | 3.52 | 0.53 | 0.16 | 9.38 | 16.21 | 1.11 | 1.63 |
| (p=0.05) | C | 5.34 | 8.00 | NS | 1.46 | NS | 2.73 | 0.41 | 0.12 | 7.27 | 12.56 | NS | 1.26 |
| | T x C | 11.95 | 17.89 | NS | 3.28 | NS | 6.11 | 0.92 | 0.28 | 16.26 | 28.08 | NS | NS |

NS: non-significant; DAS = days after sowing; C = cultivar; T = treatment

**Table 2** Effect of graded combinations of soil-applied N, P and S on physio-biochemical parameters of three cultivars of rapeseed-mustard at 45 and 60 DAS (mean of three replicates).

| Treatments | Cultivars | Net assimilation rate (g m$^{-2}$ leaf area day$^{-1}$) | Carbonic anhydrase activity [mmol($CO_2$) kg$^{-1}$ (fm) s$^{-1}$] | | Leaf N content (%) | | Leaf P content (%) | | Leaf K content (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | DAS | | | | | | | | |
| | | 45-60 | 45 | 60 | 45 | 60 | 45 | 60 | 45 | 60 |
| $N_0P_0S_0$ | Rohini | 2.71 | 1.19 | 1.28 | 3.64 | 4.09 | 0.325 | 0.328 | 3.29 | 4.43 |
| | Hyola PAC (401) | 3.09 | 1.55 | 2.11 | 3.79 | 4.16 | 0.336 | 0.341 | 3.33 | 4.53 |
| | TERI(0E) M21- Swarna | 3.02 | 1.30 | 1.74 | 3.82 | 4.30 | 0.328 | 0.334 | 3.59 | 4.49 |
| | Mean | 2.94 | 1.35 | 1.71 | 3.75 | 4.18 | 0.329 | 0.334 | 3.40 | 4.48 |
| $N_{30}P_{10}S_{17}$ | Rohini | 3.15 | 1.47 | 1.77 | 3.65 | 4.21 | 0.335 | 0.339 | 3.34 | 4.57 |
| | Hyola PAC (401) | 3.89 | 1.79 | 2.17 | 3.81 | 4.22 | 0.339 | 0.346 | 3.37 | 4.66 |
| | TERI(0E) M21- Swarna | 3.79 | 1.49 | 1.81 | 3.84 | 4.31 | 0.332 | 0.337 | 3.62 | 4.57 |
| | Mean | 3.61 | 1.58 | 1.92 | 3.76 | 4.24 | 0.335 | 0.341 | 3.44 | 4.60 |
| $N_{60}P_{20}$ $S_{34}$ | Rohini | 4.25 | 1.68 | 1.86 | 3.67 | 4.28 | 0.337 | 0.341 | 3.36 | 4.66 |
| | Hyola PAC (401) | 5.31 | 1.92 | 2.24 | 3.82 | 4.42 | 0.343 | 0.351 | 3.47 | 4.76 |
| | TERI(0E) M21- Swarna | 4.35 | 1.82 | 1.87 | 3.85 | 4.40 | 0.339 | 0.344 | 3.67 | 4.73 |
| | Mean | 4.64 | 1.81 | 1.99 | 3.78 | 4.37 | 0.339 | 0.345 | 3.50 | 4.72 |
| $N_{90}P_{30}$ $S_{51}$ | Rohini | 6.73 | 1.91 | 1.93 | 3.69 | 4.48 | 0.347 | 0.349 | 3.41 | 4.72 |
| | Hyola PAC (401) | 5.88 | 2.15 | 2.32 | 3.85 | 4.51 | 0.351 | 0.353 | 3.52 | 4.88 |
| | TERI(0E) M21- Swarna | 6.88 | 2.02 | 1.95 | 3.86 | 4.51 | 0.315 | 0.355 | 3.78 | 4.77 |
| | Mean | 6.50 | 2.03 | 2.07 | 3.80 | 4.51 | 0.337 | 0.353 | 3.57 | 4.79 |
| $N_{120}P_{40}$ $S_{69}$ | Rohini | 5.01 | 1.67 | 1.86 | 3.72 | 4.57 | 0.344 | 0.348 | 3.38 | 4.82 |
| | Hyola PAC (401) | 5.11 | 2.09 | 2.29 | 3.89 | 4.33 | 0.353 | 0.354 | 3.51 | 4.92 |
| | TERI(0E) M21- Swarna | 4.78 | 1.93 | 1.94 | 3.88 | 4.58 | 0.350 | 0.353 | 3.75 | 4.86 |
| | Mean | 4.97 | 1.90 | 2.03 | 3.83 | 4.50 | 0.349 | 0.352 | 3.54 | 4.87 |
| LSD | T | 0.35 | 0.03 | 0.05 | NS | 0.03 | 0.018 | NS | NS | 0.12 |
| (p=0.05) | C | 0.27 | 0.02 | 0.03 | 0.03 | 0.02 | NS | NS | 0.05 | 0.09 |
| | T x C | 0.61 | 0.06 | 0.08 | NS | 0.05 | NS | NS | NS | NS |

