CHAPTER - III

RESULTS AND DISCUSSIONS

A. POTASSIUM DEFICIENCY SYMPTOMS

Symptoms caused due to potassium deficiency in three *Amaranthus* species are recorded in Plate 1 and 2. The effect of K deficiency on three *Amaranthus* species was observed from early stage of growth. Plants grown in K deficient medium showed late germination than those grown in complete nutrient medium. Deficiency symptoms were observed first on the older leaves. In the initial stage yellowing of leaf lamina occurred from the margins and tips. As growth further proceeded yellow margins and tips became dry and curling or rolling of leaf lamina was observed (Plate 1). The *Amaranthus* species subjected to K deficiency did not show root rot as noticed by Park et al. (1971) in rice and Chavan (1980) in ragi but root growth was reduced in all the three *Amaranthus* species (Plate 2). There was no premature death of plants subjected to K deficiency as noticed by Sircar and Datta (1959) in rice. Thus the overall appearance of *Amaranthus* plants of all the three species was very much affected by potassium deficiency.

B. GROWTH

The process of growth is interpreted in different ways by different workers. Lockhart, (1968) considers growth as an irreversible increase in size resulting from cell division and expansion and it is controlled by rates of water uptake, metabolic mediated cell wall loosening and the

PLATE -1 Leaves of *Amaranthus caudatus* and *A. paniculatus* showing potassium deficiency symptoms

A.*A. caudatus*

B.*A. paniculatus*

TREATMENTS

1. Control
2. -K

PLATE -2. Roots of three *Amaranthus* species showing potassium deficiency symptoms

A.*A. caudatus*

B.*A. hypochondriacus*

C.*A. paniculatus*

TREATMENTS

1. Control
2. -K

PLATE –1

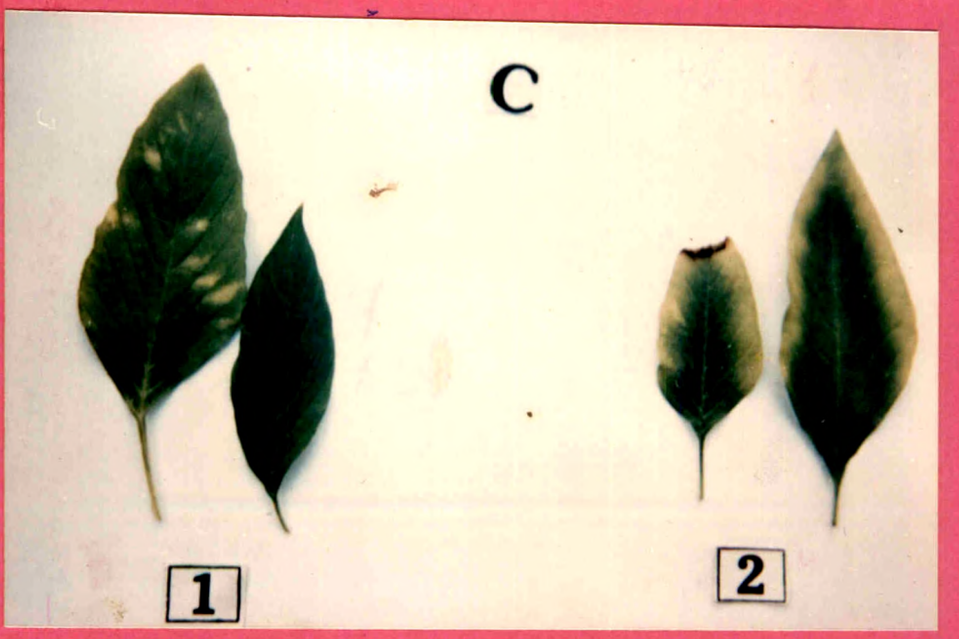
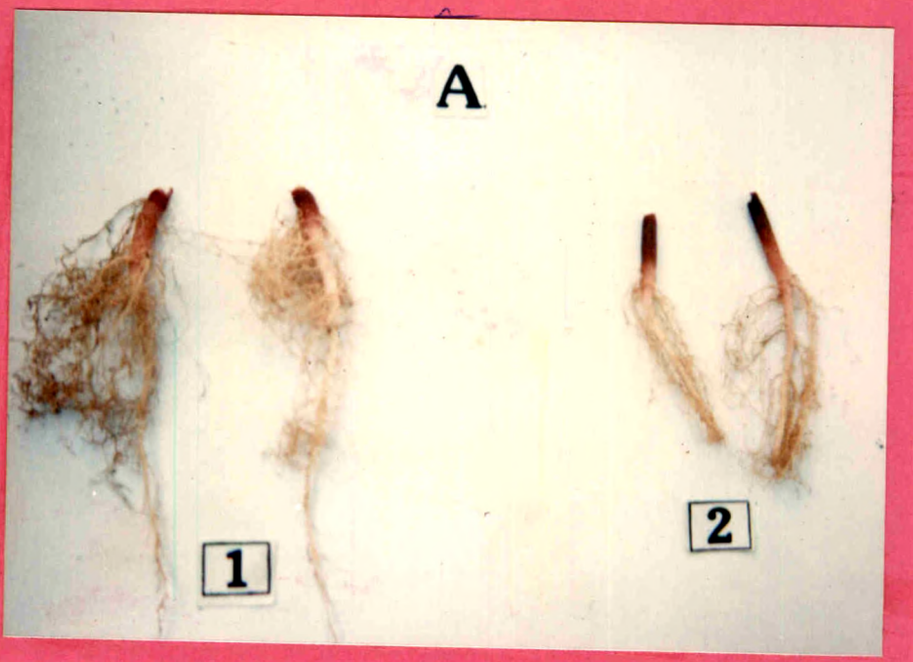
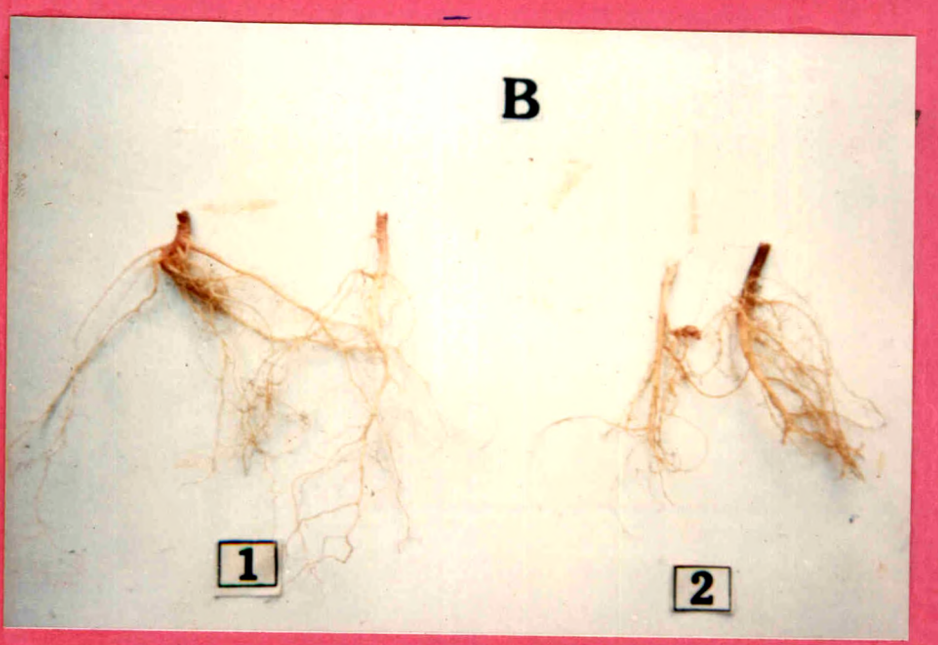
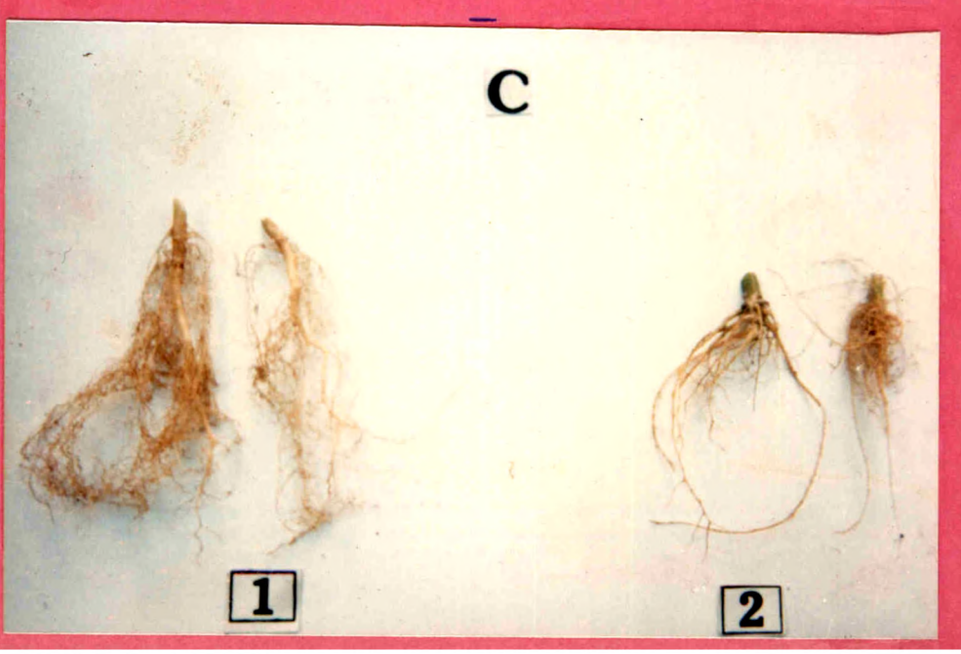


PLATE -2







uptake of nutrients in the cells. In view of He and Cramer (1993), growth analysis is fundamental to the characterization of plant response to an environmental stress. Since it provides useful information regarding the nature of the stress effect on growth. The effect of K deficiency on various parameters in *A. caudatus*, *A. hypochondriacus* and *A. paniculatus* is presented and discussed below.

1. **Average Height**

Effect of K deficiency on average plant height and length of internodes in three *Amaranthus* species is recorded in Table 1. It is clear from the table that average height and length of internode is considerably decreased in all three *Amaranthus* species due to K deficiency. The root length is also reduced due to K deficit. Usually height of the plants is a very good indicator of their conditions or the success of species in various environmental conditions. Height is a qualitative character as it has got the forage value for the herbivorus animals. Height is easily detactable nondestructive characteristic of the plant. But at the same time one cannot totally rely on plant height as the only criterion of plant growth.

Rodriauez et al. (1968) observed reduction in the shoot development of guava due to K deficiency. According to Nightingale et al. (1930), at first stage due to K deficiency

Table 1 : Effect of potassium deficiency on some growth parameters of three *Amaranthus* species

Treatment	Root length % of control	Total height % of control	Leaf Number per plant	Leaf area/ plant % of control	Plants Fresh weight % of control	Plants Dry weight % of control	Length of Inflore-scence % of control	Length of Internode % of control
A. caudatus -K	75.48	81.9	9	70.20	93.20	72.94	58.80	43.48
A. hypochondriacus -K	59.85	53.0	8	63.30	49.40	49.90	66.20	36.85
A. paniculatus -K	66.42	71.0	10	89.36	78.26	69.25	86.04	39.60

(Values are mean of three determinations)

cambium activity is lost and lignification is stimulated. Whereas Subrahmanyan (1987) emphasize that deficient plants donot have sufficient levels of nutrients and this limits the expression of their inherent metabolic capacity resulting in poor growth.

Several workers have reported decrease in height due to K deficiency in various crops like sugarbeet (Marschner et al., 1987), Maize (Repka, 1983), wheat (Scherer et al., 1982), Mustard, Black gram (Subrahmanyam, 1987), (Mondal et al., 1990), Tomato (Singh and Verma, 1991) Chickpea (Murumkar and Chavan, 1992). Recently Patra et al. (1995) also found that low levels of potassium cause reduction in total plant height. Hewitt (1963) noticed that K deficiency causes marked change in the growth habit due to shortening of internodes and extension of numerous axillary shoots usually near the base of the plant. Thus according to him K deficient plants shows bushy habit. There are few reports about change in hormonal balance due to K deficiency (Rajagopal and Rao, 1974) and this may be one of the reasons for such change in habit.

In the present investigation we also observed reduced height in K deficient *Amaranthus* plants. All the three species are adversely affected by K deficiency. Length of internodes is reduced in three *Amaranthus* species. Root growth is also reduced due to K deficiency. The negative

effect of potassium deficiency on plant height is more prominent in *A. hypochondriacus* and *A. paniculatus*.

2. Foliar Characteristics

Effect of potassium potasium deficiency on average number of leaves and leaf area is depicted in Table.1. It is clear from the table that these growth parameters were decreased due to potassium deficiency in all the three *Amaranthus* species. The reduction in leaf area is more significant in *A. caudatus*.

The growth analysis in crop involves nondestructive analysis of number of leaves and leaf area. This is due to the fact that the leaves are the most important photosynthetic producers as well as metabolic centres in plants. The rate of photosynthesis is depend on available leaf area. Besides photosynthesis, the leaves also regulate water loss and also act as a centre of many metabolic actiities. Thus according to Causton and Venus (1981), measurement of leaf area determines the plants 'Productive investment'. The leaf area is more related to crop yield and leaf development is a major determinant of plant growth and productivity. Chow et al. (1990), have emphasized that total leaf area is more important determinant of shoot dry weight than photosynthetic capacity per unit leaf area.

The reduction in number of leaves and leaf area per plant due to K deficiency was noticed in crops like barley, rice and maize (Lal and Subba Rao, 1960). SubrahmanyaN (1987) observed reduced leaf number and leaf area in black gram due to K deficiency. Huber (1984) found that total leaf area per plant decreased due to K deficiency. Patil et al. (1987) noticed that due to K deficiency there is decrease in leaf area in Bidi Tobacco (*Nicotiana tabacum* L.). Murumkar and Chavan (1992) also observed same results in chick pea due to K deficiency. Patra et al. (1995) noticed that low levels of potassium caused reduction in leaf area in groundnut plants. Thus potassium appears to be very much essential for growth and development of *Amaranthus* leaves. The deficit of this element leads to great reduction of leaf area as well as leaf number. This inturn would affect the overall crop productivity.

3. Fresh Weight and Dry Weight

Effect of potassium deficiency on fresh weight and dry weight of three *Amaranthus* species is depicted in Table 1. It is clear from the table that both fresh weight and dry-weight of potassium deficient *Amaranthus* plants is decreased due to potassium deficiency.

The overall growth of plant is an indication of increment of dry weight of plant over a periods of time. The

growth rate is linearly proportional to the plant weight. The total dry matter production gives an idea about carbon budget and productivity capacity of the plant which depends upon total area of photosynthetic organ and its efficiency to harvest solar energy. The dry weight also represents a net carbon gain since it represents a product of substraction of net respiratory loss from net phtosynthesis.

Lal and Subba Rao (1960) observed reduced fresh weight and dry weight due to nitrogen, potassium and phosphorus deficiencies in barley, paddy and maize. Subrahmanyan (1987) noticed reduced dry matter production in black gram due to K deficiency. Patil et al. (1987) observed decreased dry matter production in Bidi Tobacco (*Nicotiana tabacum* L.) due to K deficiency. Singh and Verma (1991) recorded that the low levels of potassium cause reduction in fresh weight and dry weight in tomato. Murumkar and Chavan (1992) also observed reduced fresh weight and dry weight in chickpea due to K deficiency. Patra et al. (1995) noticed that low levels of potassium cause reduction in dry matter production in both summer and kharif season groundnut plant.

In the present investigation we noticed decrease in fresh weight and dry weight of all three *Amaranthus* species due to K deficiency. In this respect *A. hypochondriacus* appears more sensitive to K-deficiency. Thus the productive investiment of biomass production is

significantly affected under K deficiency which affects overall growth performance of *Amaranthus*. These observations reveal indispensibility of potassium for *Amaranthus*.

4. Flowering

Besides causing an overall decrease in growth, potassium deficiency was also found to have negative influence on flowering process in *Amaranthus* species. Thus about seven days delay in flowering initiation was noticed in all the three species due to potassium deficiency. The size of inflorescence was also reduced in plants subjected to potassium deficiency (Table 1 and Plate 3).

Flower formation is a revolutionary phase in the life cycle of a plant. Flower initiation involves the transformation of vegetative to the floral state. The shoot meristem is reduced and is also induced to develop sepals, petals, stamens and carpels in place to leaves. The pattern and timing of flower initiation vary from species to species.

Few workers observed that due to K deficiency there is delay in flowering. Chavan (1980) observed delay in flowering and reduction in size of fingers in *Eleusine corcana* due to K deficiency. There are reports regarding effect of K deficiency on flowering which are mentioned in book "potassium nutrition of some crop plants" published by potassium research institute of India in 1994. Wheat

PLATE -3. Effect of potassium deficiency on length of inflorescence of three *Amaranthus* species

A.*A. caudatus*

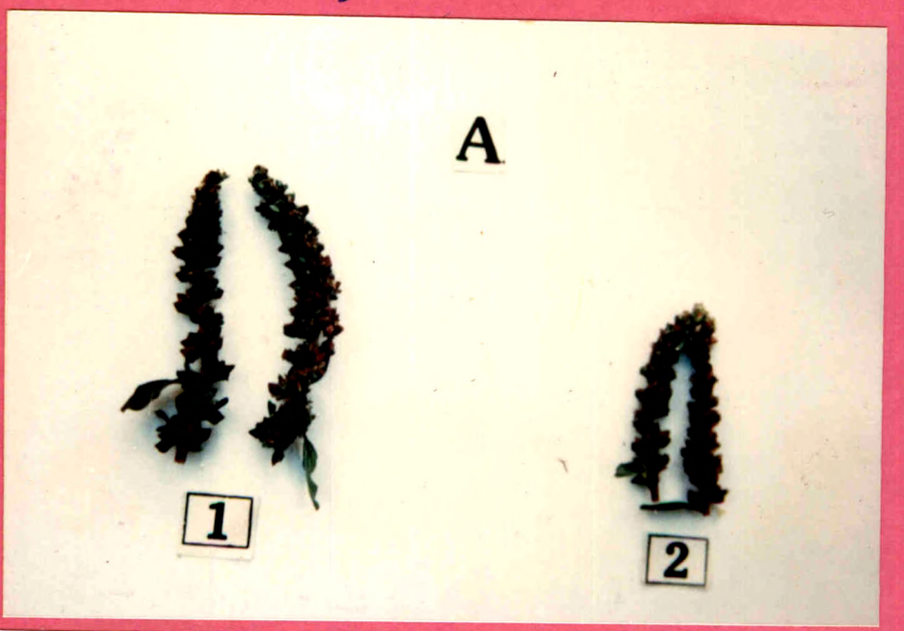
B.*A. hypochondriacus*

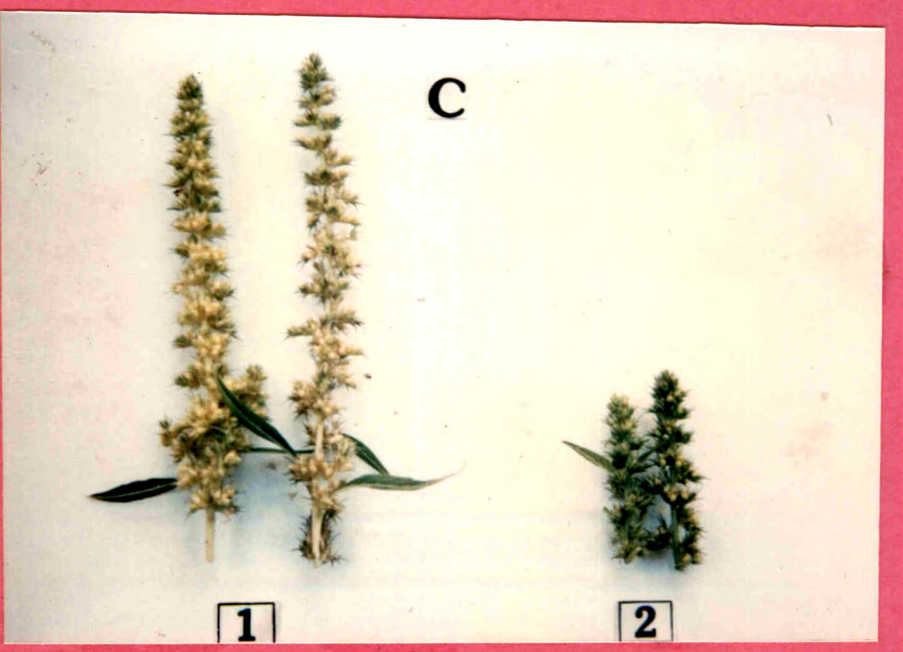
C.*A. paniculatus*

TREATMENTS

1. Control
2. -K

PLATE -3





(Chatterjee and Rashmi, 1994), Barley (Sainy and Chatterjee, 1994), Sorghum (Chatterjee and Jain, 1994b), Pearl millet (Chatterjee and Sainy, 1994b). Groundnut (Chatterjee and Sainy, 1994a), Pigen pea (Chatterjee and Jain, 1994a). All these workers observed delay in flowering due to potassium deficiency. Sainy and Chatterjee (1994) observed that in rice there is production of abortive flowers due to acute deficiency of potassium.

