SUMMARY
The present thesis entitled “Coordination of sulfur and nitrogen in the protection of photosynthesis, growth and yield of cadmium-treated mustard (Brassica juncea)” comprises of six chapters.

The importance of the problem and justifications for the present work undertaken were emphasized in Chapter 1.

Chapter 2 is the review of literature. It includes literature available on the aspects of the physiological analysis of various growth-, photosynthetic- and, biochemical-characteristics, antioxidant studies and yield of various crop plants under Cd stress. The importance of S and N nutrients in the alleviation of stress and in the regulation of plant growth and development under stress condition were also reviewed. The chapter has been divided into sections and sub-sections for better understanding of the work of other research reports in this field of study. In addition, the critical appraisal of the review of literature has also been included to identify the gap in the field of study.

The details of the material used in the study and methodology adopted to determine various characteristics recorded in the three experiments have been described in the Chapter 3. In addition the Chapter 3 also mentions the relevant information on the location of the study and the environmental conditions during the data sampling times.

Chapter 4 includes the results on the response of mustard to cadmium, sulfur and nitrogen treatments in three Experiments. The data obtained were statistically analyzed and the significance was determined at $p<0.05$.

The results obtained in the Experiments have been discussed in Chapter 5 in the light of observations recorded and supported with the earlier findings, if available. This chapter also presents the possible explanations of the data obtained to reach a conclusion and possible future prospects.

Chapter 6 present the summary of the work reported in this thesis.

The results of the Experiments are summarized below:

**Experiment 1**

The Experiment was conducted to study the effect of five concentrations of Cd viz., 0, 25, 50, 100 and 150mg kg$^{-1}$ soil on Cd accumulation in root and leaf, growth, photosynthetic and yield characteristics of five mustard cultivars (Brassica juncea L.)
namedly, Alankar, Varuna, Pusa Bold, Sakha and RH30. The treatments in this Experiment were arranged in a factorial randomized block design. Cadmium accumulation, growth and photosynthetic characteristics were studied at pre-flowering (30DAS), flowering (60DAS) and post-flowering (90DAS) growth stages, while yield characteristics were noted at harvest (120DAS). Tolerance index of the five cultivars of mustard was calculated and the cultivars were designated as Cd tolerant and Cd non-tolerant on the basis of their performance under Cd stress. The effect of Cd on growth, photosynthetic and yield characteristics was found significant at all sampling times. The interaction of Cd treatments and cultivars was also found significant. For growth characteristics, the interaction effect was found non-significant at 30 DAS. The increase in Cd levels decreased the growth, photosynthetic and yield characteristics of all the five cultivars at all sampling stages. The observations recorded at the three sampling stages showed similar pattern of cultivar response to Cd treatments. Maximum reduction in growth, photosynthesis and yield characteristics was noted with 150mg Cd kg\(^{-1}\) soil followed by 100, 50 and 25mg Cd kg\(^{-1}\) soil.

Among cultivars, Alankar showed lesser decrease in growth, photosynthetic and yield characteristics followed by Varuna and Pusa Bold, whereas, RH30 and Sakha exhibited greater reduction in growth characteristics under Cd stress. The tolerance index of cultivars was: Alankar > Varuna > Pusa Bold > Sakha > RH30.

**Experiment 2**

Experiment 2 was conducted on the basis of findings of Experiments 1. As observed in Experiment 1, Alankar emerged as Cd-tolerant and RH30 as Cd non-tolerant cultivar. Among Cd levels, 150mg Cd kg\(^{-1}\) soil was found most toxic and caused maximum reductions in the characteristics studied. In the present Experiment, the aim was to study the alleviation potential of elemental S levels (50 and 100mg S kg\(^{-1}\) soil) on the effects of 50 and 150mg Cd kg\(^{-1}\) soil. The treatments in this Experiment were arranged in a factorial randomized block design. The assessment was done by studying the changes in Cd accumulation in root and leaf, growth and photosynthetic characteristics, S and N assimilation, components of antioxidant defense system and yield characteristics of tolerant (Alankar) and non-tolerant (RH30) cultivars. The sampling stages for Cd accumulation, growth and photosynthetic characteristics, S and N assimilation, components of antioxidant defense system were pre-flowering
(30DAS), flowering (60DAS) and post-flowering (90DAS). The yield characteristics were noted at harvest (120DAS).

The growth and photosynthetic characteristics and N assimilation decreased maximally in both the cultivars treated with 150mg Cd kg⁻¹ soil. Contrarily, there was significant increase in the Cd accumulation, S assimilation, H₂O₂ and TBARS content and components of enzymatic antioxidant system and glutathione content was found. Non-tolerant cultivar RH30 exhibited greater Cd effects than tolerant cultivar Alankar. In comparison to 100mg S kg⁻¹ soil, the application of 50mg S kg⁻¹ soil maximally alleviated the toxic effect of 50mg Cd kg⁻¹ soil and improved growth, photosynthesis, S and N assimilation and components of enzymatic and non-enzymatic antioxidant system thus yield characteristics of both the cultivars. Further, no ameliorative effect of 100mg S kg⁻¹ soil was observed in plants treated with 150mg Cd kg⁻¹ soil. Alleviation effects of S were higher in Alankar than RH30.

**Experiment 3**

Experiment 3 was conducted on the basis of the findings of Experiments 2. In Experiment 2, it was observed that the application of 50mg S kg⁻¹ soil to plants treated with 50mg Cd kg⁻¹ soil alleviated Cd-induced toxicity in both the cultivars. Supplementation of 50mg S kg⁻¹ soil maximally overcome the toxic effects of 50mg Cd kg⁻¹ soil in Alankar (tolerant cultivar), while, the same combination lowered the Cd-induced toxic effects in RH30 to some extent. The present experiment was aimed to study the effect of supplementation of different N levels (40, 80 and 120mg N kg⁻¹ soil) to 50mg S kg⁻¹ soil for alleviation of adverse effects of 50mg Cd kg⁻¹ soil. The treatments in this Experiment were arranged in a factorial randomized block design. The assessment was done by analyzing the changes in Cd accumulation in root and leaf, growth and photosynthetic characteristics, S and N assimilation, components of antioxidant defense system at 30, 60 and 90DAS and yield characteristics at harvest.

The alterations in growth, photosynthesis, S and N assimilation, components of antioxidant system and yield characteristics caused by 50mg Cd kg⁻¹ soil were alleviated by 50mg S kg⁻¹ soil in tolerant (Alankar) and non-tolerant (RH30) cultivars, but the alleviation potential of S varied between the cultivars. Application of different levels of N (40, 80 and 120mg N kg⁻¹ soil) further enhanced the alleviation effect of S (50mg S kg⁻¹ soil) in both the cultivars. Among the N levels used, the application of 80mg N kg⁻¹ soil proved superior to the other N levels. A combined application of S
and N (50mg S kg\(^{-1}\) soil plus 80mg N kg\(^{-1}\) soil) not only ameliorated the Cd-induced (50mg Cd kg\(^{-1}\) soil) effects but also increased the growth, photosynthesis, S and N assimilation and components of enzymatic and non-enzymatic antioxidant system thus yield characteristics in Alankar. In RH30, this combination (50mg S kg\(^{-1}\) soil plus 80mg N kg\(^{-1}\) soil) only lowered the adverse effects of Cd.

The present chapter is followed by an up-to-date bibliography of the literature cited in the text.