NS: non-significant; DAS = days after sowing; C = cultivar; T = treatment

**Table 3** Effect of graded combinations of soil-applied N, P and S on yield parameters of three cultivars of rapeseed-mustard at harvest (mean of three replicates).

| Treatments | Cultivars | Pods plant$^{-1}$ | Seeds pod$^{-1}$ | 1000-seed weight (g) | Seed yield (kg ha$^{-1}$) | Oil content (%) | Oil yield (kg ha$^{-1}$) |
|---|---|---|---|---|---|---|---|
| $N_0P_0S_0$ | Rohini | 132.33 | 10.34 | 1.77 | 887.76 | 36.89 | 327.41 |
| | Hyola PAC (401) | 306.33 | 26.31 | 2.05 | 969.23 | 34.97 | 338.95 |
| | TERI(0E) M21- Swarna | 284.33 | 13.25 | 1.79 | 892.04 | 36.35 | 323.38 |
| | Mean | 241.00 | 16.63 | 1.87 | 916.34 | 36.07 | 329.91 |
| $N_{30}P_{10}S_{17}$ | Rohini | 138.33 | 12.36 | 2.68 | 1207.08 | 36.38 | 439.15 |
| | Hyola PAC (401) | 354.33 | 25.33 | 2.58 | 1387.43 | 34.76 | 482.31 |
| | TERI(0E) M21- Swarna | 294.66 | 15.97 | 2.73 | 1270.97 | 35.88 | 456.04 |
| | Mean | 262.44 | 17.88 | 2.66 | 1288.49 | 35.67 | 459.17 |
| $N_{60}P_{20}$ $S_{34}$ | Rohini | 234.00 | 13.40 | 3.01 | 1390.70 | 35.79 | 497.76 |
| | Hyola PAC (401) | 376.66 | 27.26 | 2.86 | 1573.43 | 34.44 | 541.88 |
| | TERI(0E) M21- Swarna | 331.00 | 16.86 | 2.99 | 1486.95 | 35.19 | 523.26 |
| | Mean | 313.88 | 19.17 | 2.95 | 1483.69 | 35.14 | 520.97 |
| $N_{90}P_{30}$ $S_{51}$ | Rohini | 258.33 | 14.68 | 3.41 | 1581.37 | 34.41 | 544.16 |
| | Hyola PAC (401) | 415.00 | 30.18 | 3.12 | 1699.35 | 34.02 | 578.13 |
| | TERI(0E) M21- Swarna | 354.66 | 17.34 | 3.58 | 1606.00 | 34.76 | 558.26 |
| | Mean | 342.66 | 20.73 | 3.37 | 1628.91 | 34.40 | 560.18 |
| $N_{120}P_{40}$ $S_{69}$ | Rohini | 230.00 | 12.25 | 2.56 | 1370.85 | 34.22 | 469.12 |
| | Hyola PAC (401) | 272.33 | 26.33 | 2.74 | 1523.49 | 33.86 | 515.85 |
| | TERI(0E) M21- Swarna | 371.00 | 14.17 | 2.79 | 1374.91 | 34.25 | 470.92 |
| | Mean | 291.11 | 17.58 | 2.70 | 1423.08 | 34.11 | 485.30 |
| LSD | T | 12.78 | 1.46 | NS | 96.95 | 0.92 | 31.37 |
| (p=0.05) | C | 9.89 | 1.12 | NS | 75.10 | 0.71 | 16.55 |
| | T x C | 22.14 | 2.52 | NS | 167.93 | 1.59 | 37.02 |

NS: non-significant; C = cultivar; T = treatment

**Table 4** Effect of graded combinations of soil-applied N, P and S on fatty acid composition (%) of the oil of three cultivars of rapeseed-mustard (mean of three replicates).