In the present investigation we found that reproductive growth of *Amaranthus caudatus*, *Amaranthus hypochondriacus* and *Amaranthus paniculatus* is affected considerably by K deficiency. Thus due to K deficiency there is delay in flowering and length of inflorescence is also reduced in K deficient plants. This may be possibly due to a marked decline in growth of vegetative parts as well as some alterations in hormonal balance essential for flowering. From above observations it is clear that in *Amaranthus* species potassium plays important role in flower initiation.

C. LEAF WATER RELATIONS

Effect of potassium deficiency on leaf water relations in three *Amaranthus* species is depicted in Table.2. It is clear from the table that leaf succulence and water content are lowered in three *Amaranthus* species whereas relative water content is increased in all three *Amaranthus* species due to potassium deficiency. Increase in

Table 2 : Effect of potassium deficiency on leaf water relations of three *Amaranthus* species.

Treatment	Water content (% of D.W.)	Leaf succulence (g)	Relative water content (%)
A. caudatus			
Control	809	9.09	52.83
-K	733	8.06	70.85
A. hypochondriacus			
Control	604	7.04	43.50
-K	525	6.25	47.19
A. paniculatus			
Control	541	6.41	53.89
-K	517	6.17	58.27

(Values are mean of three determinations)

relative water content is more prominent in *A. caudatus* than *A. hypochondriacus* and *A. paniculatus*.

Succulence is mainly due to increased elongation of palisade cells, and it tends to dilute internal ionic concentrations and it also significantly reduce the leaf surface per unit volume of tissue (Mass and Nieman, 1978). There are few reports regarding effect of mineral deficiencies on leaf succulence. Sircar and Datta (1959) reported increased leaf succulence in K deficient rice plants in the initial stages. Laetsch (1971) noticed that leaves of *Tradescantia* grown in N deficient solutions became very succulent. Murumkar (1986) also observed increased leaf succulence during early stage of K deficiency in leaves of chickpea. On the other hand Chavan (1980) reported lowered average thickness of leaf and lowered succulence in K deficient ragi plants. In the present investigation we also noticed decreased leaf succulence and lowered water content in three *Amaranthus* species due to potassium deficiency. This can be attributed to increase in transpiration (as will be seen latter) as well as decrease in root functioning (water uptake).

Relative water content (RWC) is regarded as the amount of water contained relative to what the plant organ or tissue can hold when fully turgid. RWC is a function dependent on the physical and chemical properties of the

tissues and the components of the chemical potential of water (Cowan and Milthrope, 1968). RWC may be used as a guide to its relative volume (Weatherly, 1969). In the present study we observed increased RWC in all three *Amaranthus* species due to K-deficiency. According to Umar et al. (1991), increase in RWC may be due to concomittant increase in chemiosmotic potential through the accumulation of proline, organic acids, sugars and organometallo complexes. Thus maintenance of higher RWC can help in maintaining a positive water balance under water stress conditions.

D. TRANSPIRATION

Effect of potassium deficiency on stomatal behaviour in three *Amaranthus* species is recorded in Table 3. It is clear from the table that diffusive conductance to water and transpiration rate were increased in the leaves of potassium deficient plants.

The water relations and the metabolism of land plants depend to a large extent on the diffusion of water vapour and of gases through the stomatal pores which occure on the aerial parts. These pores are situated between two specialized epidermal cells, the guard cells, which by changes in their dimensions and shapes brings about opening and closing movements of stomata. They allow to enter CO_2 into the leaf for photosynthesis and control the water loss

Table 3. Effect of Potassium deficiency on transpiration of three *Amaranthus* species.

Treatment	Diffusive conductance of water S cm^{-2}	Transpiration rate µg $cm^{-2}S^{-1}$
A. caudatus		
Control	0.10	7.22
-K	0.13	10.06
A. hypochondriacus		
Control	0.16	12.77
-K	0.20	15.94
A. paniculatus		
Control	0.15	12.49
-K	0.16	12.98

(Values are mean of three determinations)

by transpiration. The loss of water vapour from a plant is determined by the water potential gradient between leaf and atmosphere or by the resistance encountered water vapour loss from the mesophyll walls, through stomata and through the boundary layer of air around the leaf (Gale, 1975). The leaf resistance is regarded as a dynamic quantity and changes continuously with environmental conditions. Diffusive leaf conductances and resistances have both been used as quantitative parameters of stomatal function. Leaf conduction is particularly useful because transpiration, leaf water status and net photosynthesis will often be directly related to conductance, whereas they are inversly related to resistance.

Stomatal behaviour is greatly influenced by environmental changes. In particular, light or low levels of CO_2 promotes stomatal opening, white darkness high levels of CO_2, and abscisic acid induce stomatal closure (Zeiger, 1983, 1990). Stomatal movements require turgor changes in guard cells resulting from variations in the amount of osmotically active solutes within vacuoles (Ridolfi and Garrec, 1994). The stomatal behaviour is endogenously controlled by ions like potassium and calcium and growth regulators like abscisic acid IAA and cytokinins (Mansfield and Davis, 1985). According to Mansfield *et al*. (1990), K^+ is improtant in stomatal functioning as a vacuolar osmoticum,

cytosolic-free Ca^{2+} is involved in signal transduction linking the variations in environmental conditions to stomatal movements. It is commonly held that potassium is the main cation involved in stomatal opening, and the balancing ions are chloride organic acid anions, or both (Raschke, 1975). Potassium channels have been identified in intact guard cells (Blatt, 1988) and the application of patch-Clamp technology to guard cell protoplasts confirmed the existence of K^+ channels in the plasma membrane (Hosoi et al., 1988) and were thought to be involved in the stomatal movements. However, Blatt (1987) suggested that such passive mechanisms were unlikely to contribute to K^+ uptake during stomatal opening.

According to Rogers (1979), the stomatal pore remains open even through the potassium content of the guard cell decreases to a constant level at some point between 180 and 360 min. He speculated that greater metabolic energy is required for stomatal opening than for the maintenance of aperture. At longer periods at higher temperatures, solute other than potassium may be involved. Possible alternative solutes used for long term maintenance include sugar, organic acids or proline obtained directly or indirectly from starch. Recent studies on epidermal peels of *Vicia faba* leaves indicated that solute other than potassium ions, such as sucrose and fructose, also contribute to guard cell

osmotic potentials (Poffenroth, et al., 1992; Talbott and Zeiger, 1993).

Stomatal resistance and transpiration are controlled by K. Rogaler (1958) working with sunflower, wheat, barley, corn and clover grown in water culture as well as soilculture found that plants lacking in potassium transpired large amount of water and addition of small quantities of potassium resulted in a sharp decline in transpiration. Achitov (1961) suggested that sufficient potassium supply results in one or more of the following : i) reduced transpiration, ii) increased uptake of water and iii) improved water use efficiency. Brag (1972) reported that increasing K levels in peas lowered the transpiration rate through more complete closure of stomata. Hofner (1971) reported a lower transpiration coefficient in oats when plants were well supplied with K. Further it was found that transpiration rate could be regulated by varied potassium concentrations. This effect was ascribed to changes in stomatal aperture. Skogley (1976) reported that good K nutrition reduced the transpiration rate of barley under stress quickly, while deficiency of K allowed considerable transpirational loss of water before the transpiration rate levelled off. Thus potassium contents in plants might be helpful in controlling transpiration which should be checked in arid environments. Recently positive effects of K on transpiration and stomatal resistance were observed by

Saxena (1985). Umar et al. (1991,1993) observed that in groundnut and sorghum potassium improved the water use efficiency by increasing the stomatal resistance.

In the present study we noticed that due to potassium deficiency transpiration rate increased in the leaves of three *Amaranthus* species. In this respect *A. paniculatus* appears more efficient in controlling water loss as there is only slight increase in transpiration rate of K deficient leaves in this species. Thus it is clear that potassium is highly essential for regulation of transpiration rate and opening and closing mechanism of stomata.

E. MINERAL NUTRITION

1. Potassium

Effect of potassium deficiency on potassium content in different parts of the three *Amaranthus* species is depicted in Fig.4. It is obvious that there is drastic reduction in K content in various plant parts viz. root, stem, old leaves and young leaves under K deficient conditions. This decline is quite significant in the aerial tissue because in this portion of the 'control' plants of all the three species there is massive accumulation of potassium. Since potassium is a dominant cation in *Amaranthus* (Grubben, 1976; Gaikwad, 1995) potassium deficient conditions can cause several alterations in the overall mineral budget of the plants.

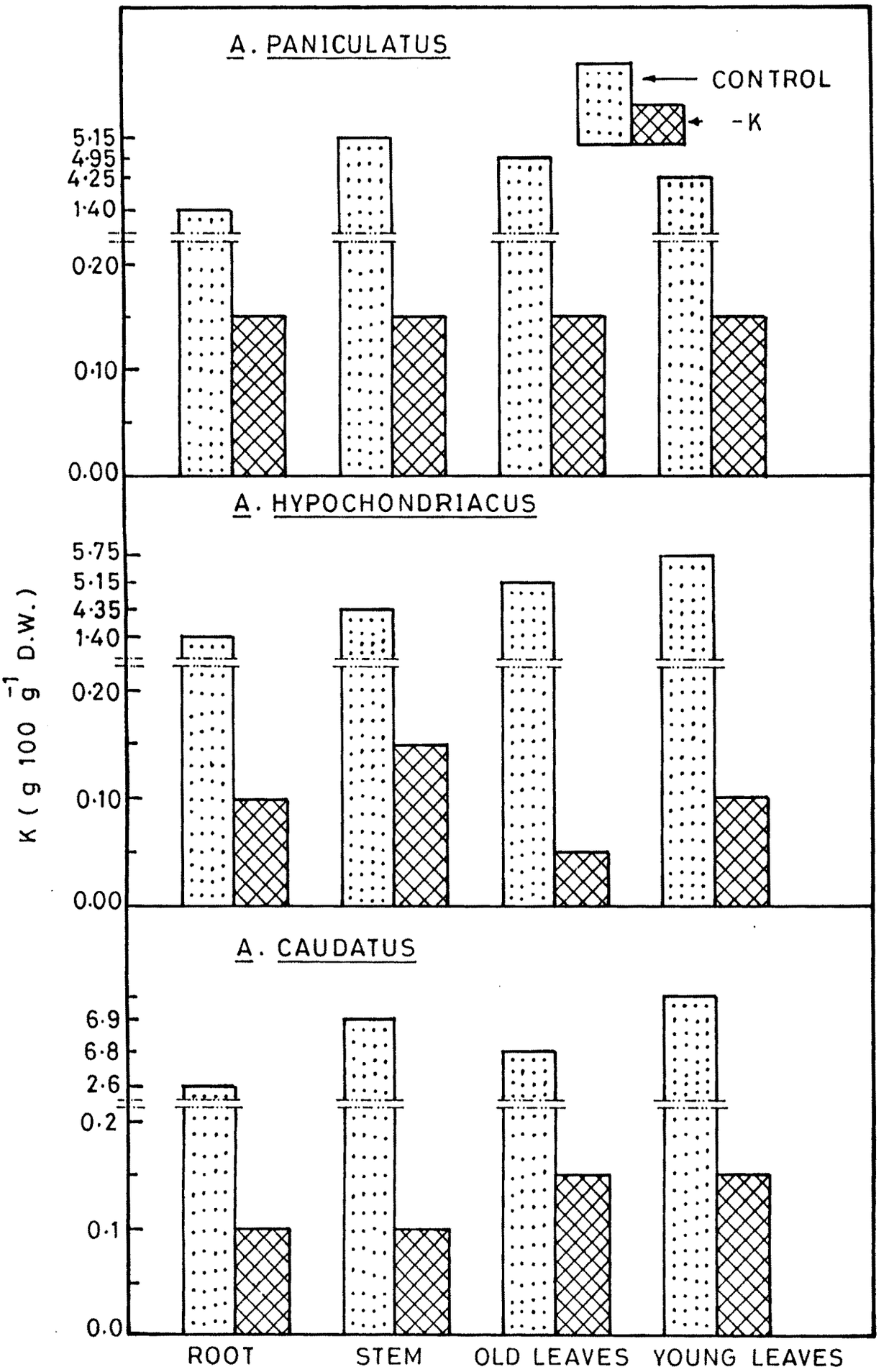


FIG. 4 EFFECT OF POTASSIUM DEFICIENCY ON POTASSIUM CONTENT IN AMARANTHUS SPECIES.

2. Sodium

Effect of K deficiency on sodium levels in different plant parts i.e. root, stem, old leaves and young leaves of three *Amaranthus* species is recorded in Fig.5. It is evident from the figure that sodium level is increased in roots and old leaves but decreased in stem and young leaves of K-deficient *Amaranthus* species.

The essentiality of monovalent cation sodium for plant metabolism and growth was not understood for many years. Halophytic plants were found to have some affinity for this element and even sodium deficiency symptoms were noticed in these plants (Waisel, 1972). Brownell (1979) claimed that Na is a micronutrient in the strict sense for C_4 plants but not for C_3 plants. He assumed that Na is involved in the shuttle of metabolites between the mesophyll and bundle sheath chloroplast. Thus Na is anticipated to be involved in C_4 photosynthetic pathway. According to Rains (1972), Na may have role in maintaining favourable water balance. In the view of Evans and Sorger (1966), Na acts as an activator for some enzyme systems. Low concentrations of Na were found to stimulate growth of *Amaranthus tricolor* (Ohta et al., 1987). However, in glycophytes higher concentrations of Na proves toxic causing specific ion toxicity by interfering in several metabolic pathways like nutritional balance, osmoregulation, stomatal behaviour and assimilation capacity (Greenway and Munns, 1980).

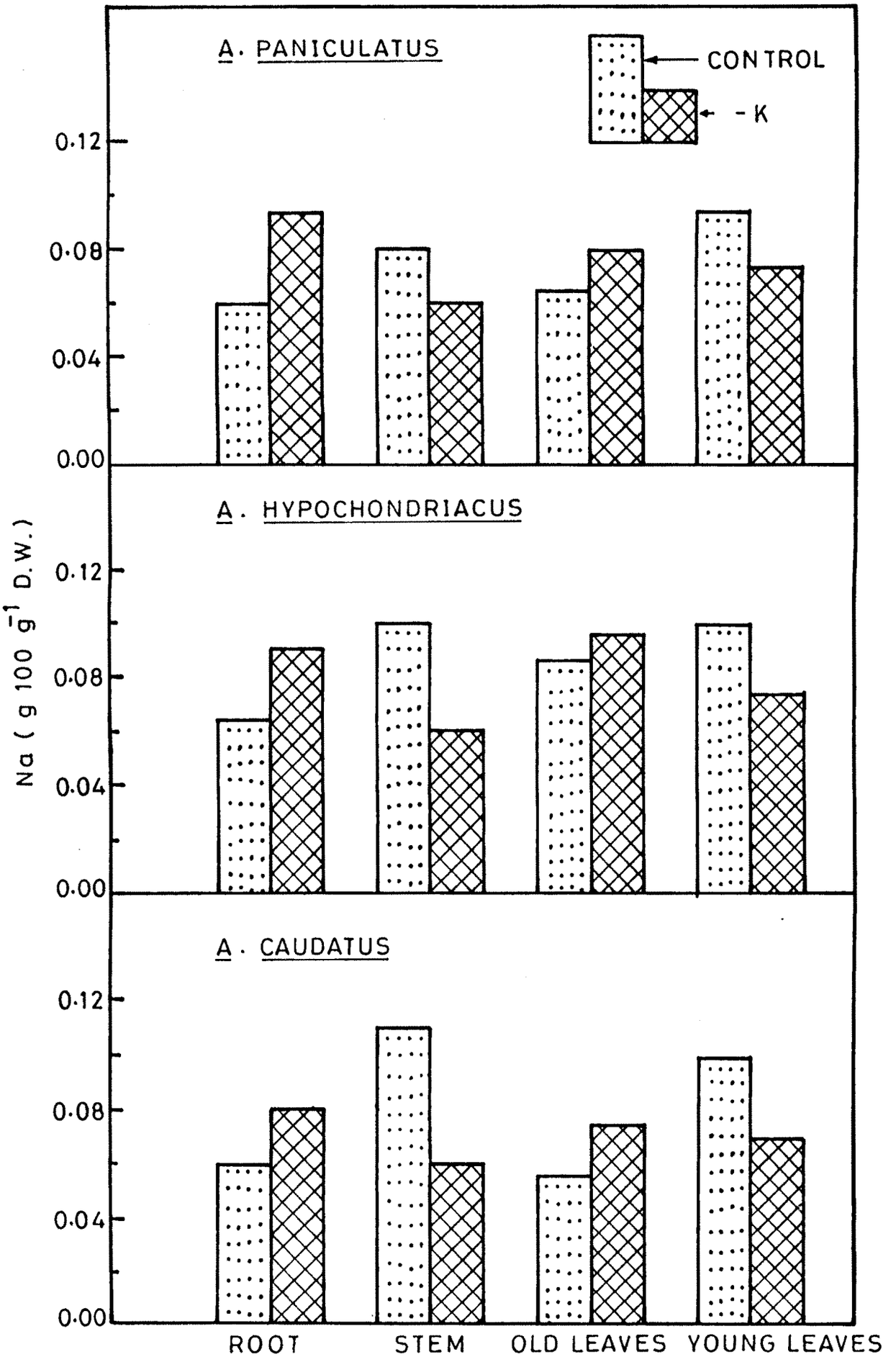


FIG. 5 EFFECT OF POTASSIUM DEFICIENCY ON SODIUM CONTENT IN AMARANTHUS SPECIES.

