INTRODUCTION

Vegetables are an integral part of human diet and a meal without vegetable is supposed to be incomplete in any part of the world. The daily minimum requirement of vegetable according to a dietician is 284 g per capita, i.e. about 20 per cent of the daily requirement of the total food of an adult, but at present the per capita intake is only 210g per day (Singh and Kalloo, 1998). Lady's Finger/Okra/Bhindi [*Abelmoschus esculentus* (L.) Moench] is a fruit vegetable commonly grown on the plains of India and consumed in all the states (Plate I). Tender fruits are cooked as vegetables. It is a rich source of vitamin A, B and C with little iron and nitrogen. Matured fruits and stem containing crude fibre are used in paper industry. In India APEDA has identified okra as one of the vegetables with good export potential. Keeping in view the large demand of vegetables for domestic consumption and enormous scope for export, the yield can be increased manifold by using advanced technology.

Crop productivity is governed by the interaction of many factors like variety, environment and agronomic practices. Soil contamination with heavy metals has become a worldwide problem, leading to the loss of crop yield and health hazard as they enter the food chain (Salt *et al.* 1995; Schlickler and Caspi, 1999). Heavy metals are defined as metals with a density higher than 5 g cm^{-3}. Fifty-three of the ninety naturally occurring elements are heavy metals (Weast, 1984). Though some of these are essential for life processes, all of these are toxic to organisms at higher concentrations. Heavy metals are natural components of the earth's crust. They cannot be degraded or destroyed. To a small extent they enter our bodies via food, drinking water and air. As trace elements, some heavy metals (e.g. copper, selenium, zinc) are essential to maintain the metabolism of the human body. However, at higher concentrations they can lead to poisoning. Heavy metal poisoning could result, for instance, from drinking-water contamination (e.g. lead pipes), high ambient air concentrations near emission sources, or intake via the food chain. Heavy metals are dangerous because they tend to bioaccumulate.

Cadmium is a byproduct of the mining and smelting of lead and zinc. It is used in nickel-cadmium batteries, PVC plastics, and paint pigments. It can be found in soils because insecticides, fungicides, sludge, and commercial fertilizers that use

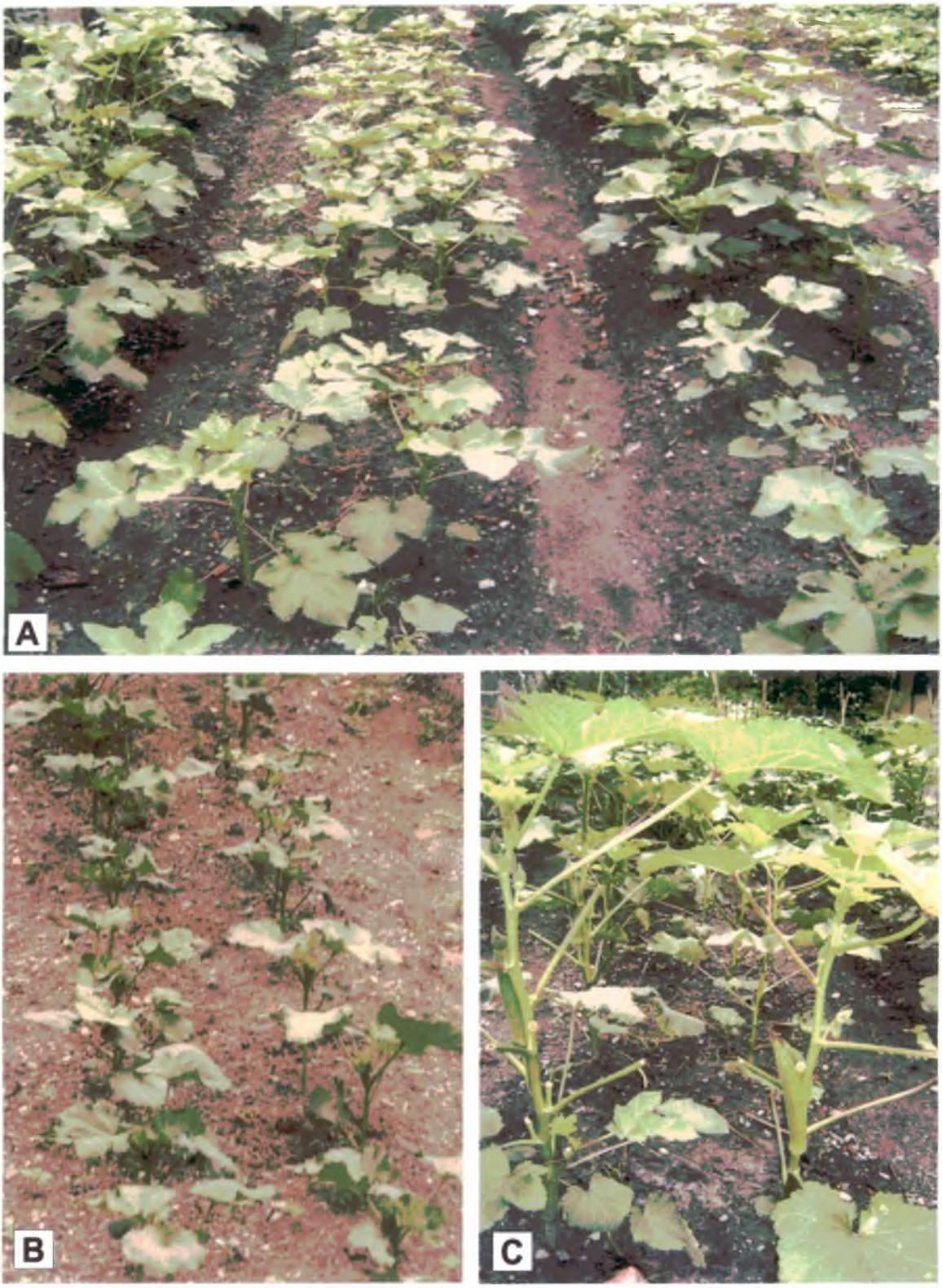

Plate I: Okra plants growing in the field. A: Flowering stage B: Seedling stage and C: Fruiting stage

cadmium are used in agriculture. Among various toxic metals, Cd is recognized as one of the most hazardous elements that is not essential for plant growth but is easily taken up by plants (Nigam *et al.* 2002).