| Treatments | Cultivars | Palmitic acid | Stearic acid | Oleic acid | Linoleic acid | Linolenic acid | Erucic acid |
|---|---|---|---|---|---|---|---|
| $N_0P_0S_0$ | Rohini | 3.44 | 1.31 | 21.12 | 13.44 | 8.11 | 35.32 |
| | Hyola PAC (401) | 4.51 | 1.51 | 57.26 | 34.01 | 8.53 | 0.22 |
| | TERI(0E) M21- Swarna | 4.41 | 1.46 | 38.56 | 38.12 | 10.23 | 0.34 |
| | Mean | 4.12 | 1.43 | 38.98 | 28.52 | 8.96 | 11.96 |
| $N_{30}P_{10}S_{17}$ | Rohini | 3.52 | 1.35 | 21.26 | 14.19 | 8.24 | 35.47 |
| | Hyola PAC (401) | 4.63 | 1.61 | 57.59 | 34.42 | 8.65 | 0.28 |
| | TERI(0E) M21- Swarna | 4.51 | 1.58 | 40.17 | 38.42 | 10.35 | 0.45 |
| | Mean | 4.22 | 1.51 | 39.67 | 29.01 | 8.09 | 12.07 |
| $N_{60}P_{20}$ $S_{34}$ | Rohini | 3.69 | 1.45 | 21.38 | 14.40 | 8.51 | 35.60 |
| | Hyola PAC (401) | 4.68 | 1.66 | 58.63 | 34.66 | 8.78 | 0.30 |
| | TERI(0E) M21- Swarna | 4.60 | 1.66 | 40.67 | 38.87 | 10.44 | 0.46 |
| | Mean | 4.32 | 1.59 | 40.23 | 29.31 | 9.24 | 12.12 |
| $N_{90}P_{30}$ $S_{51}$ | Rohini | 3.66 | 1.55 | 21.65 | 14.80 | 8.73 | 35.40 |
| | Hyola PAC (401) | 4.77 | 1.65 | 58.71 | 35.11 | 8.92 | 0.33 |
| | TERI(0E) M21- Swarna | 4.65 | 1.57 | 41.44 | 39.75 | 10.57 | 0.39 |
| | Mean | 4.36 | 1.59 | 40.60 | 29.89 | 9.41 | 12.04 |
| $N_{120}P_{40}$ $S_{69}$ | Rohini | 3.73 | 1.56 | 21.74 | 15.21 | 8.96 | 35.78 |
| | Hyola PAC (401) | 4.73 | 1.68 | 58.84 | 35.23 | 8.17 | 0.39 |
| | TERI(0E) M21- Swarna | 4.60 | 1.55 | 41.56 | 39.59 | 10.69 | 0.43 |
| | Mean | 4.35 | 1.60 | 40.71 | 30.01 | 9.27 | 12.20 |
| LSD (p=0.05) | T | NS | NS | 1.25 | 0.33 | 0.38 | 0.19 |
| | C | 0.10 | 0.07 | 0.97 | 0.26 | 0.29 | 0.15 |
| | T x C | 0.23 | NS | 2.17 | 0.58 | 0.67 | 0.34 |

NS: non-significant; C = cultivar; T = treatment

$N_{90}P_{30}S_{51}$ increased shoot length plant$^{-1}$, leaf number plant$^{-1}$, area leaf$^{-1}$, LAI, fresh weight plant$^{-1}$ and dry weight plant$^{-1}$ at both 45 and 60 DAS stages (**Table 1**). The improvement over the no-nutrient control in plant height, leaf number, leaf area and LAI that resulted from the application of nutrients corroborates the findings of Bhari *et al.* (2000), Hatmode *et al.* (2001) and Rathod *et al.* (2001) in mustard and Siddiqui *et al.* (2007, 2008a, 2008b) in rapeseed-mustard.