Forester and Mengel (1969) found that Na^+ levels were raised in leaves of spring barley grown in K deficient medium. Murumkar et al. (1982) observed an increase in Na content of shoot and roots of K deficient *Sorghum* plants. Chavan (1980) noticed that in leaves and stem of ragi the Na content increased under nitrogen and potassium deficiency and this increase is particularly more significant in K-deficient plants. He reported replacement of K by sodium in ragi under K-deficiency. Ernst et al. (1983) observed the replacement of potassium with sodium in natrophobe and natrophile *Senecio* species. These workers noticed that the diminished growth was due to increase in Na^+ in all plant organs. Krishnakumari and Singh (1991) also noticed increase in Na uptake in absence of potassium in barley. Ulrich and Kwok (1969) noticed that due to K deficiency potato leaf tissue largely excluded Na^+.

In the present investigation although an increase in Na in roots and old leaf tissues of K deficient *Amaranthus* species is noticed, the increase is very significant so as to account for replacement of K by sodium. These findings support the sodium excluding nature of *Amaranthus* noticed by Gaikwad (1995) in his salt tolerance studies. Thus sodium level remains at a micronutrient level in C_4 species *Amaranthus* even under conditions of K deficiency.

3. Calcium

Effect of potassium deficiency on calcium level in different plant parts i.e. roots, stem, old leaves and young leaves of three *Amaranthus* species is depicted in Fig.6. It is well evident from the figure that calcium content is increased in roots and old leaves whereas decreased in stem and young leaves in potassium deficient *Amaranthus* plants.

Calcium is one of the pre-dominant cations in higher plants. It plays important role in membrane functioning and in maintainance of cell integrity. It is also required in the synthesis of pectin in the middle lamella of the cell wall. In view of Van Steveninck (1965) Ca plays an important role in the regulation of membrane permeability to various ions. Hanson (1982) claimed that function of Ca is to minimize ion diffusion, maintain selective ion transport mechanisms and decrease membrane permeability. The role of Ca in membrane stability is not only of importance in ion uptake but also in other metabolic processes (Mengel and Kirkby, 1982). Cramer et al. (1985) emphasized that Ca protects membrane integrity and minimize leakage of cytosolic potassium. Ortiz et al. (1994) reported that Ca enhances, the net absorption of K. The role of calcium as transducer of hormonal and environmental signals to the responsive elements of cell metabolism has attracted great attention in recent years. According to Clark (1984),

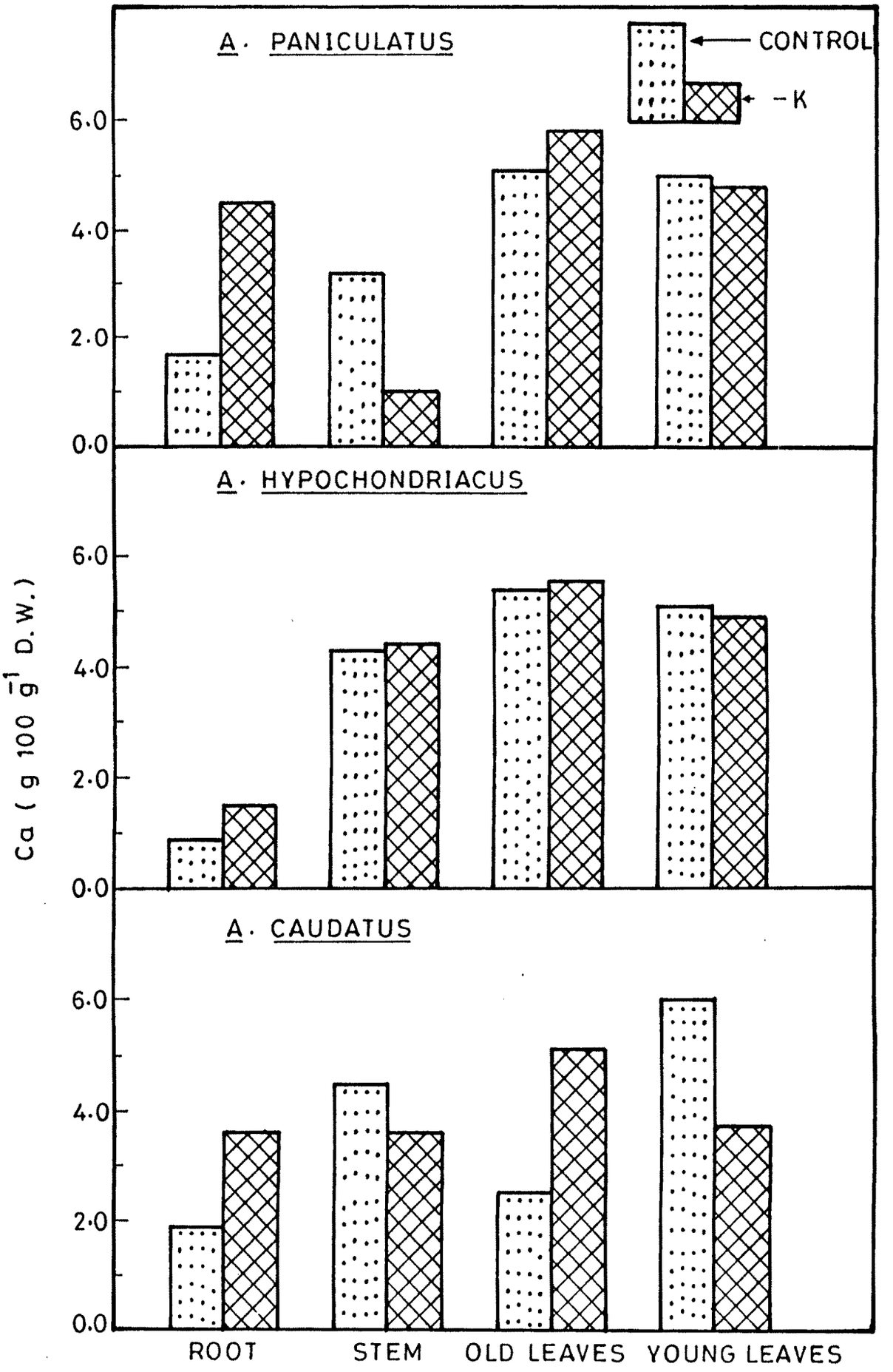


FIG. 6 EFFECT OF POTASSIUM DEFFICIENCY ON CALCIUM CONTENT IN AMARANTHUS SPECIES.

calcium either stimulate or inhibit many enzymes. These includes ATPase, protein kinase, pyruvate kinase, nucleases, α-amylase, estarase, pectin estarase, lipoxygenase, polygalactyronic transeleminase and glucose 6 phosphate dehydrogenase. According to Clarkson and Hanson (1980), a major role of calcium appears to be its binding with proteins, nucleic acids and lipids to affects cell adhesion, membrane chromatin organization and enzyme conformation. Jones et al. (1993) noticed that one of the roles of Ca is to activate and stabilize the α-amylase molecule, which is Ca containing metallo-enzyme that binds at least one atom of Ca per mole. The involvement of calcium in plant growth and developmental processes is attributed to the calmodulin. Swamy (1991) reported that besides calmodulin there are other Ca binding proteins in plants. Eventhough this element plays such vital role in plants. Eventhough this element plays such vital role in plants, it is relatively immobile and accomulates to high degree in senescent tissues.

There are few reports regarding the K-Ca interactions in the plants. Negative correlation between Ca, Mg and K was reported by Loue (1965). A decrease in Ca^{2+} content due to K deficient condition was reported in rice seedling by Tanaka and Yoshida (1970). Das and Sen (1974) studied mineral uptake in chickpea var. B-75 under nitrogen, phosphorus and potassium deficiencies. In these experiments

decline in uptake of ^{45}Ca under K-deficient conditions was observed. On other hand, Forster and Mengel (1969) observed raised Ca^{2+} level in leaves of spring barley grown in K deficient medium. Ulrich and Kwok (1969) also noticed that due to K-deficiency potato leaf tissue largely accumulate Ca^{2+} along with Mg^{2+}. Murumkar et al. (1982) observed slightly increased Ca content in the shoot of K-deficient *Sorghum*. The work of Karadge (1986) on peanut under various levels of potassium revealed that at very low K supply this divalent cation was accumulated only in leaves while in stem and root Ca^{2+} level decreased. Repka (1983) noticed increased levels of Ca^{2+} in both leaves and chloroplasts of maize plants grown in K-deficient medium. Murumkar and Chavan (1992) also reported that Ca^{2+} levels increased in all parts of chickpea grown under K-deficient conditions. Berthouly and Gurrier (1979) recorded no change in Ca^{2+} levels in K deficient *Sorghum dochna*. Recently Bhat et al. (1996) noticed that calcium and potassium shows negative correlation. They observed increased Ca level in patharnakh pear, leaves which grown under low supply of K where as Ca level decrease as K level increases.

In the present investigation three species of *Amaranthus* have show tendency to accumulate Ca^{2+} mainly in the root tissue and to some extent exclude Ca^{2+} in stem and young leaves due to omission of K in the nutrient medium.

Thus in three species of *Amaranthus* same tendency of Ca^{2+} accumulation as in potato grown under K-deficiency observed by Ulrich and Kwok (1969). Content in roots and leaves under K-deficiency may possibly contribute for maintaining the ionic balance of the cell. Calcium plays important role in maintaining membrane integrity it is also likely that increase in Ca^{2+} content can minimize the membrane damage in K deficient plants.

4. **Magnesium**

The effect of K deficiency on Mg content in different plant parts i.e. root, stem, old leaves and young leaves of three *Amaranthus* species is depicted in Fig.7. The Mg content is found to be increased in roots, old leaves and young leaves of *A. paniculatus* and *A. hypochondriacus* whereas it is decreased in stem and young leaves of *A. caudatus* and *A. hypochondriacus* under K-deficient condition.

Magnesium is a highly essential divalent cations in the plants. The most well known role of Mg is its contribution to the centre of the chlorophyll molecule, although 'Chlorophyll-Mg" is relatively a small fraction of the total Mg status of plant. According to Mengel and Kirkby (1982), Mg stabilizes the ribosomal particles in the configuration necessary for protein synthesis and is believed to have a similar stabilizing effect in the matrix of the nucleus. Mg is highly essential in many enzyme

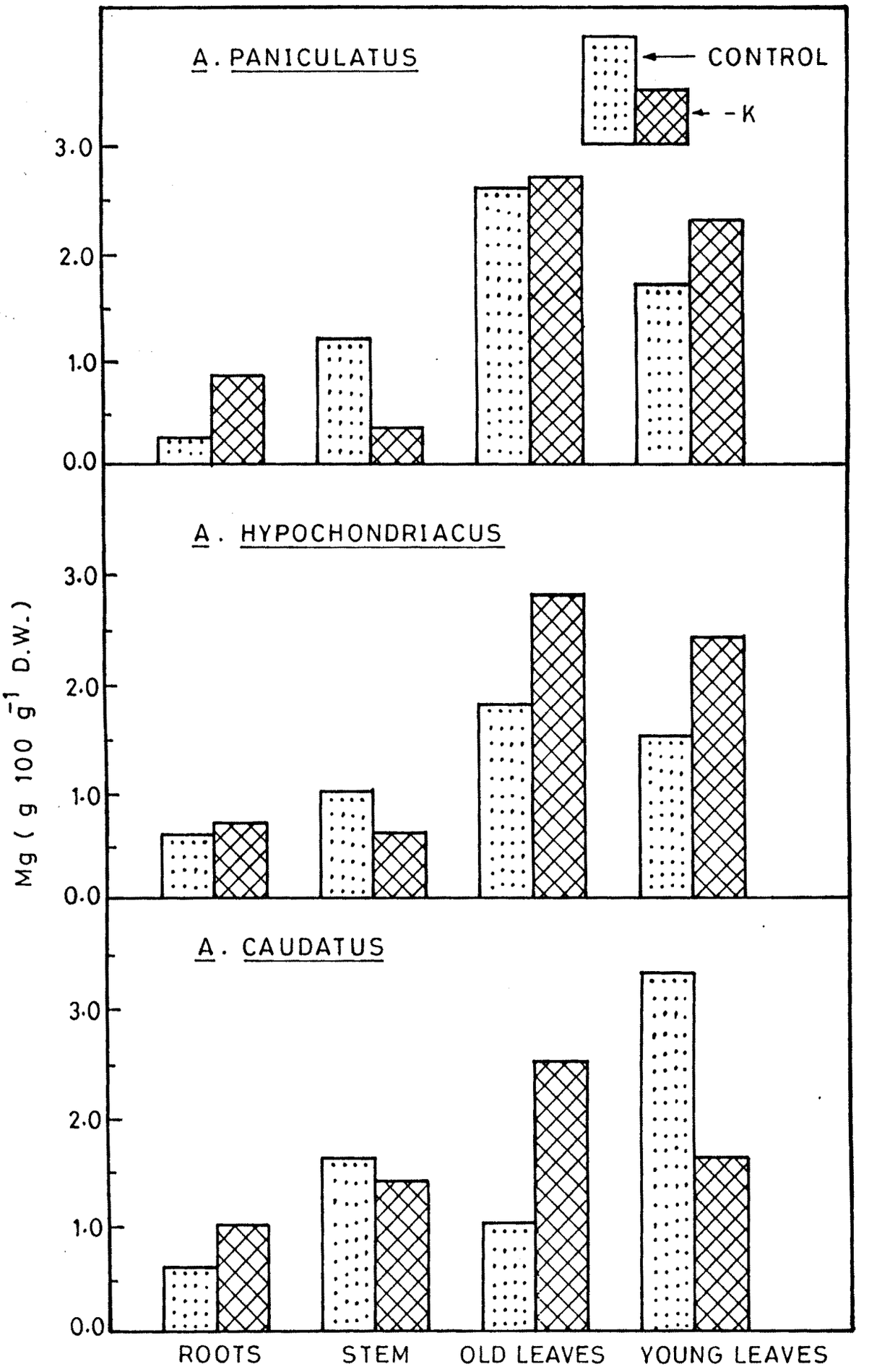


FIG. 7 EFFECT OF POTASSIUM DEFICIENCY ON MAGNESIUM CONTENT IN AMARANTHUS SPECIES.

reactions (Clark, 1984). According to Clarkson and Hanson (1980), the enzyme reactions that require Mg include PO_4^{3-} or nucleotide transfer (i.e. phosphatase, kinase, ATPases, synthatase, nucleotide transferases) carboxyl transfer (carboxylases, decarboxylases) and enzymes such as dehydrogenases, mutases and layses. Mg-ATP is the substrate for most ATPases. Mg works as a cofactor in almost all enzymes activating phosphorylation processes and it forms a bridge between the phosphate structure of ATP, ADP and the enzyme molecule and a key reaction of Mg is the action of RUBP-case (Mengel and Kirkby, 1982). Jacob (1958) noticed that Mg also promotes the formation of vitamin especially carotene. Enhanced starch accumulation in source leaves and lower starch concentrations in the sink organs (Fink, 1991; Cakmak, et al., 1994) in Mg deficient plants suggest that Mg plays a particular role in the transport of carbohydrates from source leaf to sink organs. The role of Mg in cation anion balance is also well documented.

There are several reports regarding K and Mg interaction. In 1969, Ulrich and Kwok reported that Mg^{2+} was heavily taken up along with Ca in K deficient potato plants. Berthouly and Gurrier (1979) noticed that K deficiency resulted in significant increase in Mg^{2+} of all organs of *Sorghum dochna*. Thus according to these workers Mg^{2+} replaces K^{+} under the conditions of K-deficiency, without

however fulfilling its physiological role. Repka (1983) observed accumulation of Mg^{2+} in chloroplasts and leaf of Maize plants under K-deficiency condition. A good correlation of K^+ and Mg^{2+} is exhibited in leaf and chloroplasts (Hind et al., 1974; Lauchli and Pfluger, 1980) to maintain integrity and function of photosynthesis. Bulychev and Vredenberg (1976) reported that K^+:Mg^{2+} ratio in intact chloroplasts can reach the value of 5 and even more from which it is supposed that the light induced efflux of Mg^{2+} is small in comparison with K^+. This observation indicates that the effect of light and the ratio of ions in the medium.

In the present investigation it is noticed that there is increase in Mg^{2+} content in young leaves of *A. hypochondriacus* and *A. paniculatus* due to K deficiency. The Mg accumulation is mainly in roots and old leaves of all the three *Amaranthus* species grown under K deficiency. In the stem tissue of K deficient *Amaranthus* plants the mg content is considerably lowered especially in *A. hypochondriacus* and *A. paniculatus*. Thus Mg can atleast partially replace K in cation balance in some parts of the three species. But functional replacement with respect to other roles of K^+ appear quite impossible in view of involvement of these two ions in different processes.

5. Phosphorus

Effect of K deficiency on phosphorus level in different plant parts i.e. root, stem, old leaves and young leaves of three *Amaranthus* species is depicted in Fig.8. It is evident from the figure that phosphorus level is increase in roots and young leaves whereas it is decreased in stem and old leaves of *Amaranthus hypochondriacus* and *A. paniculatus*.