Copper is a micronutrient and is essential for the plants in small amounts. Sources of copper in soil are copper containing fertilizers, fungicides and insecticides.

Mercury is generated naturally in the environment from the degassing of the earth's crust, from volcanic emissions. It exists in three forms: elemental mercury and organic and inorganic mercury. Mining operations, chloralkali plants, and paper industries are significant producers of mercury. Mercury continues to be used in thermometers, thermostats, and dental amalgam.

Lead is a very soft metal and was used in pipes, drains, and soldering materials for many years. Every year, industry produces about 2.5 million tons of lead throughout the world. Most of this lead is used for batteries. The remainder is used for cable coverings, plumbing, ammunition, and fuel additives. Other uses are as paint pigments and in PVC plastics, x-ray shielding, crystal glass production, pencils, and pesticides.

The development of industry, intensive agriculture with modern agricultural techniques, has been so rapid and extensive in the last few decades that it has led to soil and environmental pollution. Among most heavy metals cadmium and arsenic are extremely poisonous, mercury, lead, nickel and fluoride are moderately poisonous whereas boron, copper, zinc, iron, manganese, molybdenum etc. are less poisonous (Das, 2000). The heavy metals are generally present in areas with high anthropogenic pressure. The main sources of contamination in agricultural soil are fertilizer impurity (Cd^{2+}), pesticide composition (Cu^{2+} and Hg^{2+}), and use of refuge derived compost and sewage sludge (Cd^{2+}, Ni^{2+}, Pb^{2+} etc.) and to a lesser extent weathering of rocks. Soils influenced by human activities show a wide range of heavy metal contamination. Toxicity from metallic elements having high atomic weights, such as cadmium, cobalt, iron, lead, mercury, nickel and zinc, may result in cellular injury, chromosomal damage, tumours, birth defects as well as specified

poisonings following ingestion or breathing of particles of such elements alone or in compound form.

Heavy metals can directly or indirectly interfere with the various physiological processes of the plant. The contamination of agricultural land with heavy metal is a widely recognized problem. In the soil, these metals operate as stress factors that cause physiological constraints and impair metabolism after their uptake. This then results in decreased vigour and the stunted growth of the plants. Characteristic features of heavy metal toxicity are inhibition of seed germination, seedling growth, chlorosis, reduction in net photosynthetic rate leading to decreased growth and productivity (Burton *et al.* 1986; Bhattacharjee and Mukherjee, 2004; Neelima and Reddy, 2003). Metal toxicity is counteracted by the alteration in the biochemical parameters. Plant species respond differently to the same level of stress. Stress is a change in the physiology that occurs when plants are exposed to extremely unfavourable conditions that need not be fatal to the organism but will induce an "alarm response". It has been reported that oxidative stress induced by heavy metal toxicity leads to the production of reactive oxygen species (Aravind and Prasad, 2005). The reactive oxygen species (ROS) cause a variety of harmful effects in plant cells, such as inhibition of germination and photosynthetic activity, lipid peroxidation and DNA damage (MacFarlane, 2003; Malecka *et al.* 2001 ; Shaw *et al.* 2004). The ROS are scavenged in plants by antioxidant enzymes like superoxide dismutase (SOD), peroxidase (POX), catalase (CAT), and glutathione reductase (GR). Measurement of activities of antioxidant enzymes is helpful in indicating the oxidative stress in plants (Geebelen *et al.* 2002). When the oxidative stress induced metabolic changes exceed the scavenging capacity by antioxidants, cell death occurs. At the whole plant level, stunted growth as a result of decreased root and shoot elongation is the most common symptom of oxidative stress (Metwally *et al.* 2005; Zengin and Munzuroglu, 2004).

Okra [*Abelmoschus esculentus* (L.) Moench] is a common vegetable crop cultivated in all parts of India. It is an annual and grows in different soil conditions. As it is also generally grown in soil adjacent to tea gardens where soil contaminants from tea garden pesticides/fungicides run off are expected to be present, the present

work was undertaken to determine how different cultivars of this plant responds to heavy metal induced stress. The objectives of the present work were:

(i) To screen Lady's Finger/ okra/ bhindi [*Abelmoschus esculentus* (L.) Moench] cultivars for their relative resistance/ tolerance to heavy metal stress.

(ii) To study the effect of heavy metal stress on the growth parameters.

(iii) To study the effect of heavy metal stress in terms of yield.

(iv) To study the biochemical parameters associated with heavy metal stress in terms of changes in the cellular constituents of shoots and roots including carbohydrates, carotenoids, chlorophylls, proline and protein.

(v) To study metabolite partitioning during stress.

(vi) To study the effect of heavy metal stress on enzyme activities like catalase, peroxidase, ascorbate peroxidase, glutathione reductase and superoxide dismutase.

(vii) To study the specific expression of new protein(s) during heavy metal stress.

(viii) To study the accumulation of heavy metals in different plant tissues.

(ix) To ameliorate the effect of heavy metals by $CaCl_2$ and KNO_3.

In order to achieve the above-mentioned objectives, standard methods have been used which are described in the following pages. Besides, a brief review of literature in the line of work is also being presented.