The ameliorative effect of the application of N, P and S on these parameters may be explained on the basis of their roles. N is a component of many metabolically important compounds like amino acids, chlorophylls, coenzymes, enzymes, proteins, purines and pyrimidines. Likewise, P acts as an integral part of many biologically important compounds, such as coenzymes, nucleic acids, nucleosides, nucleotides, phospholipids, phosphoric acid, phosphorylated sugars and sugar phospholipids. As noted for N and P, S also acts as a constituent of several metabolically active plant constituents, including adenosine-5-phosphosulphate, biotin, coenzyme A, cysteine, cystine, enzymes, glutathione, lipoic acid, methionine, 3-phosphoadenosine-5-phosphosulphate, proteins, sulphydryl group containing compounds, thiamine and thiamine pyrophosphate (Nason and McElroy 1963; Clarkson and Hanson 1980; Salisbury and Ross 1992; Marschner 2002). Thus on the basis of roles played by these nutrients, it can easily be envisioned that their direct or indirect involvement in cell division, cell enlargement and tissue and organ formation would be expected to result in improvement in these structures. This, in turn, is responsible for an increase in plant height leading to better orientation of leaves for harvesting solar energy as well as for facilitating leaf expansion leading to larger leaf area and LAI of treated plants (**Table 1**). A significant increase in shoot length plant$^{-1}$, leaf number plant$^{-1}$, area leaf$^{-1}$ and LAI was

**Table 5** Correlation coefficient (r) values for different pairs of characteristics.

| Characteristics | Sampling stages/duration (DAS) | Fresh weight plant$^{-1}$ Sampling stages (DAS) | | Dry weight plant$^{-1}$ Sampling stages (DAS) | | Seed yield |
|---|---|---|---|---|---|---|
| | | 45 | 60 | 45 | 60 | |
| Shoot length plant$^{-1}$ | 45 | 0.888 | – | 0.960 | – | 0.998 |
| | 60 | – | 0.979 | – | 0.983 | 0.965 |
| Leaf number plant$^{-1}$ | 45 | 0.993 | – | 0.871 | – | 0.881 |
| | 60 | – | 0.826 | – | 0.763 | 0.838 |
| Area leaf$^{-1}$ | 45 | 0.826 | – | 0.972 | – | 0.750 |
| | 60 | – | 0.899 | – | 0.825 | 0.890 |
| Leaf area index | 45 | 0.967 | – | 0.753 | – | 0.860 |
| | 60 | – | 0.971 | – | 0.961 | 0.973 |
| Fresh weight plant$^{-1}$ | 45 | – | – | – | – | 0.889 |
| | 60 | – | – | – | – | 0.969 |
| Dry weight plant$^{-1}$ | 45 | – | – | – | – | 0.941 |
| | 60 | – | – | – | – | 0.980 |
| Net assimilation rate | 60-45 | – | 0.898 | – | 0.977 | 0.908 |
| Carbonic anhydrase activity | 45 | 0.973 | – | 0.959 | – | 0.960 |
| | 60 | – | 0.928 | – | 0.936 | 0.979 |
| Leaf N content | 45 | 0.933 | – | 0.670 | – | 0.677 |
| | 60 | – | 0.890 | – | 0.875 | 0.860 |
| Leaf P content | 45 | 0.830 | – | 0.474 | – | 0.601 |
| | 60 | – | 0.908 | – | 0.897 | 0.907 |
| Leaf K content | 45 | 0.980 | – | 0.949 | – | 0.916 |
| | 60 | – | 0.817 | – | 0.814 | 0.847 |
| Pods plant$^{-1}$ | – | 0.842 | 0.984 | 0.989 | 0.986 | 0.937 |
| Seeds pod$^{-1}$ | – | 0.643 | 0.924 | 0.924 | 0.925 | 0.868 |
| 1000-seed weight | – | 0.806 | 0.967 | 0.941 | 0.975 | 0.982 |

Significant at 5% (r value = 0.878), Significant at 1% (r value = 0.959). DAS = days after sowing

expectedly reflected in enhanced fresh weight of treated plants (**Table 1**). This cumulative contribution of growth parameters towards fresh as well as dry matter accumulation is also strengthened by a positive correlation with fresh and dry weight of shoot length plant$^{-1}$, leaf number plant$^{-1}$, area leaf$^{-1}$ and LAI (**Table 5**).

Increasing levels of nutrient combinations up to $N_{90}P_{30}S_{51}$ improved net assimilation rate, carbonic anhydrase activity and leaf N and K content at 45 and/or 60 DAS (**Table 2**). The enhancing effect of nutrient combinations on leaf carbonic anhydrase activity could be due to the dependence of the synthesis of structural and catalytic proteins on these nutrients (Lynch and Rodriguez 1994; Harmens *et al.* 2000; Marschner 2002). The increase in enzyme activity would enhance the rate of assimilation of carbon dioxide, hence a higher value for net assimilation rate of corresponding plants (**Table 2**). The improved net assimilation rate together with adequate nutrient content would naturally improve the dry matter accumulation of treated plants (**Table 1**).