The fact that phosphorusis an integral part of important macromolecules such as DNA, RNA, phospholipids and ATP. It speaks very high about the essentiality of phosphorus for various life processes in plants. It is either a substrate or an end product in number of enzyme reactions (e.g. ATP --> ADP + Pi) and it also controls some key enzyme reactions. Therefore the compartmentation of Pi is important for the regulation of metabolic pathways in the cytoplasm and chloroplasts. The phosphorus may function in energy storage compounds and as a compounds controlling the Pi level in the metabolic pool of the cells. The requirement of phosphorus during regetative stage of growth is range between 0.3 to 0.5% of the plant, dry weight (Marschner, 1986). Marschner (loc.cit.) emphasized that the regulatory function of Pi in photosynthesis and carbohydrate metabolism of leaves may be considered one of the major factors limiting growth particularly during the reproductive stage. The level of phosphorus supply during this period regulates

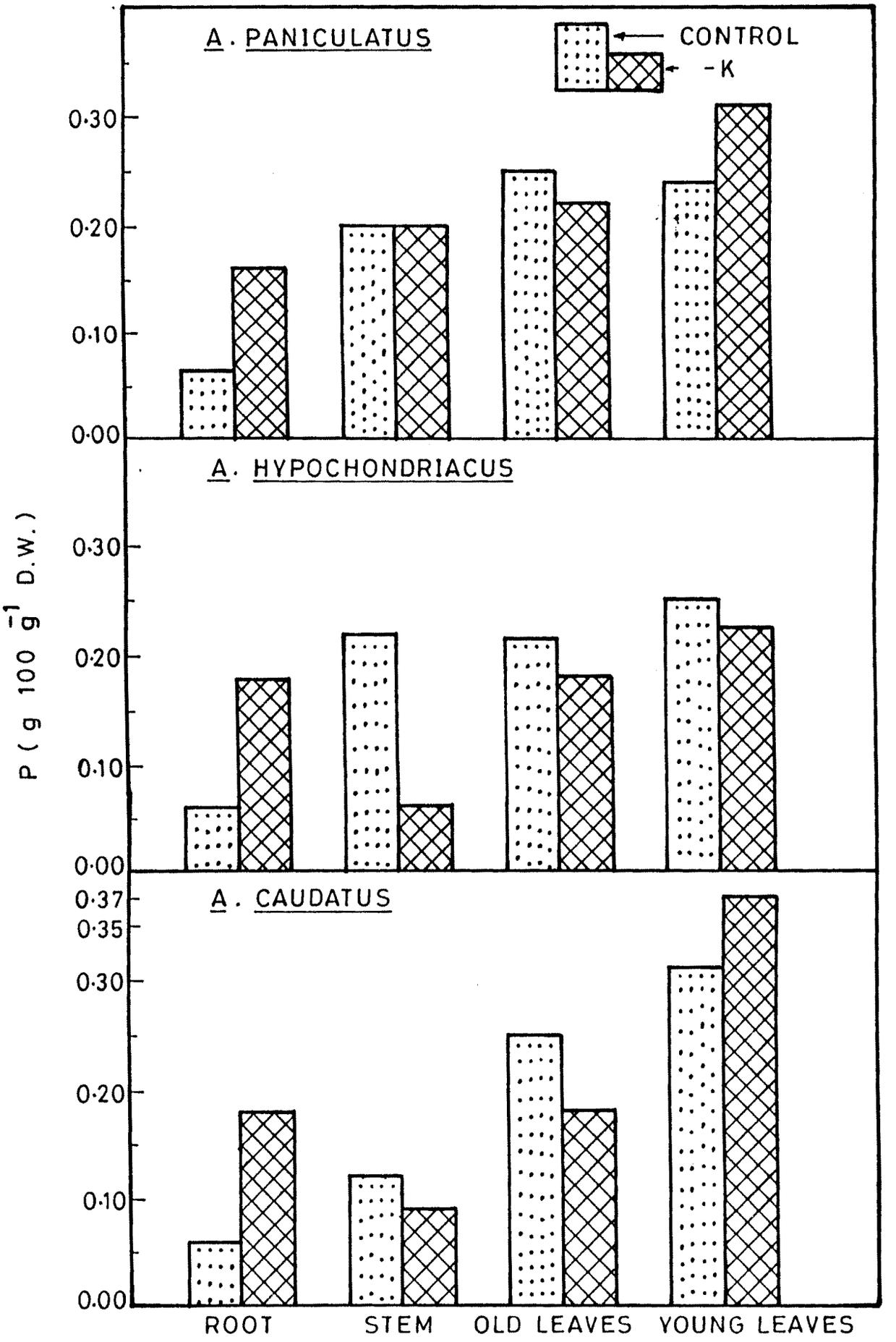


FIG. 8 EFFECT OF POTASSIUM DEFICIENCY ON PHOSPHORUS CONTENT IN AMARANTHUS SPECIES.

the starch/sucrose ratio in the source leaves and the reproductive organs. According to Martinez and Lauchli, (1991), total phosphorus in cotton plants was diluted over time by growth. A retranslocation of phosphorus from senescing leaves to young leaves and developing parts is very well documented in several plant species.

There are many reports regarding K and P interactions in the plants. Positive correlation between P and K was reported by Saric et al. (1965). They studied phosphorus metabolism under various deficiency conditions such as N,P,K, Na,Ca and S. They observed raised level of P^{5+} in shoot part of maize under K-deficiency. Tanaka and Yoshida (1970) also noticed slightly raised P^{5+} level in k-deprived rice seedlings. Coronell and Wallihan (1973) also observed increased P^{5+} content in stem and grain of K-deficient rice plants. Murumkar et al. (1982) observed that P content increases considerably in shoots of K deficient *Sorghum* plants. Similarly Repka (1983) also reported similar trend of P^{5+} accumulation in leaves and chloroplasts of Maize plants grown under K-deficient conditions. According to Sinha and Singh (1984), K-deficient Japanese mint plants showed high respiration rate and this can be correlated with accumulation of soluble nitrogen suggesting rapid turnover of P metabolism. Das and Sen (1981) studied the altered metabolism of chickpea var. B-75 under K-deficiency. These

workers noticed that K deficiency reduced the uptake of 32 phosphate. Moreover, mobilisation of ^{32}P in the reproductive parts was affected by K-deficiency. Recently Bhat et al. (1996) reported positive correlation between P and K. They observed that as K level increased, P level also increases in Patharnakh pear leaves.

In the present study we observed an increase in P content in young leaves and root tissues and decrease in stem and old leaves of K-deficient *Amaranthus* plants. Thus it is clear that P is accumulated in the main metabolic organ i.e. young leaves which may overcome the situation of K-deficiency at the metabolic level. It is also clear that translocation of P from stem to leaves is not affected by K-deficiency. At the same time plants of all the three *Amaranthus* species exhibit a capacity of retranslocation of P from old leaves to the young leaves under potassium deficiency.

6. Iron

Effect of K-deficiency on levels of iron in different plant parts i.e. root, stem, old leaves and young leaves tissues of three *Amaranthus* species is depicted in Fig.9. It is evident from the figure that Fe level is elevated in root, stem and young leaf tissue but it is decreased in mature leaf tissue of three *Amaranthus* species due to K deficiency.

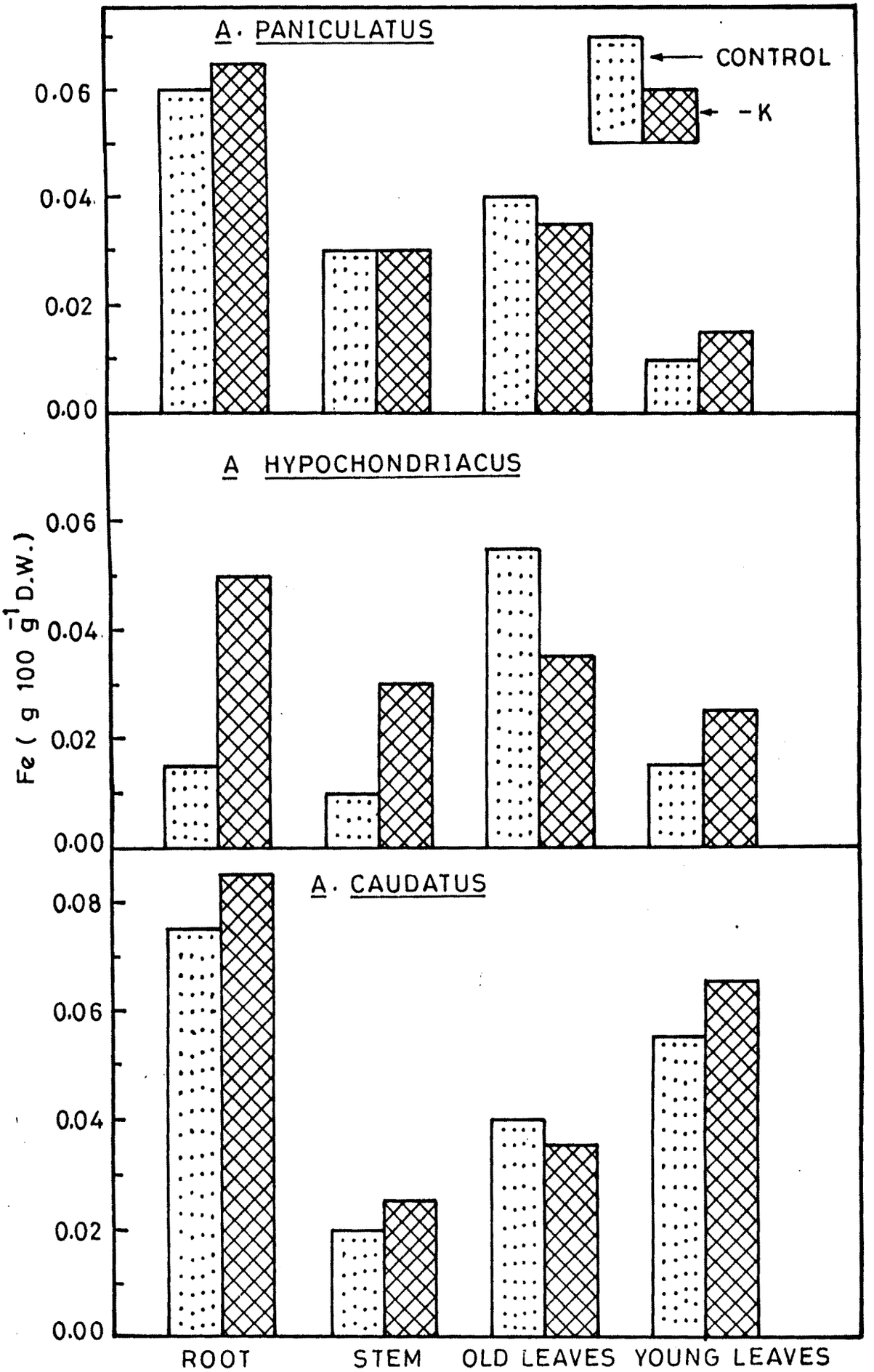


FIG. 9 EFFECT OF POTASSIUM DEFICIENCY ON IRON CONTENT IN AMARANTHUS SPECIES.

Iron has the greatest biological significance among the various micro elements. This is due to its association with proteins. It is well established that Fe(II) is a component of the enzyme aconitase, where it is required for both stability and activity of the enzyme (Hsu and Miller, 1968). The role of iron in the biosynthesis of chlorophyll is well established. Fe is required for the formation of proto-chlorophyllide from Mg-protoporphyrin (Machold and Stephan, 1969). According to Vlcek and Gassman (1979), the enzyme corproporphyrinogen oxidase is an iron protein that catalyzes the oxidative decarboxylation of Mg-protoporphyrin. Marschner (1986) state that iron is stored in plant cells in the stroma of plastids as phytoferritin. Smith et al. (1984) studied Fe nutrition in some C_3 and C_4 species. They observed that plants having the C_4 photosynthetic pathway required higher concentrations of iron in the nutrient solution for maximum growth (when grown in sand culture) than those with the C_3 pathway. According to Stout (1961), the adequate value of iron for optimal growth of plants is 0.01%. Our observations indicate that in plant parts of *Amaranthus* quite higher iron contents are seen and this possibly indicates 'luxury consumption' of iron.

Few attempts have been made to study influence of K-deficiency on iron nutrition. Wallace and Hewitt (1946) reported that deficiencies of N, P and Ca possibly cause

apparent iron deficiency in plants. According to Tanaka and Yoshida (1970), the toxicity of iron accompanies the plants suffering from deficiencies of mineral elements. They observed that iron content was decreased in roots of K-deficient rice plants and increased in the leaves. Chavan (1980) reported reduction in iron content in ragi plants due to K-deficiency. Whereas Murumkar (1986) found increased iron level in roots and decreased in stem and leaves of K-deficient chickpea plants. Das and Sen (1981) have reported that due to K-deficiency iron uptake was hampered severely. Krishnakumari and Singh (1991) noticed that the different levels of K application did not significantly affect uptake of Fe in barley.

In the present investigation we also noticed that the iron content is increased in root, stem and young leaves of three *Amaranthus* species where as it is decreased in old leaves of all *Amaranthus* species. However, the increase is not so significant so as to account for any iron toxicity as indicated by Tanaka and Yoshida (1970).

7. **Manganese**

Effect of potassium deficiency on Mn level in different plant parts i.e. root, stem, old leaves and young leaves of three *Amaranthus* species is depicted in Fig.10. It is evident from the figure that under the conditions of potassium deficiency Mn level is increased in all plant

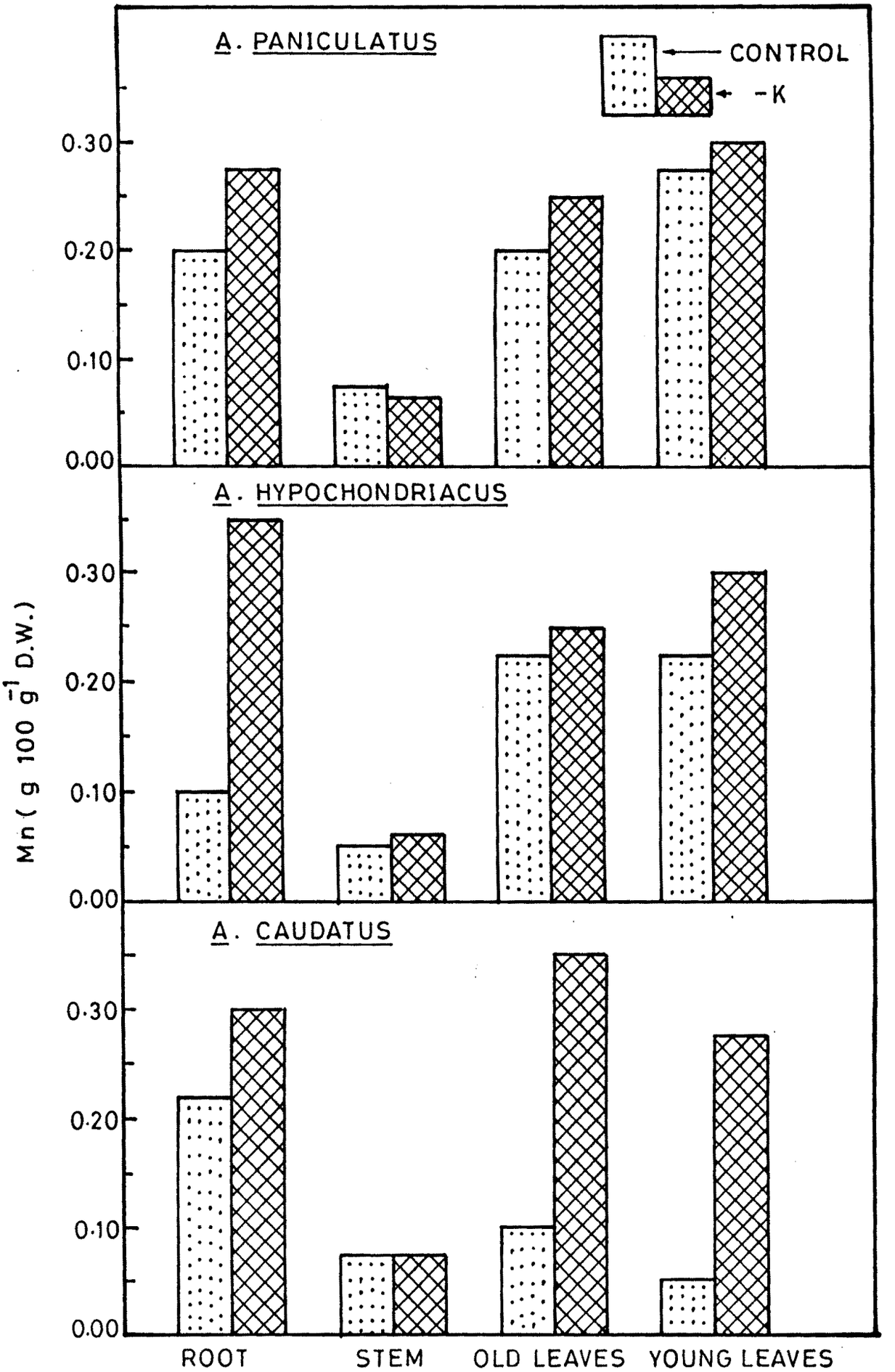


FIG.10 EFFECT OF POTASSIUM DEFICIENCY ON MANGANESE CONTENT IN AMARANTHUS SPECIES.

parts, the alteration being quite insignificant in the stem tissue.

Manganese is essential in both lower and higher plants for the Hill reaction. The water spliting and O_2 evolving system in photosynthesis and PS-II contain a mangano-protein which catalyzes early stages of O_2 evolution. According to Takahashi and Asada (1977), in chloroplasts larger fraction of Mn is held in a less tightly combined state and seems to be most closely involved in O_2 evolution, whereas the smaller fraction may be more directly involved in stability of thylakoid structure. Mumford et al. (1962) noticed that Mn brings about the oxidation of IAA by activating IAA oxidase. Mn is directly involved as a component of the biotin enzyme in the biosynthesis of fatty acids (Marschner, 1986). He also stated that Mn not only competes much more effectively but also in some way blocks the binding sites for Mg. Mengel and Kirkby (1982) noticed that in some cases Mn activates decarboxylases and dehydrogenases of TCA cycle. Thus this microelement plays various kinds of roles in plant metabolism.

There have been very few attempts to study the effect of mineral deficiencies on Mn uptake. Tanaka and Yoshida (1970) observed that deficiencies of phosphorus, potassium, calcium and magnesium caused decrease in Mn content of the rice plant. Whereas in another experiments in

libon soil, these workers found that Mn content in the straw was unaffected by phosphorus deficiency and slightly increased by K deficiency. Das and Sen (1974) also reported increased level of Mn in flag leaf and second leaf of K-deficient rice plants. Chavan (1980) noticed that due to K-deficiency Mn content was reduced in roots and stem of ragi and increased in leaves. Das and Sen (1981) have reported that in K deprived chickpea plants the uptake of ^{54}Mn was severely hampered. Krishnakumari and Singh (1991) noticed that the different levels of K application did not significantly affect the uptake of Mn in barley.

In the present investigation we noticed that there is slight increase in Mn content in roots, old leaves and young leaves but there is no increase in stem tissue of K-deficient three *Amaranthus* species. Thus the overall Mn uptake and distribution is not altered by potassium deficiency in *Amaranthus*.

8. Zinc

Effect of K deficiency on zinc content in different plant parts i.e. root, stem, old and young leaves of three *Amaranthus* speciesis recorded in Fig.11. It is evident from the figure that Zn level is increased in root and stem tissues of *A. caudatus* and *A. hypochondriacus* where as it is decreased in leaf tissue. In *A. paniculatus* Zn level is increased in all plant parts due to K deficiency.

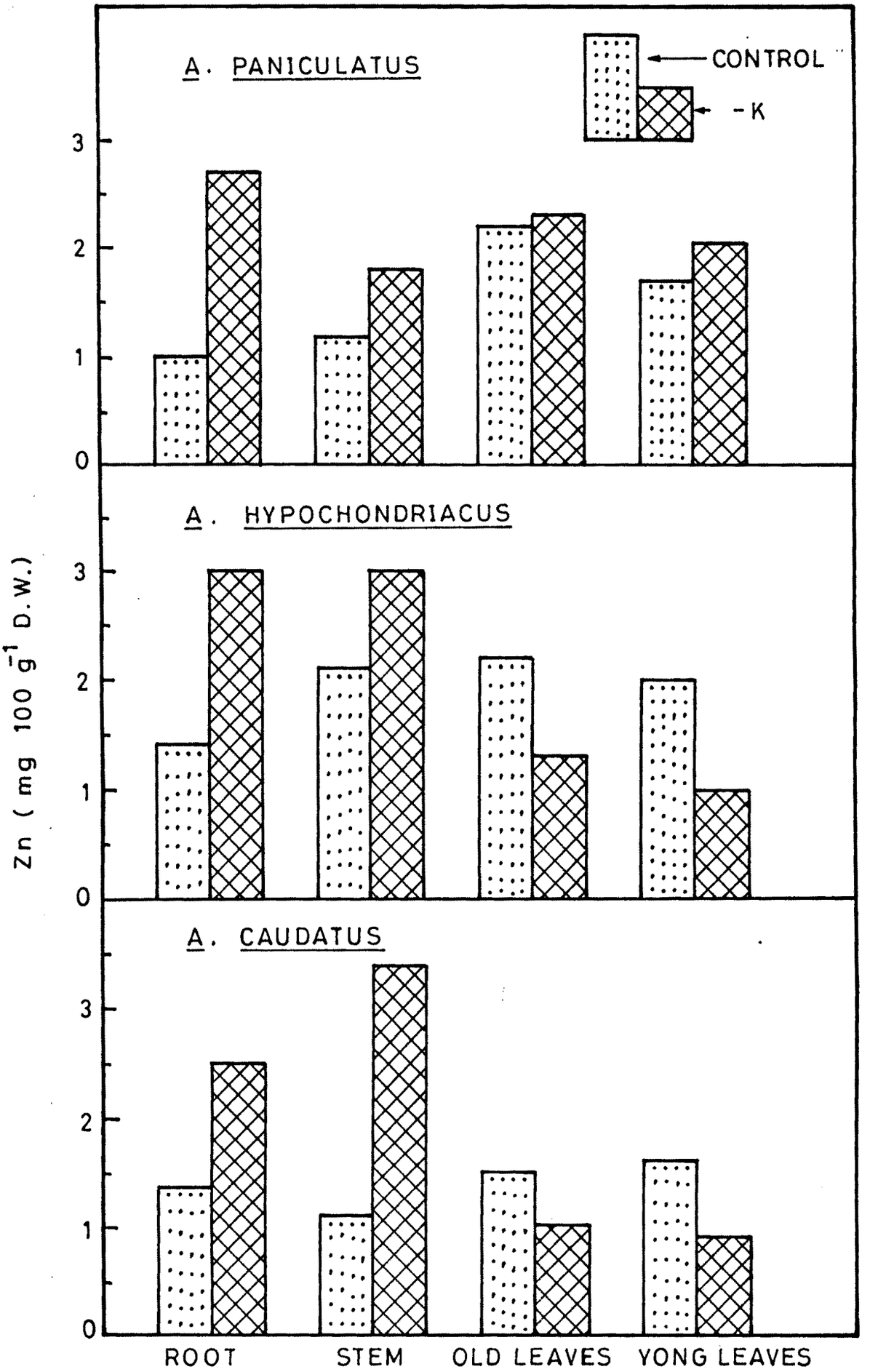


FIG.11 EFFECT OF POTASSIUM DEFICIENCY ON ZINC CONTENT IN AMARANTHUS SPECIES.

Zinc is one of the key microelements in the plants. It acts either as a metal component of enzymes or as a functional, structural or regulatory cofactor of large number of enzymes. Ghildiyal et al. (1986) observed a decrease in protein-nitrogen content and increase in free amino acid content of linseed varieties under Zn deficiency which indicates that Zn is playing a prominent role in nitrogen metabolism. Zinc is known to have a role in protein synthesis (Rhodes and Klug, 1993). Low levels of Zn decreases protein synthesis in general rather than affecting particular proteins (Zhang and Wu, 1989). Cakmak and Marschner (1990) noticed that Zn deficiency alters uptake of other nutrients. Zinc deficiency affects the integrity of plasma membrane, which becomes low in phospho-lipids and sulfhydryl groups and show enhanced production of super oxide radicals. Zinc may play a role in the regulation of transmembrane ion fluxes by preventing oxidation of sulfhydryl groups disulfides in proteins involved in ion-channel gating in the plasmamembrane of root cells (Welch, 1995). Recent observations of Sharma et al. (1995) indicates involvement of Zn in stomatal opening, possibly as a constituent of carbonic anhydrase needed for maintaining adequate [HCO_3^-] in the guard cells, and also as a factor affecting K^+ uptake by the guard cells.

Das and Sen (1981) studied the effect of nitrogen,

phosphorus and potassium deficiencies on the uptake and mobilization of various ions in Bengalgram (*Cicer arietinum*). These workers found that the uptake of ^{65}Zn along with other cations was severely affected by these imposed deficiencies and this negative effect was more pronounced under the conditions of nitrogen deficiency. Tiwari et al. (1982) reported a beneficial effect of K treatment on Zn uptake by potato. They observed that at low levels of K, zinc uptake is reduced but as K in the medium increases zinc uptake also increased. Murumkar (1986) reported decreased level of Zn in leaf tissues of potassium deficient chickpea. Krishnakumari and Singh (1991) also noticed positive correlation between K and Zn in barley grown under different levels of K. Wallace (1971) showed that due to potassium deficiency tobacco plant accumulate more Zn in all parts. Ernst et al. (1983) also reported similar observations in both *Senecio sylviaticus* and *S. viscosus*.

In the present investigation, we can notice that due to K deficiency plants of *Amaranthus caudatus* and *A. hypochondriacus* show accumulation of Zn in root and stem tissues where as reduced level of Zn in leaf tissues. Thus the distribution of zinc within the plants rather than the overall zinc uptake is disturbed due to K deficiency in these two species. On the otherhand the overall zinc uptake

appears to be promoted in *A. paniculatus* due to K decificiency as Zn level in every plant part is increased. Thus interspecific differences are clearly evident with respect to this aspect.

F. PHOTOSYNTHETIC PIGMENTS

a. Chlorophylls and Carotenoides

The effect of potassium deficiency on the chlorophyll and carotenoid contents of the leaves of three *Amaranthus* species is depicted in Fig.12. It is evident that potassium deficiency has influenced the level of chlorophyll and carotenoid in different manner at different growth stages. Due to potassium deficiency there is an increase in the chlorophyll and carotenoid content at vegetative phase but at flowering stage the pigment content is reduced in all the three *Amaranthus* species.

Higher plants are characterised by the presence of chlorophyll-a and chlorophyll-b which are constituents of photosynthetic apparatus chloroplast. Chlorophyll-a being an antenna pigment plays a key role in bioconversion of solar energy while chlorophyll-b plays a secondary role in this process. It is because of these reasons, attempts are continuously made to correlate the state and amount of these pigments with photosynthetic efficiency of the plants. But such attempts do not yield meaningful information every times thus in case of shade leaves which are rich in

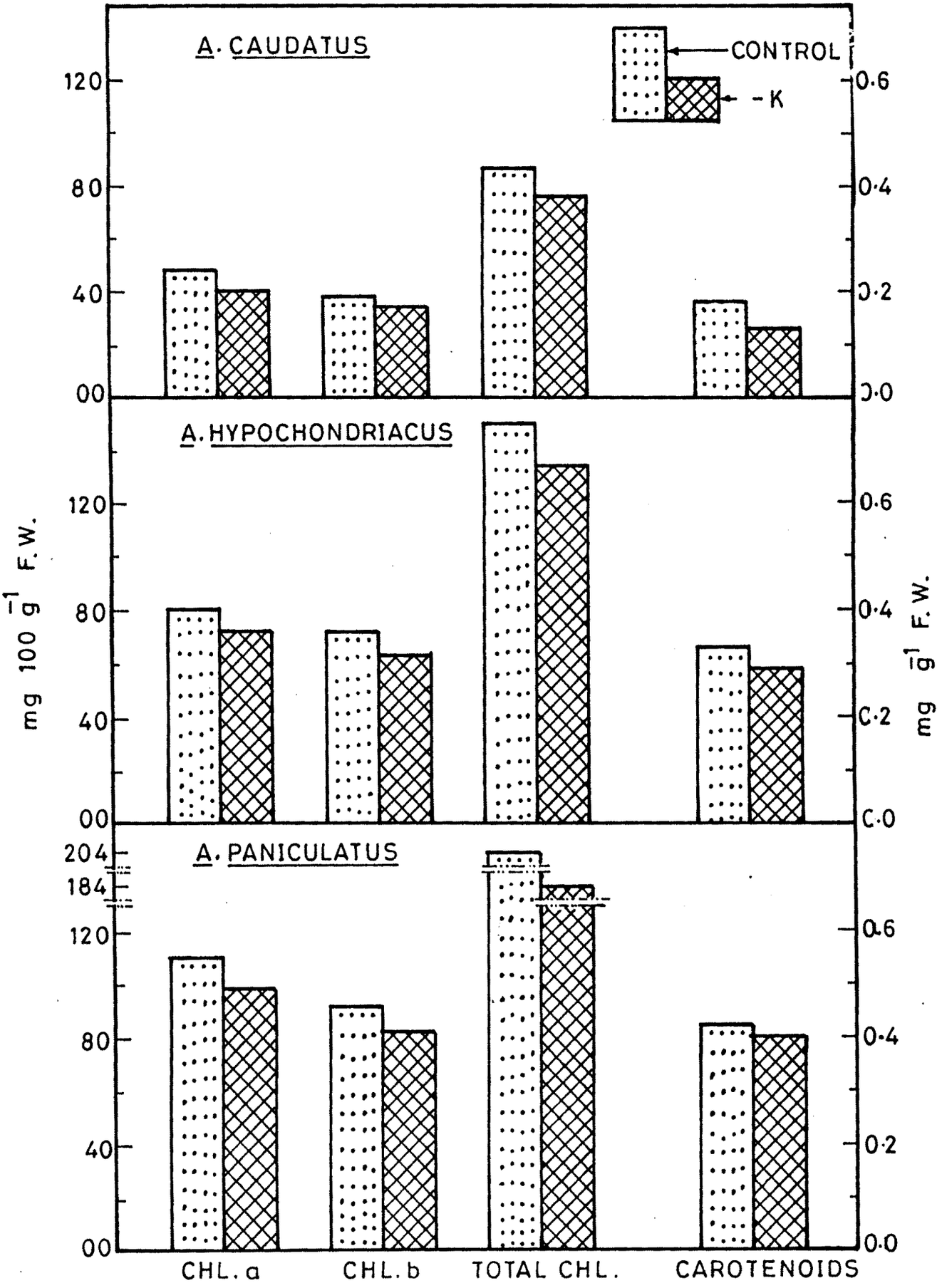


FIG. 12 EFFECT OF POTASSIUM DEFICIENCY ON PHOTOSYNTHETIC PIGMENTS IN LEAVES OF AMARANTHUS SPECIES.

chlorophylls but low in photosynthetic efficiency as compaired to sun leaves. Carotenoids are lipid pigments which are universally present in nearly all higher plants. They are associated with chlorophyll and located in the two photosystems in the thylakoid membrane where they are non-covalently linked to membrane associated proteins. In the view of Demming Adams (1990) the carotenoids firstly act as accessory light harvesting pigments, trapping light energy and passing this on to chlorophyll molecule. Secondly carotenoids protect the photosynthetic apparatus from light mediated stress. According to them carotenoids are also involved in the interconversion of three xanthophylls (violoxanthin, antheraxanthin and zeaxanthin) and this is related to the dissipation of excess excitation energy under the adverse conditions.

Decrease in the pigment content is a common phenomenon observed in plants under deficient conditions of major elements. There are several reports regarding the adverse effect of deficient condition on quantitative status of the pigment composition. Lal and Subba Rao (1960) observed lowered chlorophyll content in barley, paddy and maize due to K deficiency. Ozbun et al. (1965) showed that in beans chlorophyll degradation and retardation of photosynthesis took place only under severe K deficiency. Botrill and Possingham (1969) found that chlorophyll

contents were lowered in spinach leaves under K deprived conditions. Radi et al. (1973) noticed differences in responses of tomato and maize to potassium deficiency regarding the chlorophyll contents. They found that potassium deficiency increased chlorophyll content in tomato while decreased the same in maize. Work of Geister and Stamp (1978) revealed that in K deficient condition chlorophyll content was decreased. Similar effects of K deficiency on chlorophyll content was reported by Rao and Rao (1984) in pigeonpea leaves. Tsitsilashvili (1985) found that due to K deficiency content of chlorophylls was reduced in grape plants. Murumkar (1986) also observed reduced chlorophyll and carotenoids contents in chickpea leaves due to K deficiency. Subrahmanyam and Pandey (1987) reported decrease in chlorophyll content in potassium deficient black gram (*Vigna mungo* L. Hepper). Chatterjee et al. (1986) also observed reduced chlorophyll content in wheat due to K deficiency. Cakmak (1994) also noticed decrease in chlorophyll content in K deficient leaves of potato plants. Fabin-Galan (1970) observed that in sunflower K deficient condition caused as initial increase in chlorophylls however latter on a severe decrease was noticed. In case of *Amaranthus* also we noticed an initial increase in chlorophyll while there is decrease in pigments in later growth stages.

Some workers reported malformations of the chloroplasts potassium-deficient plants Hall, et al. (1972). According to Lawanson et al. (1977), K deficiency decreased the formation of protochlorophyll and retarded the rate of transformation of protochlorophyll to chlorophyll in maize seedlings. Penny et al., (1976) investigated effect of K deficiency on cotyledon photosynthesis and seedling development in *Cucumis sativus* L. They further noticed that electron microscopic examination of the cotyledons revealed that potassium starved chloroplasts were associated with poorly defined granal stacks and a proliferation of integranal thylakoids. Thus a damage to photosynthetic apparatus can also cause lowering of pigment content in K deficient leaves. Cakmak (1994) suggested that in K deficient leaves, utilization of photoreductants in CO_2 fixation is restricted because of impaired export and thus accumulation of photosynthates. This disturbance might lead to enhanced photoreduction of molecular O_2 to toxic O_2 species causing chlorophyll destruction. In case of *Amaranthus* species such situation might arise at latter growth stages since in old plants we can notice a decline in pigment content.

b. Betacyanin

Effect of potassium deficiency on betacyanin content is recorded in Table 4. It is evident from Table that

Table 4 : Effect of potassium deficiency on Betacyanin content of two *Amaranthus* species

Treatment	A 525 nm
A. caudatus	
Control	0.83
-K	0.88
A. hypochondriacus	
Control	0.24
-K	0.26

(Values are mean of three determinations)

betacyanin content is slightly increased due to potassium deficiency in *Amaranthus caudatus* and *Amaranthus hypochondriacus*.

The betacyanins are pigment of great taxonomic significance. These have been detected in ten families of flowering plants belonging to order centrospermae. Mabry (1966) noticed that in common with most of the members of the centrospermae *Amaranthus* contains a betacyanin pigment amaranthin which replaces anthocyanins of other angiosperms order. Even within *Amaranthus* genus betacyanins are not present in species like *A. paniculatus*.

Extensive studies in last twenty years indicate that accumulation of betacyanin in *Amaranthus* is a complex process which depends on gene activation and new enzyme synthesis (Piattelli et al., 1971) and it is the under control of either cytokinins in the dark (Bamberger and Mayer, 1960) or of the phytochrome system (Elliott, 1976). There are some inorganic elements which influence betacyanin accumulation in *Amaranthus*. According to Koehler and Dieter (1970), nitrogenous salts induce amaranthin biosynthesis in seedlings of *A. caudatus*. They observed that KNO_3, promoted betacyanin production in light while other alkali metal salts NH_4, Na, Li, Rb, chlorides and nitrates showed little or no effect on betacyanin production. They further concluded that a specific effect was dependent upon the

presence of K^+ and NO_3^- but KCl did not promote betacyanin formation. This KNO_3 promoted betacyanin synthesis was suppressed by inhibitors of protein and RNA synthesis. The endogenous Ca^{2+} and calmodulin (Vallon et al., 1989), Ca^{2+} and magnesium chelators (Obrenovic, 1986) are involved in the regulation of amaranthin synthesis in A. tricolor and *A. caudatus* respectively. Besides potassium, sodium also appears to be involved in this process. According to Elliott (1979-b), increased betacyanin may be due to increased tyrosine uptake, stimulated by Na^+ ions. Matoh et al., (1986) also reported in A. tricolor that betacyanin content was higher in Na-sufficient than in Na-deficient plants. Elliott (1979-b) also noticed K^+ ions at lower concentration stimulated betacyanin synthesis in *A. tricolor*.

In the present experiment we used Na in place of K int the nutrient solution. Thus the increase in betacyanin level in *Amaranthus caudatus* and *A. hypochondriacus* plants under K^+ deficiency can be attributed to Na-sufficiency of nutrient medium as indicated by Matoh et al. (1986).

G. TITRATABLE ACID NUMBER (TAN)

Effect of K deficiency on TAN is shown in Fig... It is clear from the Fig.13, that TAN is decreased in leaves of potassium deficient *Amaranthus caudatus*, *A. hypochondriacus* and *A. paniculatus*. In general the value of TAN reflects the free organic acid content of the plants.

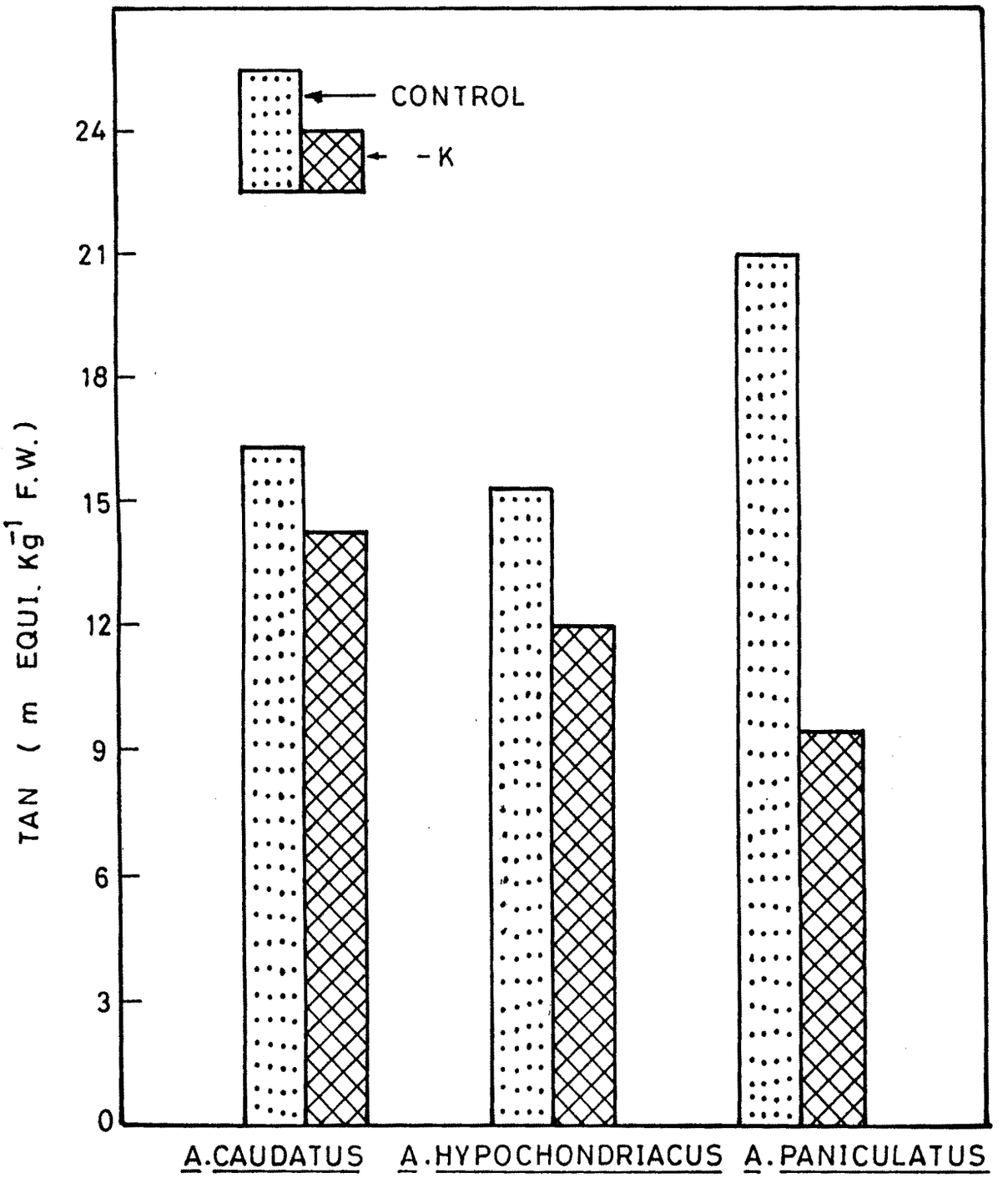


FIG.13 EFFECT OF POTASSIUM DEFICIENCY ON TITRATABLE ACID NUMBER IN LEAVES OF AMARANTHUS SPECIES.