## Yield attributes and yield

Data for yield characters (**Table 3**) showed that the application of nutrients up to $N_{90}P_{30}S_{51}$ enhanced pods plant$^{-1}$, seeds pod$^{-1}$, seed yield ha$^{-1}$ and oil yield ha$^{-1}$. These results broadly corroborate the findings of other researchers working on rapeseed-mustard. For example, the maximum pods plant$^{-1}$ and seeds pod$^{-1}$ were recorded by Chaubey *et al.* (2001) on applying 120 kg N + 26.2 kg P + 33.2 kg K ha$^{-1}$ and 120 kg N + 30 kg S + 33.2 kg K ha$^{-1}$ to *B. juncea* 'Rohini'; by Hotmode *et al.* (2001) and Rathod *et al.* (2001) on applying 60 kg N + 21.8 kg P ha$^{-1}$ to *B. juncea* 'Pusa Bold' and 'CAN 9'; and Siddiqui *et al.* (2008b) on applying basal application of 70 kg N + 28 kg P ha$^{-1}$ supplemented with foliar spray of 20 kg N + 2 kg P + 2 kg S ha$^{-1}$ to *B. juncea* 'TERI (0E)', 'M21-Swarna' and 'Rohini' and *Brassica napus* L. cv. 'Hyola PAC-401'. Hotmode *et al.* (2001) and Siddiqui *et al.* (2008b) also reported maximum seed and oil yield in their studies. Increased leaf area and net assimilation rate (**Tables 1, 2**) seem to be mainly responsible for the increase in yield characteristics studied (**Table 3**). The enhanced leaf area of treated plants coupled with efficient carbon assimilation enabled them to produce larger quantities of photosynthates as is reflected by the higher dry weight of treated plants (**Table 1**). The combined effect of improved carbonic anhydrase activity and sufficient leaf NPK content (**Table 2**) that caused a positive response of various growth parameters to the nutrient application increased the dry matter accumulation in treated plants (**Table 1**). As expected, this led to a positive effect on yield attributes studied (**Table 3**), which in turn resulted in maximized seed yield (**Table 3**). These conclusions are confirmed by correlation studies wherein seed yield was found to be significantly and positively related to most characteristics studied at various growth stages (**Table 5**).

## Quality attributes

The data in **Table 4** revealed that most fatty acids studied increased with the application of nutrients over the no-nutrient control. These results broadly corroborate those of other groups. For example, an improvement in palmitic, stearic, oleic, linoleic, linolenic and erucic acid content was noted due to basal application of 100 kg N + 16.37 kg P ha$^{-1}$ by Thakral *et al.* (1995) in *B. juncea* 'RH-781', *B. napus* 'GSH-1' and *Brassica carinata* 'C-6 YS-7-B'; in linoleic, linolenic and erucic acid content due to basal application of 60 kg N ha$^{-1}$ and in oleic, linoleic and linolenic acid content due to basal application of 40 kg S ha$^{-1}$ by Joshi *et al.* (1998) in *B. juncea* 'Pusa Bold'; and in stearic, oleic, linoleic, linolenic acid content due to basal application of 60 kg N + 40 kg S ha$^{-1}$ by Ahmad and Abdin (2000) in *B. juncea* 'Pusa Jaikisan' and *Brassica campestris* 'Pusa Gold'. A higher content of oleic and linoleic acids in the oil improves the nutritional quality of oil but the linolenic and erucic acids deteriorates it (Axtell 1981; Kaur and Islam 2003; Agnihotri *et al.* 2004). In the present study, the increase in linolenic acid and erucic acid due to $N_{90}P_{30}S_{51}$ over the no-nutrient control is not very high (5.02 and 0.67%, respectively) and thus could be overlooked. The application of $N_{90}P_{30}S_{51}$ improved the quality of the oil of these genotypes by increasing the linoleic and oleic acid content, when compared with no-nutrient control (**Table 4**). Holmes and Bennett (1979) commented that the fatty acid composition of rapeseed-mustard oil is mainly under genetic control, but can be modified to some extent by N nutrition.