Organic acids are considered as an important metabolite in living cells due to their active participation in TCA cycle CAM and C_4 pathways. They also supply carbon skeleton for synthesis of number of important metabolites. The accumulation of organic acids in plant is relevant to the adjustment of the cation-anion balance in plant sap and to facilitate the transport of metabolic cations in plant (Popp and Kinzel, 1971; Triplett et al., 1980).

There are few reports which show definite relation between organic acid metabolism and mineral nutrition. Iljin (1951) found that there is a correlation between chlorosis and citric acid content of the plant. A positive correlation between the ratio of citrate to malate and ratios of P:Fe and K:Ca was suggested by DeKock and Morison (1958). Williams (1957) observed that the citrate : malate ratio was doubled due to phosphorus deficiency. Work of Clark (1968) on organic acid metabolism in maize under mineral deficient conditions revealed that under all major element deficiencies organic acid content was increased. He observed that potassium, calcium, magnesium and phosphorus deficiencies increased in content of malate and citrate and decrease the content of aconitic acid. According to Trudel and Ozbun (1971), low potassium nutrition causes a decrease in TAN in young tomato fruits and this was further reflected by decrease in levels of citrate, malate, fumarate and

oxaloacetate. Thus it is clear that the changes in total organic acid content are accompanied by qualitative changes in organic acid composition. Chavan (1980) observed increased TAN value under nitrogen deficiency whereas lowered TAN value due to potassium deficiency in *Eleusine coracana*. Murumkar (1986) also found low TAN value in K deficient chickpea leaves. According to Bellinger and Larher (1987), the low organic acid content of salinized tomato leaves would suggest an impaired respiration and decreasing energy supply. Similar situation may prevall in leaves of potassium deficient *Amaranthus* species, in particular *A. paniculatus*.

H. PHOTOSYNTHETIC PRODUCTS-CARBOHYDRATES

Effect of potassium deficiency on carbohydrate status of leaves of three species of *Amaranthus* is depicted in Fig.14. It is evident from the figure that carbohydrate fractions such as reducing sugars, total sugars and starch are increased in leaf tissue of *Amaranthus* under K deficiency. Among the three fractions the accumulation of starch in K deficient leaves is particularly significant.

Starch and sucrose are the primary products of photosynthetic CO_2 fixation. Among these the sucrose is most important transport disaccharide in plants which is translocated from the source organ to sink organ. Sucrose is synthesized in cytosol of source organ and stored in

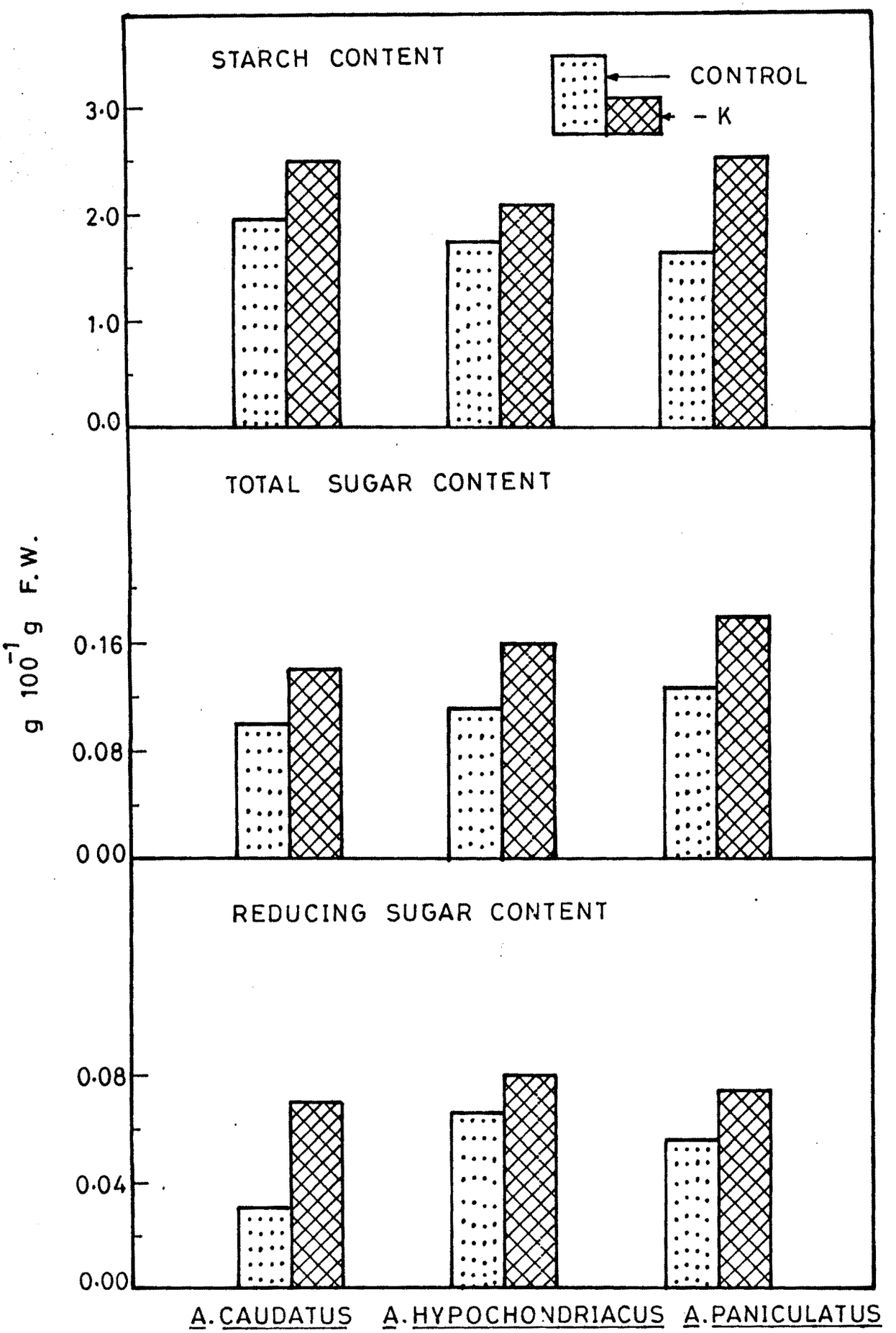


FIG. 14 EFFECT OF POTASSIUM DEFICIENCY ON CARBOHYDRATE CONTENT IN LEAVES OF AMARANTHUS SPECIES.

vacuole, then it is translocated via the phloem to sink organ. In sink organs sucrose is cleaved via sucrose synthase or invertase to form glucose and fructose and deposited in the form of reserved compounds like starch or lipids. In the view of Mooney (1972), the level of soluble sugars can be interpretated as a parameter of plant energy status.

The role of K in carbohydrate metabolism is very well documented by Evans and Sorger (1966) who reported that activities of nearly 19 different enzymes of carbohydrate metabolism are related to the presence of K. Aldolase, fructokinase, hexokinase, isocitric dehydrogenase, lactic dehydrogenase, malic enzyme, phosphohexokinase, pyruvate kinase and succinic dehydrogenase are some of these enzymes. The accumulation of carbohydrates under K deficient conditions is evident in the experments of several workers (Radi et al., 1973; Scherer et al., 1982; Hanson et al., 1982). This increase is mainly because of increased levels of reducing sugars, which play an active part in the osmoregulatory processes (Scherer et al., 1982). Yamashita and Hikasa (1988) also noticed that in *Morus alba* leaves, the starch, fructose and glucose contents increased in K deficient plants. Evans and Sorger (1966) claimed that the accumulation of carbohydrates under K deficient conditions can be due to an inadequate activation of many enzymes.

Rathert and Doering (1983) observed that activities of enzymes of starch metabolism like α-amylase, ß-amylase and phosphorylases decreased under extreme Ki:Na (1:9) conditions in two soybean varieties. According to Hartt (1970) and Amir and Reinhold (1971), the retardation of translocation from the leaf to the rest of the plant is the primary effect of potassium deficiency. This view has been supported by Haeder (1981). Gauch (1957) claimed that the accumulation of carbohydrates often associated with K-deficiency may be only indirect effect of the deficiency with no direct connection between the element and translocation of carbohydrates. According to Cakmak et al. (1994-a), in K deficient leaves of bean plants, despite a distinct accumulation of sucrose and reducing sugars, the starch content were not much higher than in the control plants. They also reported that potassium is important for high sink activity and thus it is expected that K-deficiency should results in accumulation of carbohydrates in source organs. Cakmak et al. (1994-b) also observed accumulation of carbohydrates in source (leaves) in K-deficient bean plants and they suggest that the export of carbohydrates from source (leaves) to sink is depressed by K-deficiency.

In case of *Amaranthus* (as already mentioned) potassium deficiency caused delay in flowering and also reduced the inflorescence (sink) size. Thus a decline in

translocation capacity can result in increase in level of various carbohydrate fractions in the K^+ deficient leaves (source). Such an accumulation further cause many other metabolic abnormalities in the leaves.

I. POLYPHENOLS

Effect of potassium deficiency on total polyphenol content in three *Amaranthus* species is recorded in Fig.15. It is clear from the figure that the total polyphenol content is increased in leaves of all three *Amaranthus* species due to K deficiency. This increase is more significant in *A. caudatus*.

Polyphenols represents the aromatic compounds formed during secondary metabolism. These compounds include a wide range of plant substances which poses in common an aromatic ring bearing one or more hydroxyl substituents. Lignins, melanins and tannins are some examples of important polyphenols which are widely distributed in plants. Anthocyanins. Leucoanthocyanins and anthoxanthins hydroxy benzoic acids, glycosides, sugar esters of quinone and shikmic acid esters and coumarine derivatives are included in this class.

Polyphenols are widely occuring in higher plants. Secondary compounds serve both endogenous and exogenous functions in higher plants because they are involved in

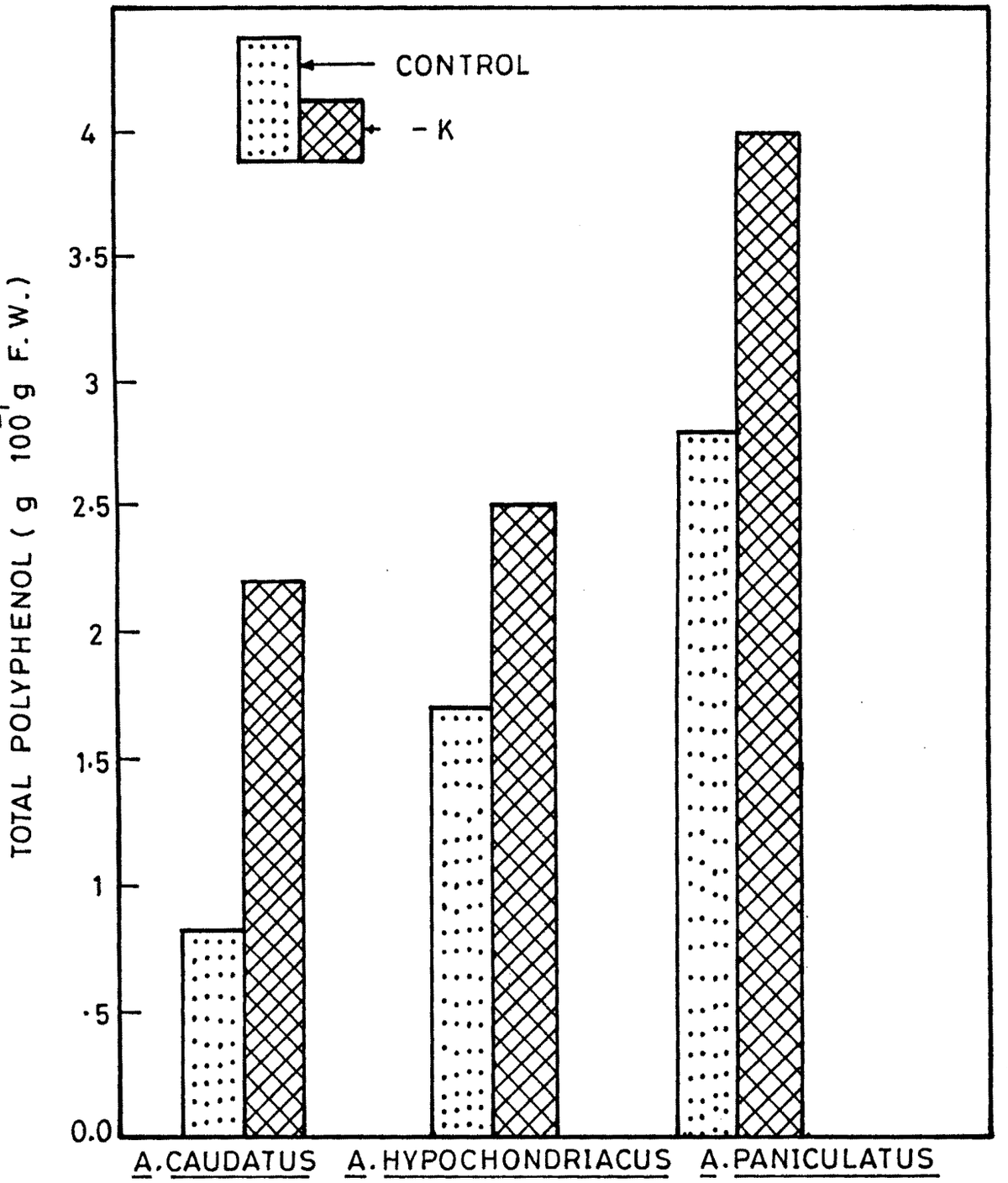


FIG.15 EFFECT OF POTASSIUM DEFICIENCY ON TOTAL POLYPHENOL IN LEAVES OF AMARANTHUS SPECIES.

plant growth and development as well as intraspecific and interspecific reactions. The lignification of cell wall and pigmentation of flower are well established functions of these compounds. Wallace and Mansell (1975) considered that these products are protective in function against, different types of diseases in plants. There are some reports which indicate that the Phenolics plays an protective role or adaptive role in plants during stress conditions. Phenolics also act as an inhibitors in plants e.g. cinnamic acid inhibits auxin activity. Jacobson and Corcoran (1977) suggested that tannins are important antagonists and regulators of gibberellins. Singh et al. (1987) has noticed that both mono and diphenols have a positive effect on growth and yield of groundnut. Sharma et al. (1988) reported the possible involvement of phenolics in stomatal movements in *Commelina obliqua*. In oxidation reduction reaction phenolics functions as H^+ donors or acceptors. Phenolics also interfere with growth and other energy dependent activities by uncoupling oxidative phosphorylation. Number of processes may be disturbed due to small changes in phenol metabolism. According to Rice (1979), phenolic compounds affect fundamental plant processes such as photosynthesis, chlorophyll production and plant water relations. Demos et al. (1975) observed there is disturbance in respiration process due to accumulation of phenolics. The secondary metabolism is greatly influenced by both endogenous and

environmental factors and this is reflected in alterations in the composition and levels of various phenolic compounds. Loche and Chouteau (1963) observed that deficiencies of calcium, magnesium and phosphorus in tabacco grown in water culture caused an accumulation of polyphenols. Roger (1972) reported that nitrogen deficiency stimulated the contents of chlorogenic acid and isochlorogenic acid in sunflower. Lehman and Rice (1972) also found that the nigrogen, potassium and sulphur deficient leaves of sunflower contained more polyphenols than the leaves from plants provided with complete nutrition. Shkolnik (1974) observed that microelements like boron also result in accumulation of polyphenols. Chavan (1980) observed that in *Eleusine coracana* total polyphenol content increased due to nitrogen and phosphorus deficiencies. Murumkar (1986) noticed increased polyphenol content in chickpea leaves under conditions of K deficiency. Karadge (1986) also reported accumulation of phenolics in K stressed leaves of peanut.

In the present study we noticed that polyphenols content increased due to potassium deficiency in all three *Amaranthus* species. It is difficult to ascribe reasons for increase in polyphenol content in potassium deficient leaves. Increased polyphenol content in potassium deficient leaves of *Amaranthus* species might be due to stimulation of secondary metabolic activities.

J. FREE PROLINE

Effect of potassium deficiency on free proline content in three *Amaranthus* species is recorded in Fig.15. It is clear from the figure that the proline content is found to be increased in K deficient leaves of three *Amaranthus* species. Among three species *A. paniculatus* shows greater accumulation of proline due to K deficiency.

In last two decades considerable attention has been paid to amino acid proline because of significant accumulation of this compound under variety of environmental conditions. According to Palfi et al. (1974), proline is a highly water soluble amino acid which is the most stable one as regards resisting oxidative acid hydrolysis. According to them proline increases considerably the amount of bound water in the leaves. At high concentration, it acts as a solute for intracellular osmotic adjustment (Strogonov, 1964; Steward and Lee, 1974; Hanson et al, 1979 and Handa et al, 1986) and provides a store of nitrogen and carbon for subsequent utilization after the period of stress (Barnett and Naylor, 1966). It has been suggested that free proline synthesized from glutamate serves as an energy donor during environmental stress (Dashek and Erickson, 1981). Savitskaya (1976) noticed that proline may be the single source and precursor of the cell walls. Participating in the cell extension process and may serves as reserve or energy

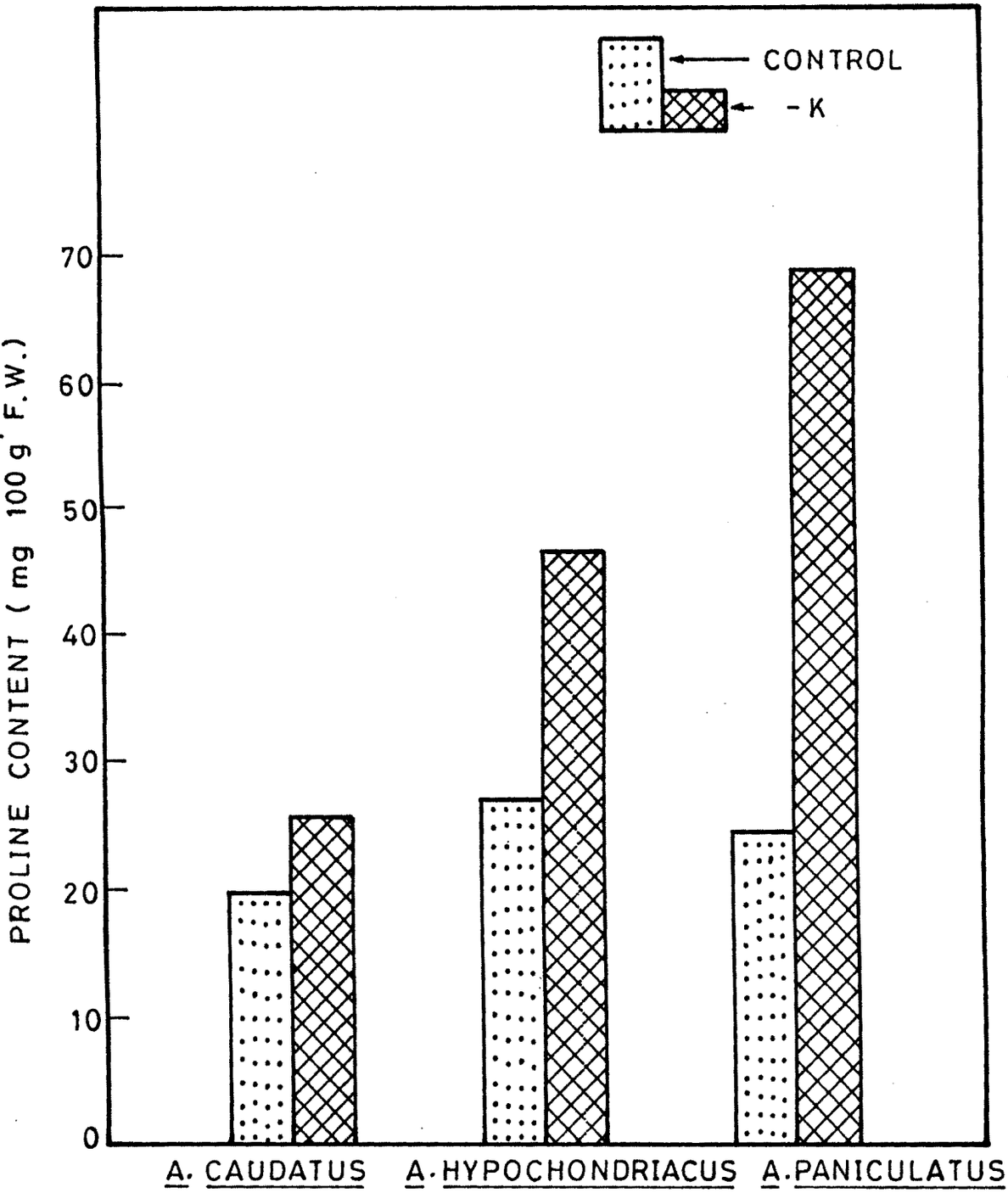


FIG.16 EFFECT OF POTASSIUM DEFICIENCY ON PROLINE CONTENT IN LEAVES OF AMARANTHUS SPECIES.

material for respiration. According to Weimberg et al. (1982), if the proline accumulates in the cytoplasm, it can play a key role in osmotic adjustment. Paleg et al. (1981) recognized that proline in a concentration dependent manner protect several different enzymes with a wide range of thermal sensitivities and from different sources, against the in-vitro inactiviting effects of heat stress. Schobert and Tschesche (1978) showed that the proline affects the solubility of various proteins and protects bovine albumin from denaturation by $(NH_4)_2SO_4$ or ethanol. It was suggested that this property of proline may be due to an interaction between proline molecule and hydrophobic surface residues on the proteins, which increases the total hydrophilic area of the associated molecule and hence their stability. Imamul Hug and Larher (1984) claimed that proline accumulation in the plants deserves special mention and considered to be a stress marker.

The investigations of several workers have shown the existance of specific relationship between mineral nutrition and proline accumulation. It is wellknown that under various stress conditions (heat, drought, salt) plant accumulate free proline. Murumkar et al. (1982) observed that there is significant increase in the free proline content in the shoot parts of potassium deficient *Sorghum* plants. Ebeid et al. (1983) also observed accumulation of

proline in Mesquite (*Prosopis juliflora*) due to potassium deficiency. Goering and Thien (1979) have observed an increase in proline content in roots and shoots of maize seedling subjected to deficiencies of nitrogen. Phosphorus and potassium. Tang, et al. (1985) have suggested the possible physiological role of proline towards the protection of plant from injurious effects of potassium shortage. These workers have reported that feeding proline is beneficial for alleviation of injurious effects caused by K shortage as judged from time and frequency of appearance and severity of K shortage symptoms in Sorghum seedlings grown in K deficient conditions. Murumkar (1986) observed accumulation of proline in root tissue of chickpea due to K deficiency. According to Murumkar et al. (1982) considerable enhancement of protease activity in K deficient shoots may lead to accumulation of amino acids. They also observed that there is accumulation of some amino acids like alanine, glutamic acid, glutamine, proline, serine, threonine and tyrosine in shoot parts of *Sorghum*. While the synthesis of aspartic, cystine, glycine, histidine, phenylalanine and valine is affected due to K deficiency. They noticed that this disturbed nitrogen metabolism may be as a result of stimulation of protein hydrolysis and/or inhibition of protein synthesis, in *Sorghum* during K deficiency.

In the present investigation proline content is

found to be increased in all three *Amaranthus* species subjected to potassium deficiency (but this increase is more significant in *A. paniculatus* and *A. hypochondriacus*) the role of proline in post stress recovery of drought prone plants and in osmoregulation in salt stressed plant is well known, but its exact contribution under varying conditions of mineral nutrition is still not understood. In *Amaranthus* proline might be playing a protective role or any major role under K deficient conditions because plant shows tendency of accumulation of proline after getting deprived of potassium.

K. GLYCINEBETAINE

Effect of potassium deficiency on glycinebetaine content in leaves of three *Amaranthus* species is depicted in Fig.17. It is evident from figure that due to potassium deficiency glycinebetaine content is increased in *A. caudatus* and *A. hypochondriacus* where as it is slightly lowered in *A. paniculatus*.

The quaternary ammonium compound glycinebetaine is structurally the simplest of the betaines. According to Wyn Jones and Storey (1981), glycinebetaine is widely distributed and often occurs in very large quantities and is associated with halophytic and xerophytic plants of arid and salty habitats. Storey and Wyn Jones (1977) noticed that glycinebetaine is normally found mainly in shoot than in root tissue of mature palnts. Hanson et al. (1985) stated

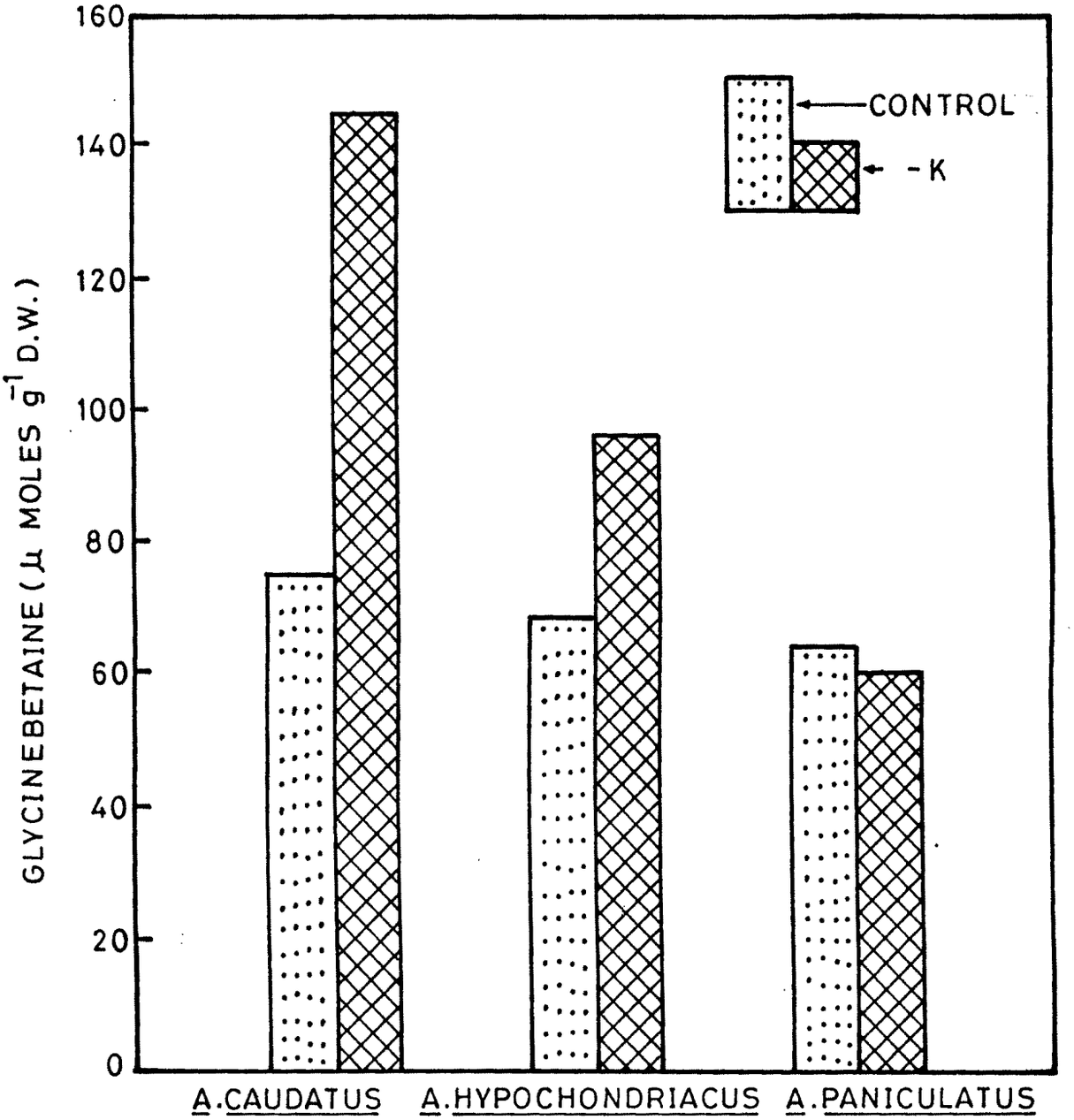


FIG.17 EFFECT OF POTASSIUM DEFICIENCY ON GLYCINEBETAINE CONTENT IN LEAVES OF AMARANTHUS SPECIES.

that in chenopodiaceae betaine biosynthesis is localized in the chloroplast. Kent and Hanson (1992) claimed that glycinebetaine is produced by two step oxidation of chloine via the intermediate betaine aldehyde. According to Stewart and Larher (1980), glycinebetaine is synthesized via the methylation of ethenolamine rather than the sequential methylation of glycine.

Glycinebetaine is a major cytoplasmic non toxic osmotica in certain plants families such as chenopodiaceae, Amaranthaceae and Poceae adapted to salt or water stress (Wyn Jones and Storey, 1981) Gaikwad (1995) noticed accumulation of glycinebetaine in salt treated *Amaranthus* species, *A. caudatus* and *A. hypochondriacus*. There is close relation between glycinebetaine concentration and sap osmotic potential. Paleg et al. (1981) emphasized that role of glycinebetaine in protecting the cellular enzymes and membrane proteins against dehydration and conformational changes and thus maintaining their activity. According to Weretilnyk et al. (1989), betaine could serves as a methyl group donor for plant metabolism. However, there is possibility of this compound becoming a "dead end" metabolite since it is not subsequently metabolised (Stewart and Larher, 1980). Thus eventhough there is same contraversy regarding the role of glycinebetaine it is very clear that the compound accumulates in response to stress and is

nontoxic for the plants. Our observations indicate that among the three *Amaranthus* species studied *A. caudatus* and *A. hypochondriacus* have the potential to accumulate glycinebetaine under conditions of K deficiency and this compound may play a protective role for overall metabolic machinery of the plants.

L. TOTAL NITROGEN AND SOLUBLE PROTEINS

Effect of potassium deficiency on total nitrogen content and soluble protein content is recorded in the Fig.18. and Table 5 respectively. It is evident from figure that the potassium deficient *Amaranthus* species shows accumulation of total nitrogen in roots whereas it is reduced in leaves. From the Table 5, it is clear that the soluble protein is also decreased in leaves of three *Amaranthus* species due to K deficiency.

Among various elements required by the living organisms, nitrogen is the most indispensible. It is regarded as a touchstone of crop productivity. Nitrogen is most prevalent element in the living organisms and it is invariably found in such an essential compounds as proteins, nucleic acids, some of the plant regulators viz. IAA and cytokinins, and in many of the vitamins. Nitrogen is involved in most of the biochemical reactions that drive life. Nitrogen insufficiency is single major factor which limits crop growth and yield. Hence all our fertilizer

Table 5 : Effect of potassium deficiency on soluble protein content of three *Amaranthus* species

Treatment	Soluble Protein ($mg\ g^{-1}$ F.W.
A. caudatus	
Control	7.07
-K	6.18
A. hypochondriacus	
Control	7.07
-K	5.96
A. paniculatus	
Control	7.95
-K	5.96

(Values are mean of three determinations)

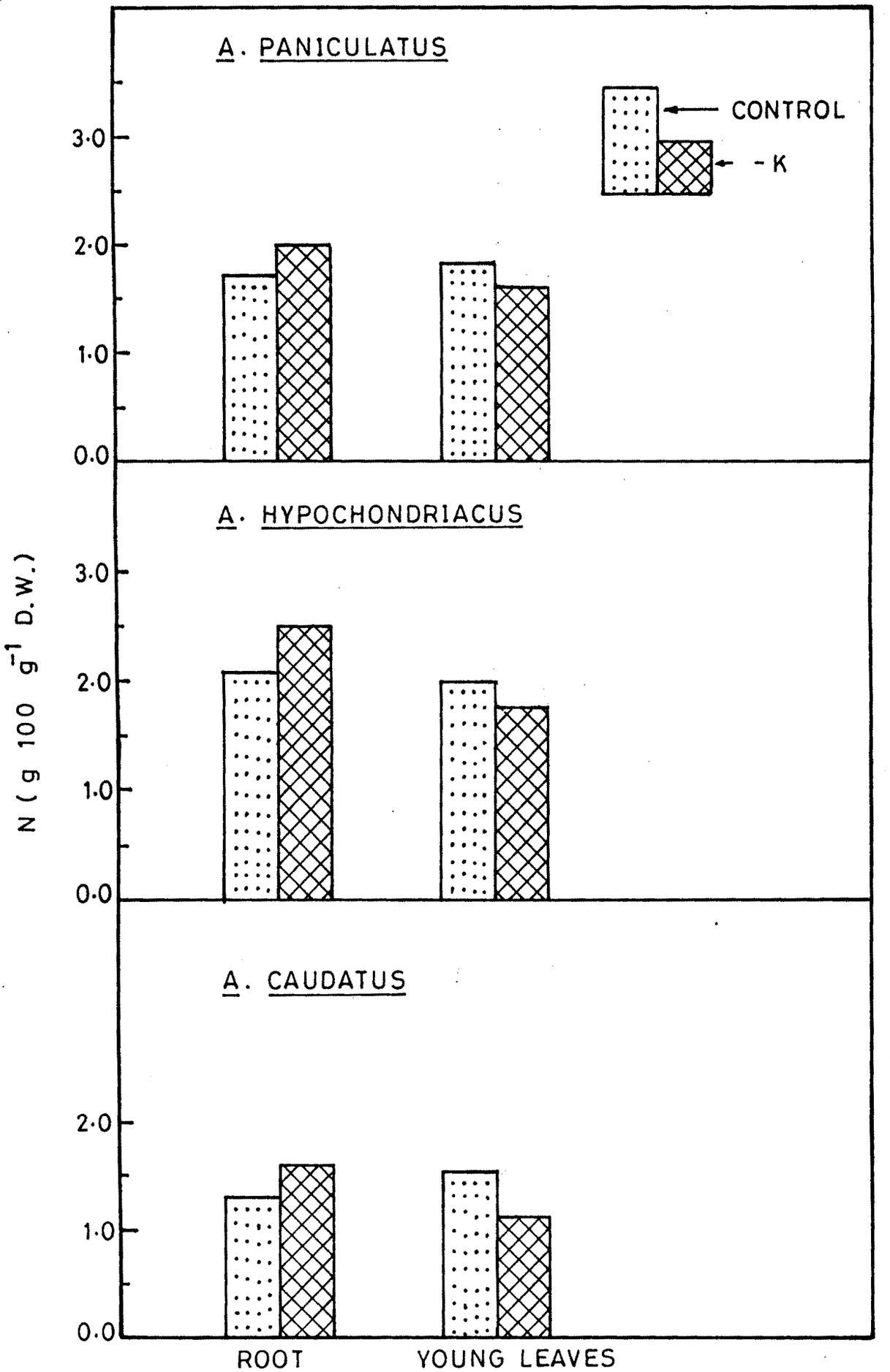


FIG.18 EFFECT OF POTASSIUM DEFICIENCY ON NITROGEN CONTENT IN AMARANTHUS SPECIES.

practices are ultimately dependent on proper and reasonable application of this element in various forms. Marschner (1986) emphasized that the nitrogen content required for optimal growth varies between 2 to 5% of the plant dry weight and it depends on the plant species, developmental stage and organ of the plant.

Nitrogen nutrition under the condition of K-deficiency has been investigated in number of plants. There are reports of both increase and decrease in total nitrogen in plants growing under potassium deficient conditions. A decline in total nitrogen content in K-deficient plants has been evident in several experiments (Sircar and Datta, 1959; Bottrill and Possingham, 1969; Sinha and Singh, 1984). On the other hand some workers have reported accumulation of nitrogen due to K deficiency. Radi et al. (1973) have noticed that total nitrogen content was increased in maize and tomato under K-deficient conditions. Murumkar and Chavan (1992) observed accumulation of total nitrogen in roots and stem tissues and its decline in leaf tissues of chickpea grown under potasisum deficiency. Recently Bhat et al. (1996) observed a highly significant positive correlation between foliar K and nitrogen in patharnakh pear grown under different concentrations of potassium. They noticed that increasing potassium concentration in nutrient medium resulted into highly significant increase in the

concentration of nitrogen whereas low potassium concentration in nutrient medium resulted into decrease in nitrogen concentration in leaf.

In the present investigation, we noticed accumulation of nitrogen in root tissues and concamittant decrease in nitrogen in leaf tissues of potassium deficient *Amaranthus* plants. Thus the transport of nitrogen from root to shoot is affected by K deficit. It is also accompanied by a decline in leaf soluble protein level (Table 5). Sinha and Singh (1984) also observed that K deficiency cuases decrease in protein nitrogen in Japanese mint. Laetsh (1971) emphasized that K^+ levels favours protein synthesis in young leaves and low K levels help the mobilisation of soluble nitrogen in old leaves. From the present study it can be well suggested that due to K deficiency protein synthesis is arrested.

M. ENZYMES

1. Nitrate Reductase

Effect of potassium deficiency on activity of nitrate reductase from leaves of three *Amaranthus* species in depicted in Fig.19. It is clear from the figure that the activity of nitrate reductase is slightly stimulated under K deficient condition in the leaves of three *Amaranthus* species.