Data in **Tables 1-4** also revealed that cultivars vary in their performance. For example, maximum values were recorded for plant height, leaf number, dry weight and leaf N content, particularly at 60 DAS, linoleic acid and linolenic acid of 'TERI (0E) M21-Swarna'; leaf area, leaf area index, fresh weight, net assimilation rate, carbonic anhydrase activity and leaf K content, particularly at 60 DAS, pod number, seed number, seed yield, oil yield and oleic acid of 'Hyola PAC-401' and erucic acid of 'Rohini'. Similarly genotype variations for various parameters have been reported by other groups. For example, among 10 cultivars of *B. juncea* 'Varuna' had maximum pods plant$^{-1}$, seed yield ha$^{-1}$ and oil yield ha$^{-1}$ (Mohammad *et al.* 1984); of three *Brassica* species, *B. napus* 'GSH-1' possessed maximum palmitic, stearic and oleic acid (Thakral *et al.* 1995); of two *Brassica* species, *B. juncea* 'Pusa Jaikisan' had higher linoleic, stearic, eicosenoic and erucic acid content (Ahmad and Abdin 2000); and among four *Brassica* species, *B. juncea* 'Cutlass' gave maximum seed yield (Malhi *et al.* 2007, among others, working on cultivars of rapeseed-mustard other than those selected for the present study). The variation in cultivars in terms of various parameters could be ascribed to their genetic make-up.

## CONCLUSION

Among the NPS combinations, $N_{90}P_{30}S_{51}$ proved best. 'Hyola PAC-401' surpassed other cultivars for most parameters studied. The $N_{90}P_{30}S_{51}$ x 'Hyola PAC-401' as well as $N_{90}P_{30}S_{51}$ x 'TERI (0E) M21-Swarna' interactions proved superior for most parameters, including seed yield, oil yield and erucic acid content. These results reveal that NPS supply is important to improve yield and nutritional quality of rapeseed-mustard. The proper nutrient supply must be instituted according to the specific production goal.

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## REFERENCES

**Agnihotri A, Prem D, Gupta K** (2004) Biotechnology in quality improvement of oilseed Brassicas. In: Srivatava PS, Narula A, Srivastava S (Eds) *Plant Biotechnology and Molecular Markers*, Anamaya Publishers, New Delhi, pp 144-155

**Ahmad A, Abdin MZ** (2000) Interactive effect of sulphur and nitrogen on the oil and protein contents and on the fatty acid profiles of oil in the seeds of rapeseed (*Brassica campestris* L.) and mustard (*Brassica juncea* L. Czern. & Coss). *Journal of Agronomy and Crop Science* **185**, 49-54

**Axtell JD** (1981) Breeding for improved fedding quality, In: Frey KJ (Ed) *Plant Breeding II*, Lowa State University Press, pp 365-414

**Batra SR** (2000) Rapeseed-mustard at the doorstep of the new millennium In: Bhatnagar AK, Shukla RK, Singh HB (Eds) *Rapeseed-mustard at the Doorstep of the New Millennium*, Mustard Research and Promotion Consortium, New Delhi, pp 1-9

**Bhari NR, Siag RK, Mann PS** (2000) Response of Indian mustard (*Brassica juncea* L.) to nitrogen and phosphorus on torripsamments of north-western Rajasthan. *Indian Journal of Agronomy* **45**, 746-751

**Chaubey AK, Kaushik MK, Singh SB** (2001) Phosphorus and sulphur fertilization in relation to yield attributes and seed yield of Indian mustard (*Brassica juncea* L.). *Bioved* **12**, 53-56

**Clarkson DT, Hanson JB** (1980) The mineral nutrition of higher plants. *Annual Review of Plant Physiology* **31**, 239-298

**Dejoux JF, Meynard JM, Reau R, Roche R, Saulas P** (2003) Evaluation of environmentally-friendly crop management systems based on very early sowing dates for winter oilseed rape in France. *Agronomie* **30**, 725-736

**Duke SH, Reisenauer HM** (1986) Role and requirements of sulfur in plant nutrition. In: Tabatabai MA (Ed) *Sulfur in Agriculture, Agronomy Monograph*, No. 27, American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, Wisconsin, pp 123-168

**Dwivedi RS, Randhawa NS** (1974) Evaluation of rapid test for hidden hunger of zinc in plants. *Plant and Soil* **40**, 445-451

**Fiske CH, Subba Row Y** (1925) The colorimetric determination of phosphorus. *The Journal of Biological Chemistry* **66**, 375-400