Plant kingdom is capable of using nitrate and/or

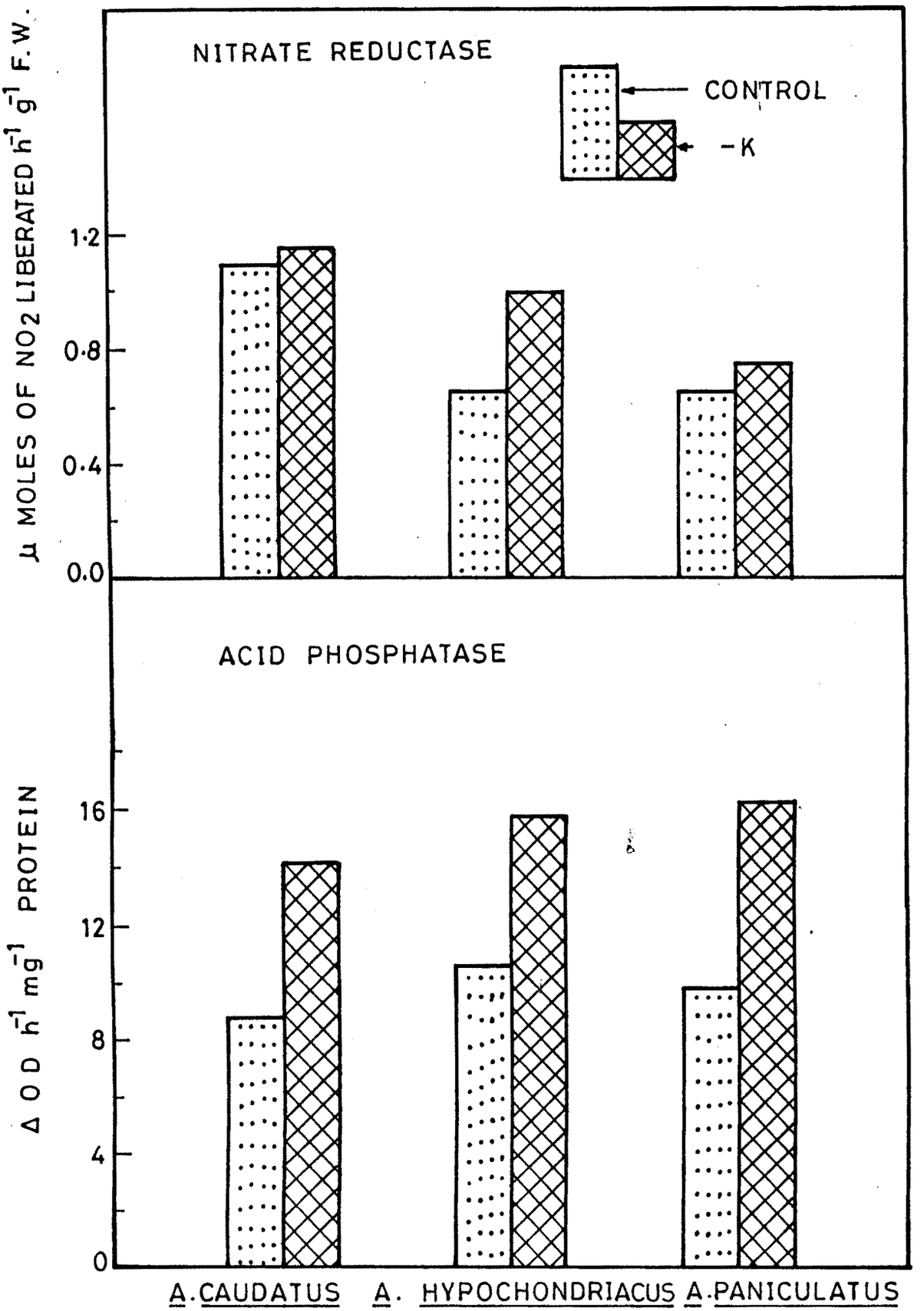


FIG. 19 EFFECT OF POTASSIUM DEFICIENCY ON ENZYME ACID PHOSPHATASE AND NITRATE REDUCTASE ACTIVITY IN LEAVES OF AMARANTHUS SPECIES.

ammonium as nitrogen sources, both of which must be converted enzymatically into organic compounds. Among these two sources nitrate is a major source of nitrogen available to higher plants. Nitrate is reduced by nitrate and nitrite reductases to ammonium which, like the ammonium taken up, is then usually assimilated by glutamine synthatase and glutamate synthase (Beevers and Hageman, 1983). The resulting glutamate can then be transformed by transaminases to other amino acids. These enzyme systems occur in roots as well as in shoots of higher plants and therefore the site of nitrogen assimilation can, in principle, be localized in either organ. For nitrate, the site of reduction depends on the plant species and external nitrate concentrations (Andrews, 1986). Also the cation-anion balance can determine the site where nitrate is reduced (Jeschke and Wolf, 1988; Forster and Jeschke, 1993). Nitrogen assimilation is tightly linked to energy/C-metabolism as energy and C-skeletons are needed to convert inrorganic nitrogen to organic compounds. Whether nitrogen assimilation occurs in the root or the shoot, there is a high demand for carbon, independent of the N-soruce.

Thus the first step of nitrogen assimilation is catalyzed by NR. Therefore it is one of the most important enzyme systems in plants. It catalyzes the reduction of nitrate to nitrite. The enzyme system includes a reduced

pyridine nucleotide (NADPH or NADH) as an electron donor, flavinadenine dinucletide (FAD) and molybdenum. According to Guerreo et al. (1981) during the reduction electrons are directly transformed from molybdenum to nitrite. This enzyme is regarated as a rate limiting step in nitrogen assimilation process in higher plants. The activity of this enzyme determine overall assimilation of nitrate.

According to Srivastava (1980), activity of NR is found to be influenced by several endogenous as well as environmental factors. Sinha and Nicholas (1981) speculated that the enzyme may be regulated through i) the availability of nitrate, ii) an inhibition of protein synthesis consequent upon the reduction in polyribosomes level during stress and inherent turnover rate of the enzyme or, iii) a reduction in the availability of NADH through effects on photosynthesis or respiration.

According to Dillon and Reilly (1980), greater efficiency in the assimilation of limited nitrogen ultimately depends upon balanced nutrition with particular attention to nutrients which interact with nitrate uptake and assimilation. Several workers investigated fate of this enzyme under various nutrient deficiencies. There are contraversial reports regarding the response of NR activity to imposed potassium deficiency. As early as 1970, Hsiao et al., observed that the level of nitrate reductase was

related to the NO_3 supply rather than to K level in maize plants. Reilly (1979) and Dillon and Reilly (1980) have reported that in wheat under K deficient conditions activity of NR in old leaves was increased. Mileva and Kluzyak (1983) observed that in K deficient conditions NR activity was stimulated in pepper plants. Gutierrez et al. (1992) also observed stimulated NR activity in potassium deficient bean plants. They also noticed that, maximum enzyme activity was detectable before flowering.

Gutierrez et al. (1978) studied the response of NR activity to potassium deficiency in Brazilian bean plants. A varietal difference was exhibited. In 'carioca' variety NR activity was reduced while it was increased in 'Goiano precoce' variety under K deficient conditions. In the present investigation we noticed that there is stimulation of NR activity in leaves of all the three *Amaranthus* species due to K deficiency. According to Dillon and Reilly (1980), high rates of nitrate reductase activity reflect abnormal nitrate accumulation because when assessed on a crop area basis, debilitated potassium deficient plants donot assimilate nitrogen at levels comparable to that of healthy plants.

2. Acid Phosphatase

Effect of K deficiency on the activity of enzyme acid phosphatase from leaves of three *Amaranthus* species is

recorded in Figure.19. It is evident from the fig. that the activity of acid phosphatase is stimulated under K deficient condition in leaves of all three species of *Amaranthus*. This increase is particularly significant in *A. paniculatus* leaves.

The orthophosphate anion (Pi) is the preferentially assimilated form of phosphorus for plants that obtain their mineral nutrients directly from the environment. Pi plays a vital functional role in energy transfer, metabolic regulation and it is structural constituent of many important biomolecules. According to Vincent et al. (1992), efficient utilization of phosphorus requires enzymes known as phosphatase which function to hydrolise Pi from orthophosphate monoesters in a thermodynamically favourable process. Plant alkaline phosphate exhibits an absolute substrate specificity. Whereas, acid phosphatases (Apases) donot exhibit an absolute substrate specificity. The Apases are specialized enzymes such as the 3-P-glycerate (3-PGA) phosphatase from maize leaves (Randoll et al., 1971) and the phosphoenol pyruvate (PEP) phosphatase of Brassica nigra suspension cell cultures (Duff et al. 1989) which display a clear but nonabsolute substrate specificity.

Acid phosphatases have been found in all plant species and tissues that have been studied and many

electrophoretically distinguishable isoforms are often found in a given tissues or cell type. According to Duff et al. (1994), differential glycosylation might represent a soluble form of cellular control, either targeting phosphatases to specific compartments or increasing their affinity for specific proteins or enzymes.

Since many phosphates such as ATP, GTP, sugar phosphates are the major energy currencies in the cell. Phosphorus metabolism enzymes are linked with energy status of the cell and ultimately plant. Goldstein et al. (1989) and Lefebyre et al. (1990) speculated that the secreted acid phosphatase may be used by plants to scavenge phosphate from organic sources under phosphate limiting conditions.

There are contradictory reports regarding effect of K deficiency on activity of acid phosphatase. Mileva and Kluzyak (1983) observed decreased activity of enzyme acid phosphatase in Pepper plants due to K-deficiency. Dillon and Reilly (1980) suggested that reduced enzyme activity under prolonged potassium deficiency presumly arose from the enzymes functions in macromolecular biosynthesis and restrictions in this area could reduce both the level and requirement of the enzyme in the plant. Fritsch and Jung (1984) have correlated the decrease in enzyme activity towards induced senescence in relation to low nutrient supply. On the other hand Hewitt and Tatham (1960) observed

increased activity of enzyme acid phosphatase in magnesium, potassium and phosphorus deficient tomato plants. Chavan (1980) also found stimulated activity of enzyme acid phosphatase in *Eleusine corocana* due to nitrogen, potassium and phosphorus deficiencies. Murumkar et al. (1982) observed increased acid phosphatase activity in K-deficient *Sorghum*. As phosphatase is a hydrolytic enzyme the increase in it's activity may not be beneficial for the plant. However, it may help in redistribution of phosphorus under deficient condition. According to De Leo and Sacher (1970), acid phosphatase exhibits a wide range of activities and ATPase activity is also a part of this enzyme. Thus the significant increase in acid phosphatase under deficient conditions might be affecting ATP level in plant thereby causing reduction in growth.

In the present investigation stimulated activity of acid phosphatase in all three *Amaranthus* species has been noticed due to potassium deficiency. This indicates a definite trend towards promotion of hydrolytic and catabolic processes in potassium deficient plants.

3. Catalase

Influence of K deficiency on the activity of catalase in leaves of three *Amaranthus* species is recorded in Fig.20. It is clear from the fig. that the activity of catalase is stimulated under K deficient conditions in the

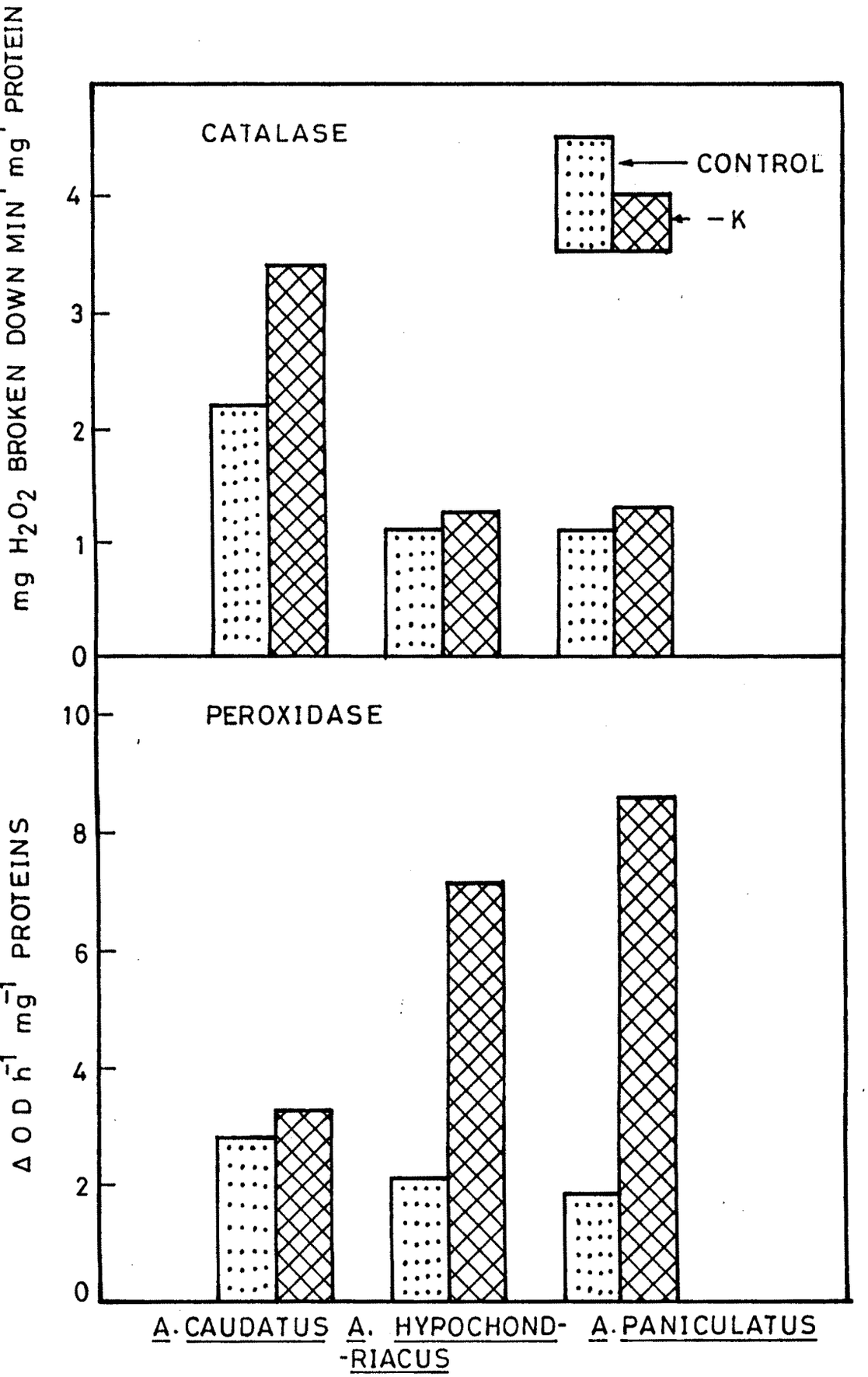


FIG. 20 EFFECT OF POTASSIUM DEFICIENCY ON ENZYME PEROXIDASE AND CATALASE ACTIVITY IN LEAVES OF AMARANTHUS SPECIES.

leaves of three *Amaranthus* species. Among the three species a marked increase in catalase activity is evident in potassium deficient leaves of *A. caudatus*.

Catalase is an oxidative enzyme with very high efficiency in catalysing the peroxidative oxidation of certain substances. Catalase is one of the first enzymes to be isolated in pure state, plant catalase has been isolated from only a few sources such as spinach leaves, lentil leaves, cucumber cotyledons and sweet potato roots (Esaka and Asahi, 1982). Cytochemical and biochemical evidence indicate that catalase in plant cells is mostly located in microbodies (peroxisomes and glyoxysomes).

Main function of catalase is to remove H_2O_2 from the organism. Catalase brings about H_2O_2 decomposition in glyoxysomes of fatty seeds and in leaf peroxisomes where H_2O_2 is generated during photorespiration by glycolate oxidase. Grinberg (1971) has suggested that since catalase has got more affinity for H_2O_2 it is mainly involved in regulation of H_2O_2 level in plant tissues. According to Asada (1992), variety of toxic oxygen species e.g. oxygen superoxide anion, hydroxyradical, single oxygen and/or hydrogen peroxide are produced in plants exposed to environmental stress and may lead to severe damage of cell molecules, membranes and other structures. Hydrogen peroxide is regarded as one of the harmful metabolite in cells since

it plays a key role in oxidative stress. Besides photorespiration this compound is produced in some other metabolic pathways also. The enzyme catalase is involved in protective mechanism against oxidative streses in the cell. Suzuki et al.(1986) made a comparison fo photosynthetic and photorespiratory enzyme activities between green leaves and colourless part of variengated leaves of the C_4 plant *stenotaphrum*. They found that among the peroxisomal enzymes, catalase was remarkably reduced in the colourless tissues of a C_4 plants. This may indicate an essential role of catalase in the photosynthetic tissuess in destroying H_2O_2. The mechanism of regulation has not been determined but could be the results of changes in rates of synthesis, degradation or covalent modification of protein (Annon, 1990). According to Paul and Mukherjee (1972), activity of catalase is related with respiration rate and thus it is indicator of respiration rate.

Horovitz et al. (1968) found that deficiencies of nitrogen, phosphorus and potassium, caused activation of catalase. Aoki and Yamamoto (1968) noticed increased catalase activity in mulberry seedling due to lack of potassium. They also observed that due to addition of K, the situation is improved considerably. Chavan (1980) also observed increased catalase activity in *Eleusine coracana* due to deficiencies of nitrogen phosphorus and potassium.

In the present investigation the activity of enzyme catalase is found to be increased in all three *Amaranthus* species due to potassium deficiency. This significant increase in the activity in K deficient plants indicate a disturbed metabolism. According to Cakmak (1994) due to K deficiency there is enhancement in activity of H_2O_2 scavenging enzymes (or production of H_2O_2) in bean (*Phaseolus vulgaris*). H_2O_2 scavenging enzymes are predominantly localized in the chloroplasts and chloroplasts are the major sites of H_2O_2 production in leves (Halliwell, 1981; Herouart et al. (1994) and Gressel and Galun (1994) noticed increased activity of protective enzymes or anti-oxidative enzymes in K deficient plants. In *Amaranthus* species we also noticed increased activity of enzyme catalase due to K deficiency. From this it is clear that due to K deficiency activity of H_2O_2 scavenging enzymes is increased which controls further toxic consequences. This can be certainly regarded as an adaptive feature in *Amaranthus* which is basically a C_4 species and hence lacks photorespiration. Among the three species *A. caudatus* appears more efficient in this respect.

4. Peroxidase

Influence of K-deficiency on the activity of enzyme peroxidase from leaves of three *Amaranthus* species is

recorded in Fig.20. It can be well noted from the figure that the activity of peroxidase is stimulated under K deficient condition in leaves of all the three species. This increase is particularly significant in *A. hypochondriacus* and *A. paniculatus*.

According to Fric (1976), peroxidase is widely distributed oxidative enzyme located in various subcellular components. Peroxidase is involved in the organization of chromosomes and in electron transfer system from $NADH_2$ to cytochrome C. It has also improtant role in ribosome synthesis and oxidation of hormones like IAA and ascorbic acid. Pilet et al. (1970) speculated that peroxidase is related to polyphenol and auxin metabolism.

Activity of peroxidase has also been considered as an indicator of respiration rate. In this respect Horovitz et al. (1968) observed enhancement of respiratory rate along with stimulated peroxidase activity. Cakmak (1994) also observed increased peroxidase activity in potassium and magnesium deficient bean plants. Baba et al. (1964) studied 'Akagare' disease of rice and they observed that this disease is caused by K deficiency. The diseased leaves showed increase in respiration rate, a decline in cytochrome oxidase activity and increase in peroxidase activity. They suggested that though the respiration rate increases in K deficient plants, it is wasteful process which has nothing

to do with the supply of energy. In view of these workers polyphenols are oxidised by peroxidase into quinones which combine with amino acids and metals like iron to form brown substance. In *Amaranthus* species such brown colouration of leaves was not evident on large scale as in rice under K deficiency. An increase in peroxidase during leaf senescence has been reported by many workers and the enzyme has been implicated in this process. Under K deficient conditions elevated peroxidase activity can play a similar role. Further it also indicates a marked stimulation of secondary metabolism, since peroxidase play 'multiple' roles in plant metabolism. Only a detailed isozyme analysis can throw more light on this problem.