**Harmens H, Stirling CM, Marshell C, Farrar JF** (2000) Does down-regulation of photosynthetic capacity by elevated $CO_2$ depend on N supply in *Dactylis glomerata*? *Physiologia Plantarum* **108**, 43-50

**Hatmode CN, Rathod DL, Ingole AS, Deotale RD, Chore CN** (2001) Effect of different levels of fertilizers on biochemical, yield and yield contributing parameters in mustard. *Journal of Soils and Crops* **11**, 229-234

**Hawkesford MJ, Schneider A, Belcher AR, Clarkson DT** (1995) Regulation of enzymes involve in the sulfur assimilation pathway. *Zeitschrift für Pflanzenernährung und Bodenkunde* **156**, 55-57

**Holmes MRJ, Bennett D** (1979) Effect of nitrogen fertilizer on the fatty acid composition of oil from low erucic acid rape varieties. *Journal of the Science of Food and Agriculture* **30**, 264-266

**Joshi NL, Mali PC, Saxena A** (1998) Effect of nitrogen and sulphur application on yield and fatty acid composition of mustard (*Brassica juncea* L.). *Journal of Agronomy and Crop Science* **180**, 59-63

**Kaur P, Islam F** (2003) Nutritional aspects of mustard oil. *Proceedings of 5th National Convention on Health Nutrition and Value Addition of Indian Mustard*, New Delhi, pp 62-70

**Kaushik N, Agnihotri A** (1997) Evaluation of improved method for determination of rapeseed-mustard FAMES by GC. *Chromatographia* **44**, 97-99

**Lindner RC** (1944) Rapid analytical methods for some of the more common inorganic constituents of plant tissue. *Plant Physiology* **19**, 76-89

**Lynch J, Rodriguez NS** (1994) Photosynthetic nitrogen-use efficiency in relation to leaf longevity in common bean. *Crop Science* **34**, 1284-1290

**Malhi S, Gan Y, Raney JP** (2007) Yield, seed quality, and sulfur uptake of *Brassica* oilseed crops in response to sulfur fertilization. *Agronomy Journal* **99**, 570-577

**Marschner H** (2002) *Mineral Nutrition of Higher Plants* (2nd Edn), Academic Press, London, 889 pp

**Milthorpe FL, Moorby J** (1979) *An Introduction to Crop Physiology* (2nd Edn), Cambridge University Press, Cambridge, 244 pp

**Mohammad F, Samiullah, Afridi MMRK** (1984) Comparative performance of ten mustard varieties in relation to yield and quality. *Geobios* **11**, 92-93

**Nason A, McElroy WD** (1963) Modes of action of the essential mineral elements. In: Steward FC (Ed) *Plant Physiology – A Treatise* (Vol III), Academic Press Inc., New York, pp 451-536

**Pachauri RK** (2001) *Agriculture*, TERI. Vision 37, New Delhi, pp 1-2

**Rathod DL, Hatmode CN, Deotale RD, Chore CN, Patil RR** (2001) Physiological response of mustard to different levels of fertilizers under irrigated condition. *Journal of Soils and Crops* **11**, 146-150

**Salisbury FB, Ross CW** (1992) *Plant Physiology* (4th Edn), Wadsworth Publishing Co., Belmont, USA, 682 pp

**Siddiqui MH, Khan MN, Mohammad F, Khan MMA** (2008a) Role of nitrogen and gibberellic acid ($GA_3$) in the regulation of enzyme activities and in osmoprotectant accumulation in *Brassica juncea* L. under salt stress. *Journal of Agronomy and Crop Science* **194**, 214-224

**Siddiqui MH, Mohammad F, Khan MN, Khan MMA** (2008b) Cumulative effect of soil and foliar application of nitrogen, phosphorus, and sulfur on growth, physico-biochemical parameters, yield attributes, and fatty acid composition in oil of erucic acid-free rapeseed-mustard genotypes. *Journal of Plant Nutrition* **31**, 1284-1298

**Siddiqui MH, Mohammad F, Khan MN** (2007) Sensitivity analysis of erucic acid free cultivars of rapeseed-mustard under nutrient application. *Indian Journal of Plant Physiology* **12**, 153-161

**Thakral SK, Singh BP, Faroda AS, Gupta SK, Kumar S** (1995) Fatty acids composition in seeds of *Brassica* species as affected by moisture and fertility levels. *Crop Research* **10**, 137-140

**Watson DJ** (1958) The dependence of net assimilation rate on leaf area index. *Annals of Botany* **22**, 37-54